DOCUMENT REFERENCE:
9.20LC OTH

Little Crow
Solar Park

Little Crow Solar Park, Scunthorpe

TECHNICAL GUIDE

DEADLINE 1

Revision: New Doc
Regulation No: APFP Reg: 5(2)(q)
PINS Reference: EN010101

Author: Pegasus Group
Date: May 2021

On behalf of INRG Solar (Little Crow) Ltd

MAY 2021

TECHNICAL GUIDE

ON BEHALF OF INRG SOLAR (LITTLE CROW) LTD

CONTENTS:

APPENDICES:

1. INTRODUCTION

1.1 This Technical Guide has been prepared to assist in the understanding of how the proposed authorised development comprising of a PV generating station and Battery Energy Storage System at Little Crow Solar Park operate and interact with the local electricity network. The Note has been prepared and submitted pursuant to the action arising from Issue Specific Hearing 1 held virtually on Tuesday 20 and Wednesday 21 April 2021.

2. DESCRIPTION OF THE WORKS

2.1 The main element of the project is the construction, operation, maintenance and decommissioning of a ground mounted solar park and associated battery energy storage system with an intended design capacity of over 50MWp (megawatts peak). The project is connected to the electricity network via a single main connection at 132kV to the Northern Powergrid ('NPG') electricity network located within the Order Limits. The location of the Point of Connection ('PoC') to the NPG electricity network is shown on Figure 1 below.

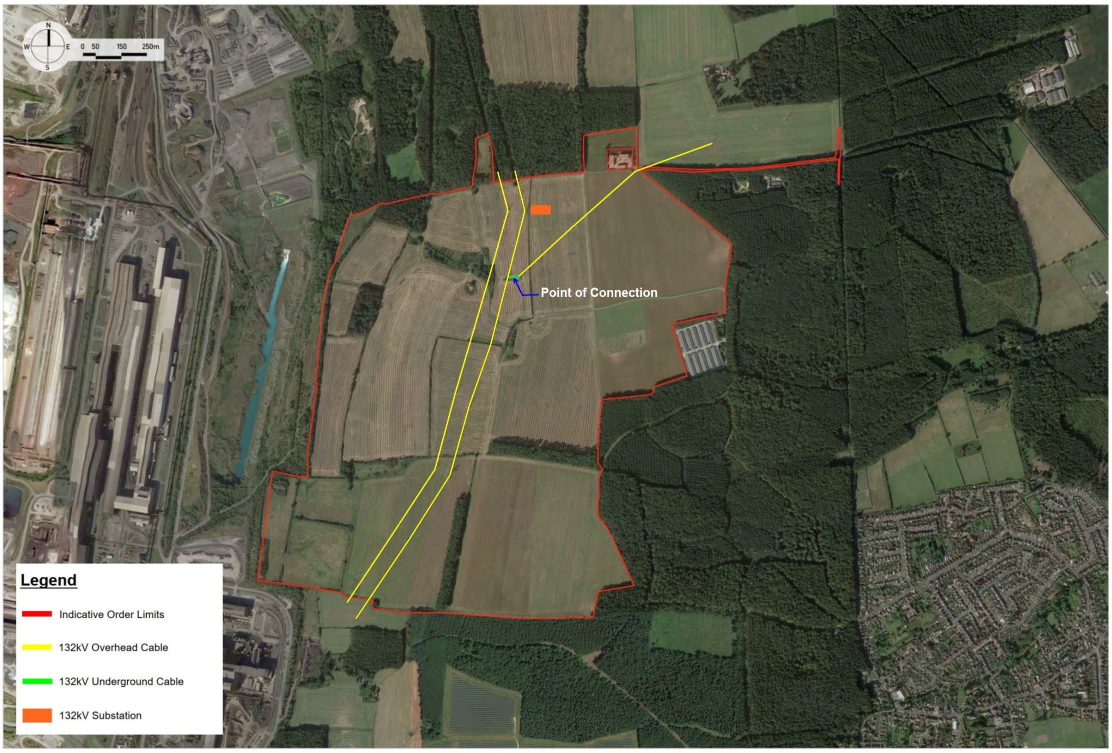


Figure 1

2.2 The connection has been designed to sit fully within the development, with the PoC located in the northern half of the site and connected to the 132kV substation via an underground section of 132kV cable c250m in length.

3. HOW DO PV SOLAR PANELS PRODUCE ELECTRICITY?

3.1 PV solar panels convert sunlight into direct current ('DC') electricity through a process known as the photovoltaic effect. Whilst the technology may be considered as being modern the photovoltaic effect was first discovered in the 1830s and photovoltaic cells were first produced in the 1950s. The majority of PV solar panels currently deployed in solar parks around the world consists of a number (typically 60 or 72) of photovoltaic cells which are connected in series on the underside of a sheet of glass and held in place by an aluminium frame.

3.2 Each photovoltaic cell is a sandwich made up of two slices of a semi-conducting material – see Figure 2 below. The most common semi-conducting material used in PV solar panels is silicon. To generate the electricity an electric field needs to be established and this is created in the manufacturing process where phosphorous is added to the top layer of silicon (creating a negative charge) and boron is added to the bottom layer (creating a positive charge).

3.3 When direct or indirect (light that has passed through clouds) sunlight hits the silicon molecules from both layers, an electron is knocked loose. These electrons are attracted to the top layer of silicon (the phosphorus layer) and repelled from the bottom layer of silicon (the boron layer). Metallic strips located along the top silicon layer collect the electrons. The metallic strips collectively join up with the metallic strips in all the other cells in the PV solar panel at the junction box located on the rear of the PV solar panel where the power cable that carries the electricity produced by the PV solar panel exits the junction box and connects to the inverter to convert the electricity from DC to alternating current ('AC') so that it can be used in homes and businesses.

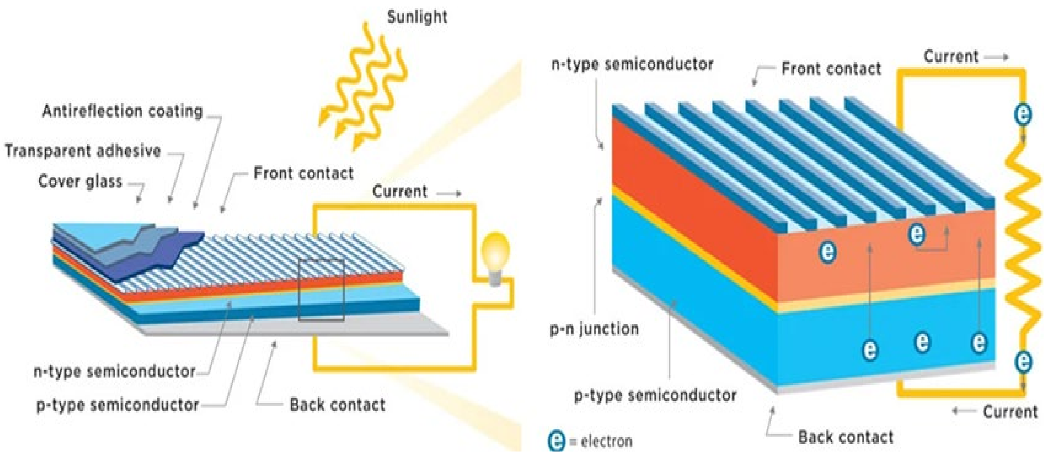


Figure 2

4. WHAT DOES Megawatts Peak (MWp) MEAN?

4.1 Solar PV systems are rated in MWp.

4.2 MWp is the term used to express the nominal power output expected from a PV solar park under Standard Test Conditions ('STC'). The STC were introduced across the PV solar industry to ensure uniformity in the testing of PV solar panels and are outlined below:

- Solar Irradiation of 1,000W/m2
- Solar cell temperature of 25°C
- Air mass of 1.5 – i.e. how much atmosphere sunlight must pass through to strike the earth

4.3 The units MWp describe the installed capacity of a solar park. However, they don't describe how much electricity is produced in a specified period of time (the output of the solar park). This quantity is described in kilowatt-hours (kWh) or megawatt-hours (MWh). Under STC a 1MWp ground mounted PV solar park would be expected to produce 1,000MWh of electricity.

4.4 If any or all of the conditions alter this will have an impact on the amount of electricity the solar park will produce and amount of electricity produced will be directly related to the changes in the conditions. To put this context due the much higher solar irradiance in southern Spain a 1MWp ground mounted PV solar array in southern Spain would produce circa twice as much electricity as the same 1MWp ground mounted PV solar array located in Scotland.

5. HOW PV SOLAR PANEL EFFICIENCY AND POWER OUTPUT HAS IMPROVED IN RECENT YEARS AND WHAT IS THE POTENTIAL FOR CONTINUED IMPROVEMENTS?

5.1 Whilst the first photovoltaic cells were produced in the 1950s the technology was for many decades considered too expensive so advances in the technology were slow. In the early 2000’s Germany introduced an incentive program known as a ‘Feed in Tariff’ to promote the development of PV solar parks to assist the country in reducing its greenhouse gas emissions. The program was a success and it spawned the global PV solar panel manufacturing industry that we see today. Other countries quickly followed Germany and the number of PV solar panel manufacturers increased rapidly to match the global appetite for panels. The majority of the manufacturers are currently based in China.

5.2 Due to the amount of competition in PV solar panel manufacturing there is a constant race between the manufacturers to increase the PV solar panel output and efficiency (the efficiency is the percentage of sunlight that hits the PV solar panel and is converted into useable electricity). To put this in some context in 2010 when the UK introduced its ‘Feed in Tariff’ solar park design typically utilized panels with an output of between 250 – 300Wp and an efficiency of c14%.

5.3 Today it is common to see project designs utilizing panels with outputs 400 – 500Wp and efficiencies of c21%. Some manufacturers have recently introduced panels with outputs of c600Wp and whilst not mainstream currently it is likely that these higher outputs will start to be utilized in project design over next 12 – 18 months. In laboratory testing efficiencies of >40% have been recorded however these have not been achieved in mass production.

5.4 Other recent developments in PV solar manufacturing are the introduction of:

(i) <u>Bifacial Panels:</u> Bifacial panels (see Figure 3 below) have cells on both sides to capture what is known as the albedo off the surface over which the panels are erected. The albedo is a dimensionless quantity and is usually expressed as a percentage — the higher the reflectivity of a surface, the higher its albedo. For example, a black surface that absorbs a large amount of light has a low albedo, while a white surface that reflects a large amount of light has a high albedo. The albedo will decrease over time depending on the surface e.g. a white surface will darken over the years with weathering. Typical expected increases in output from utilizing bifacial panels over different surfaces are outlined below:

- On grass: c5% increase in output.

- On grass with a tracker: c11% increase in output.
- On sand: c11% increase in output.
- On sand with a tracker: c24% increase in output.
- On white-painted surface: c22% increase in output.
- On white-painted surface with a tracker: c33% increase in output.

Figure 3

(ii) Half Cell PV Solar Panels: Half Cell panels (see Figure 4 below) use cells that are cut in half thus reducing the resistive losses and improving the panels performance. Half cut cells are also more durable because they are less prone to micro cracks given their smaller size. One other advantage of half cell panels is that they work better in shaded conditions compared to conventional panels. If some cells in a conventional panel are in shade this can affect many of the cell rows due to the way in which conventional panels are wired and a reduction in the output of a panel will occur however with half cut cell panels there are more rows of cells and additional wiring so the same amount of shading will result in less reduction in output.

Figure 4

(iii) <u>Tracker Systems:</u> Tracker systems (see Figure 5 below) enable the panels to track the sun as it crosses the sky initially pointing to the east in the early morning, reaching due south by midday and turning to the west in the evening. This cycle repeats itself on a daily basis. Tracker systems are very common in locations where the sunlight levels are high e.g. California, Spain etc where the additional costs to install the tracker systems are offset by the increased output from the panels. Whilst not common in the UK at present a small number of recent PV solar parks have utilized tracker systems in the design.

Figure 5

5.5 The overall design of each PV solar park is different and a design that works on one park may not be suitable for another due to a number of factors e.g. topography, location, grid connection characteristics, field layouts etc. The newer technologies will have higher outputs and efficiencies, but will not always be the right solution and each PV solar park goes through a rigorous design process before deciding on the type of panels to use. As the global PV market is vast (research by IHS Markit is forecasting that the global PV market in 2021 will be 158GWp[1]) availability of different types of panels can also be a factor in panel selection.

5.6 In terms of the future development of PV solar panels it is clear that manufacturers will continue to seek an edge on their competitors and this will lead to a constant pipeline of innovation in the sector. The International Energy Agency recently confirmed that PV solar is now the cheapest form of electricity production[2] in many countries and with this trend set to continue over the coming years the global deployment of PV will increase and to ensure market share manufacturers will have to continue to seek technological improvements from their panels.

5.7 So what improvements are we likely to see in PV panel technology?

(i) Panel Efficiency: As efficiencies of >40% have been achieved in laboratory conditions it is likely to be only a matter of time before manufacturers are able to mass produce panels with higher efficiencies than the current c21%.

(ii) Multi-Junction Cells: Multi-junction cells are essentially conventional PV panels but with added layers to increase efficiency. Each layer is optimised for different wavelengths of sunlight so the panel is more efficient at converting the sunlight into electricity. High production costs due to the additional materials required in the manufacturing process means that multi junction cells are not currently commercially viable however considering the major leaps in PV solar panel technology over the past 20 years and the continued drop in costs (to construct a 1MWp ground mounted PV solar park in the UK in 2010 would have cost c£3M compared to today's price of c£450,000) it is feasible to think that with continued research and development, a commercially viable PV solar panel formed of multi-junction cells will be available within the next 10 years.

[1] https://ihsmarkit.com/Info/0121/cleanenergytechtrends2021.html

[2] https://www.iea.org/reports/world-energy-outlook-2020?mode=overview

(iii) Perovskites: Perovskite is a naturally occurring mineral that is also a superconductor. Recent testing of solar cells formed of perovskite has shown improvements in efficiency from c 3% upto c20% and this rapid increase in efficiency has piqued the interest of the PV manufacturers. Whilst its early days in terms of mass production due to the decomposition rate of perovskite being higher than silicon it is promising as an alternative to silicon.

6. THE POWER GENERATION PROFILE EXPECTED FROM A PV SOLAR PARK IN THE UK

6.1 The annual output from a PV solar park in the UK will be directly related to the location of that park. This is due to the variation of solar irradiance levels across the UK – see UK Solar Irradiance map in Appendix 1.

6.2 A 1MWp PV solar park constructed using the exact same equipment on land with the same topographical features will produce c 20% more electricity in Cornwall than the same solar park will produce in Scotland.

6.3 The House of Parliament POSTnote No. 398 on Solar Photovoltaics[3] states "*The amount of solar irradiation available in the UK ranges from 960 kilowatt hours per metre squared (kWh/m2) in the far north, to 1240 kWh/m2 in the south-west. This compares with 900 kWh/m2 for Norway and 1,900 kWh/m2 for Spain"*.

6.4 The typical hourly production graph in percentage terms for a PV solar park in the UK is shown in Figure 6 below. This will vary across the seasons with electricity production starting later in the Winter months compared to the Summer months. Times will also vary across locations as sunset and sunrise times vary with location.

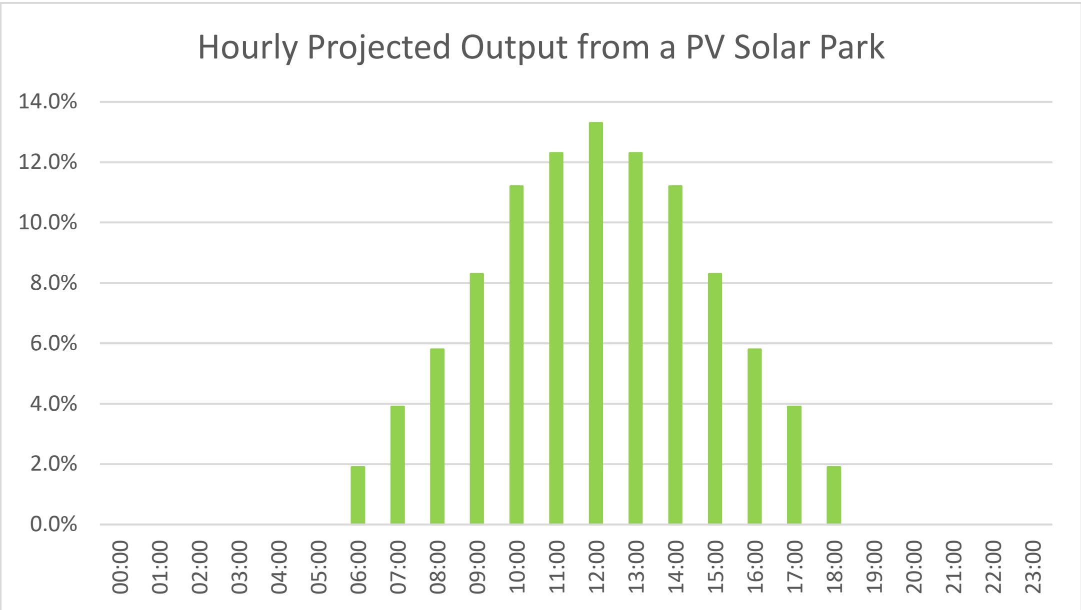


Figure 6

6.5 In terms of the annual production graph in percentage terms for a PV solar park in the UK this is shown in Figure 7 below. As is evident from the graph c70% of the annual production is squeezed into the months from April to October.

[3] https://post.parliament.uk/research-briefings/post-pn-398/

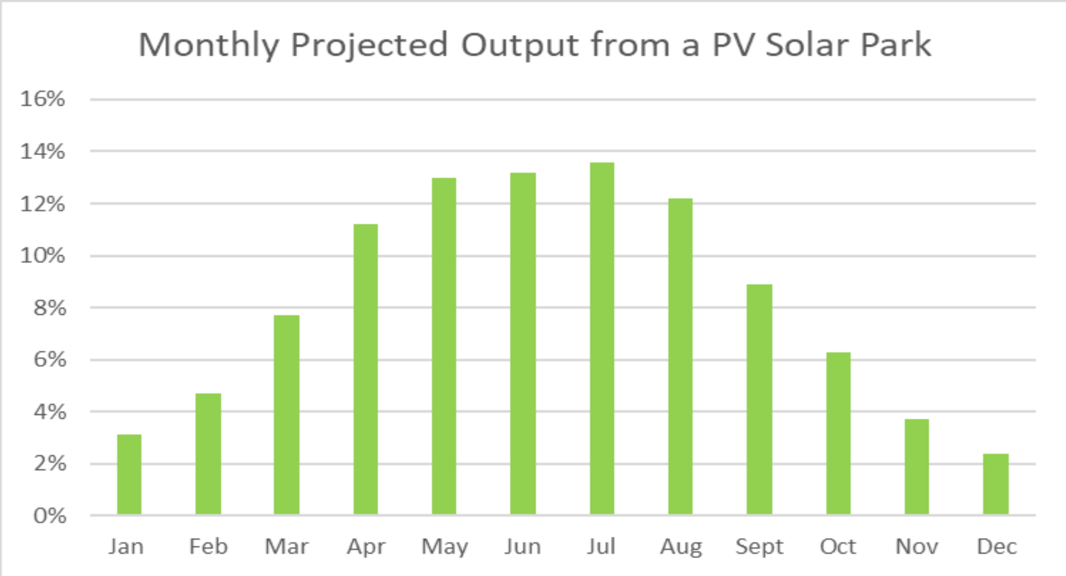


Figure 7

6.6 Whilst PV solar panels have been designed and built to handle as well as endure harsh and unpredictable weather conditions over prolonged periods of time, like all power plants the PV solar park output will reduce over time due to 'wear and tear' in the various components. When discussing the drop in output from a PV panel the term 'degradation' of the panel is used. Similar to the efforts around panel efficiencies manufacturers have also focused heavily on minimising the degradation levels of PV panels and warranties on minimum panel output of c85% 25 years after installation is commonplace among manufacturers. Typical annual degradation rates promoted by manufacturers are now c0.3% from year 1. Longer term studies have been undertaken across the globe on PV installations some which were in excess of 30 years in operation and the results of these were collated in a report published by the National Renewable Energy Laboratory in the US which showed average annual degradation at rates for silicon panels at 0.36 – 0.64%[4]. The continued improvement in both degradation rates and panel efficiencies has led to an increase in the expected operational lifespans of PV solar parks with typical expected lifespans of at least 35 years compared to 25 years in 2010.

[4] https://www.nrel.gov/docs/fy12osti/51664.pdf

7. HOW THE POWER GENERATED BY PV SOLAR PANELS REACHES THE LOCAL ELECTRICITY NETWORK AND WHAT HAPPENS TO THAT POWER

7.1 Section 4 dealt with the process of electricity production from PV solar panels but for the power to be used in homes and businesses it must be exported to the local electricity network.

7.2 PV solar panels produce electricity at low voltage typically 40 – 50V (Volts). The electricity produced is also DC and as the electricity we use in our homes and businesses is AC the first process is converting the electricity from DC to AC. This process is completed by an inverter. The inverter completes the process by rapidly switching the direction of the DC input back and forth resulting in an AC output and the electricity is now in a useable form for homes and businesses. Inverters come in various sizes from small 'string' inverters (see Figure 8 below) that sit under the PV solar arrays to the larger 'central' inverters (see Figure 9 below) which are located throughout a solar park.

Figure 8

Figure 9

7.3 With the electricity converted to AC it is still at low voltage and this must be increased to match the voltage at the PoC of the local electricity network. The voltage at the PoC will vary by solar park and will typically be one of 11,000V, 33,000V, 66,000 or 132,000V (Volts). In the case of Little Crow Solar Park the local electricity network is operated by NPG and the voltage at the PoC is 132,000V (also referred to as 132kV). To achieve the increase in voltage required to ensure that NPG accept the connection to the local electricity network a series of transformers are used across the solar park to increase the voltage from 40 – 50V to 11,000 – 33,000V depending on the design of the solar park and Powerstations similar to the one in Figure 10 below are used for this purpose. As in the case of Little Crow Solar Park the voltage may be required to be increased further prior to the connection to the local electricity network. This further increase in the voltage to 132,000V will take place at the transformer in the Customer Compound located in the 132kV Substation. Once the electricity produced from the solar park is at the same voltage as the PoC the solar park can be connected to NPG's network.

7.4 The grid connection offer secured for Little Crow Solar Park is independent of any another grid connection offer relating to other solar parks in the same region and the operation of Little Crow Solar Park is not affected by the operations of any other power generating station.

Figure 10

7.5 Following completion of the connection to the local electricity network the electricity produced by the solar park is free to travel around the local electricity network and into the transmission network. Typically the electricity will be used locally however the actual electricity produced may be purchased by a company in another part of the UK as part of a Corporate Power Purchase Agreement ('PPA'). PPAs from renewable energy sources are increasingly seen as viable options for corporate entities to reduce their carbon footprint whilst also being able to purchase electricity directly from the producer. These arrangements create a win-win situation for both the corporate entity and the operator of the solar park and the network operators secure a payment for the use of their network to transmit the power.

7.6 The electricity produced may also be used to assist National Grid in ensuring the safe operation of the electricity network in the UK and this is discussed in more detail in paragraph 8.4.

8. BATTERY ENERGY STORAGE SYSTEMS – HOW DO THEY WORK AND WHAT ARE THE BENEFITS OF CO-LOCATING WITH A PV SOLAR PARK?

8.1 A Battery Energy Storage System ('BESS') is an electrochemical device that is charged by collecting energy from the grid or a power plant and then discharges that energy at a later time to provide electricity or other grid services when needed. National Grid now consider BESS an essential technology that will play an increasingly pivotal role between renewable energy supplies and responding to electricity demands.[5]

8.2 There are a number of different technologies currently in use:

(i) Lithium-Ion Batteries: Lithium-Ion ('Li-ion') batteries are currently considered to be the most cost-effective electricity storage solution. Li-ion batteries were first produced in the early 1990's and were widely used in consumer products from this time. As Li-ion batteries are extremely versatile in terms of in size and scale they can be used in small consumer products in addition to utility scale BESS and this versatility has made Li-ion batteries the dominant technology in BESS. This coupled with the reality that to transition to low carbon electricity production, battery storage will be required to deal with the challenge of matching demand with the intermittent supply from renewable energy technologies has led to a massive increase in the production of Li-ion batteries across the globe. This increase in production has led to dramatic cost reductions of c85% over the past 10 years.

Li-ion batteries are formed of a series of cells with each cell having the following components – a positive electrode (cathode), a negative electrode (anode), a separator and a chemical electrolyte. The anode stores the lithium and is typically made from carbon. The cathode also stores the lithium and is made from a chemical compound that is a metal oxide – typically lithium iron phosphate is used in the newer Li-ion batteries. The separator blocks the flow of negative and positive electrons inside the battery but allows lithium ions to pass through. The electrolyte sits between the two electrodes and it carries the positively charged lithium ions from the anode to the cathode and vice versa depending on whether the battery is charging or discharging. The movement of the lithium ions creates free electrons in the anode which creates a charge. When the battery is

5 https://www.nationalgrid.com/stories/energy-explained/what-is-battery-storage

discharging the lithium ions flow from the anode to the cathode and the process is reversed when the battery is charging – see Figure 11 below.

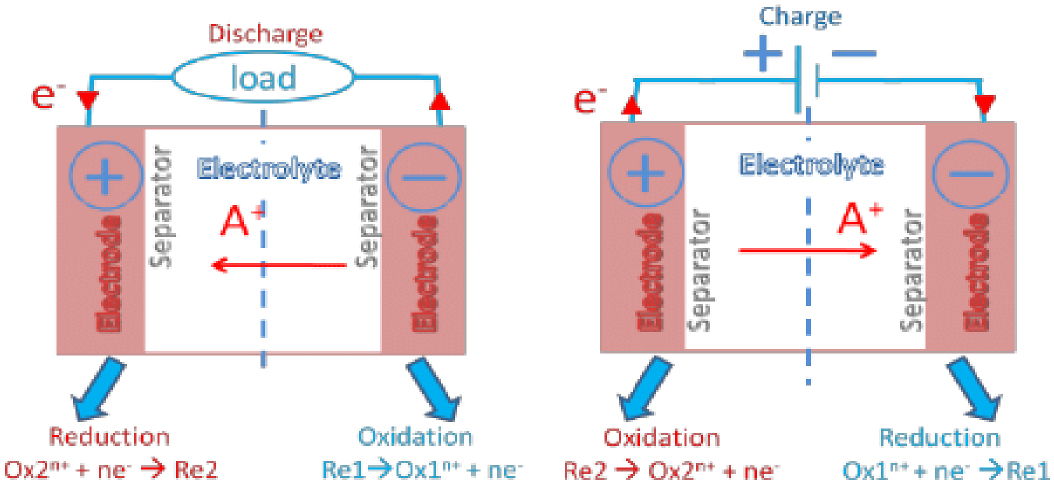


Figure 11

(ii) Redox Flow batteries: Redox Flow Batteries differ from conventional batteries in that the energy storage material is conveyed by an energy converter. This requires the energy storage material to be in a flowable form. The best-known representative of redox flow batteries today is the Vanadium Redox Flow Battery ('VRFB'). VRFB use various states of vanadium to store and release charges in a water-based electrolyte containing vanadium salts. The electrolyte is stored in two tanks which simply sit there until needed. When pumped into a chemical reactor, the two solutions flow adjacent to each other past a membrane and generate a charge by moving electrons back and forth during charging and discharging – see Figure 12 below.

First invented in the 1980's the technology is lagging behind Lithium-Ion batteries in terms of deployment mainly due to higher costs. VRFB's are also considered to be more effective over longer durations of service e.g. 6hrs of charging/discharging however very few applications require durations of this length with typical grid service requirements being charging/discharging of 1 – 2 hrs.

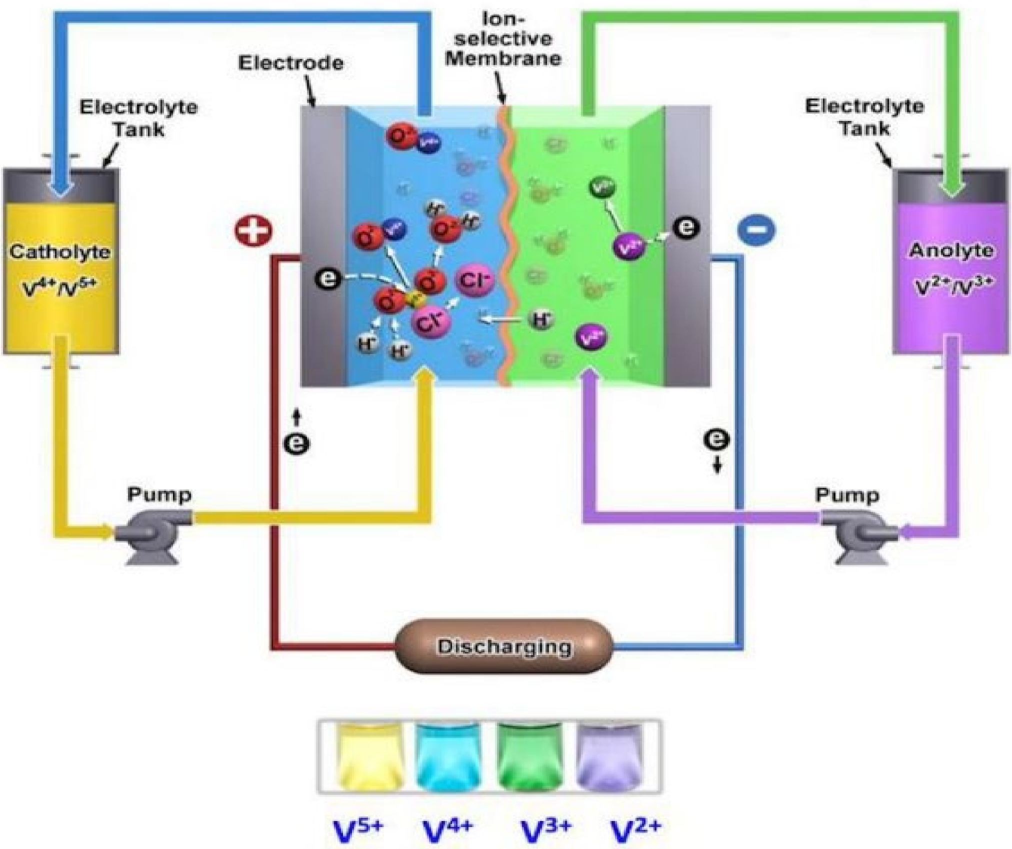


Figure 12

8.3 Co-locating a Battery Energy Storage System with a PV solar park creates many benefits with the technologies being complementary in many ways. Also referred to as 'hybrid-power plants' the introduction of BESS offers the solar park operator a number of options for the electricity produced. A traditional PV solar park would export the electricity produced to the local electricity network at the time it is produced but the addition of a BESS gives the operator the alternative strategy of holding on to that electricity and releasing it to the local electricity network later in the day.

8.4 In addition to the PPA's discussed in paragraph 7.5 the operator of a co-located BESS also has the following options for the electricity produced available to it:

(i) <u>Capacity Market:</u> The Capacity Market was introduced by the UK Government in response to the increase in renewable electricity generators connecting to the electricity network. As renewable electricity generating stations are less predictable in terms of their generation profile the

Government introduced the mechanism to provide an insurance policy against future blackouts e.g. in times of low generation and high demand. The Capacity Market works by guaranteeing payments to power plant operators for an agreed amount of electricity generation and those power plants must always be available at short notice to meet any request to supply electricity. National Grid calculate the potential shortfall in electricity production and annual auctions take place to secure the additional supply to ensure that blackouts do not occur.

(ii) Ancillary Services – Maintaining System Frequency: The system frequency of the UK electricity network is 50 Hertz (Hz) and whilst it varies continuously National Grid's role is to maintain the frequency at 50Hz +/- 1%. At times when demand is greater than generation the frequency falls and when demand is less than generation the frequency rises. Large deviations in frequency can lead to blackouts or in extreme cases grid failure where major repairs are required.

On Friday 9th August 2019 lightning strikes causes two power stations to trip out and in less than 2 mins, 1800MW of generation came off the network causing the frequency to drop to 48.8Hz. As there was not sufficient backup generators available National Grid had no alternative but to immediately instruct District Network Operators to reduce demand by 5% which led to a blackout for c1 million customers for c40mins and impacted the transport network for following two days. At times of increased generation the frequency will increase beyond the 50Hz +1% range and this can lead to generation having to be switched off.

To avoid these scenarios National Grid procure frequency response services on a weekly and monthly basis from power plant operators whereby National Grid can instruct the power plant operator to either consume or generate electricity at extremely short notice (can be as low as milliseconds) for short periods of time (typically no longer than 30 mins).

Dynamic Frequency Response is the pre-fault response programme which monitors frequency continuously and power plant operators either reduce electricity demand or generate a little more electricity as frequency varies above or below the 50Hz threshold.

Static Frequency Response (Non-Dynamic) is the post-fault response programme and requires power plant operators to either reduce electricity demand or increase generation very quickly when the frequency hits a pre-determined trigger level above or below 50Hz set by National Grid.

(iii) Balancing Mechanism: In an ideal scenario there is 100% balance in the electricity network between generation and demand however due to forecasting errors and unexpected outages imbalances occur. National Grid is obliged to manage network imbalances and one of the methods of doing this known as the Balancing Mechanism. The Balancing Mechanism is a real time tool used by National Grid at half hourly intervals each day. Where National Grid predicts that there will be a discrepancy between electricity generation and demand during a certain time period, they may accept a 'bid' or 'offer' from a power plant operator to either increase/decrease generation or increase/decrease demand.

8.5 Technological advancements in remote monitoring and control of Battery Energy Storage Systems ensure immediate response times are available when discharge of stored electricity is required during times of increased demand on the electricity network or when charging is required during times of over generation on the electricity network. BESS are perfectly placed to assist National Grid in ensuring the safe operation of the electricity network.

8.6 The remote monitoring and control systems within the BESS are also interlinked with the remote monitoring and control systems for the PV solar park to ensure the seamless operation of both technologies. The operator of a co-located BESS uses algorithms to co-ordinate electricity production and depending on what contracts the operator has entered into the electricity produced will either be exported to the local electricity network as it is produced, used to charge the BESS or used in part for both options. The quantities of electricity used for export/BESS charging will depend on the contracts entered into by the operator and the algorithms will ensure that a situation never arises where the BESS is fully charged and the PV solar park is generating more electricity than can be exported.

8.7 Typical the nominal installed capacity from a PV solar park in the UK will be based on 1.2 – 1.3 times the export capacity in the grid offer with the lower end of the scale being relevant to locations with higher irradiation eg Cornwall. In the case of Little Crow Solar Park the export capacity is 99.9MW so the optimum nominal installed capacity of the solar park to maximise the use of the export capacity would be 99.9MW x (1.25-1.3) = 125 - 130MWp. In determining the optimum nominal installed capacity of a solar park operators use software such as PVSyst to analyse different configurations of design to ensure that the final design is optimised based on the project location and the export capacity secured. In Appendices 2 and 3 PVSyst reports have been included based on the candidate design of 356,670 panels x 420Wp = 149.8MWp and also a similar design using 530Wp bifacial panels giving an alternative design of 356,670 panels x 535Wp = 190.8MWp. In both cases the design is in excess of the optimum design based on the export capacity of 99.9MW and as is the case in most renewable energy generation projects the export capacity is a limiting factor. However the introduction of a BESS to Little Crow Solar Park ensures that the maximum nominal installed capacity possible within the parameters assessed in the Environmental Statement can be achieved by storing of any excess electricity produced which can then be discharged to the local electricity network later in the day as the electricity production from the PV solar reduces with the reduction in sunlight levels. The continued improvement in panel output and efficiency may lead to a further increase in the nominal installed capacity of Little Crow Solar Park. It is important to note that the NPG grid offer assumes a constant export of 99.9MW into the local electricity network 24 hours a day so the discharge of batteries in the local electricity network could occur at any time once the 99.9MW export capacity is not exceeded.

8.8 With regard to the charging times for BESS from a PV solar park this will vary depending on the output from the solar park and also the loss in efficiencies across both technologies. For example, it would take up to 1.25 hours to fully charge a 100MW BESS system using a 100MWp PV solar park assuming that the solar park produced a constant 100MWh for at least 1 hour. The time taken to fully charge the 100MW BESS will vary up or down depending on the output above or below the 100MWh from the 100MWp solar park.

9. WHAT ARE THE ANNUAL MAINTENANCE REQUIREMENTS FOR A PV SOLAR PARK?

9.1 Once constructed and operational the viability of a PV solar park is dependent on how good the Operation and Maintenance ('O & M') program is. PV solar parks (other than those that utilise tracker systems) have no mechanical moving parts however they are complex power plants that require continuous monitoring to ensure that the solar park is operating at optimal performance levels. Technology has advanced to the point that monitoring of the solar park is completed remotely.

9.2 There are many companies active in the UK now that offer O & M services to the operators of solar parks. Typical services offered within O & M contracts are:

(i) 24 hr Remote Monitoring

(ii) Output Data Analysis

(iii) Performance Optimisation

(iv) Preventative Maintenance

(v) Rapid Response to on-site Issues

(vi) CCTV Monitoring and Security

(vii) PV Panel Cleaning

(viii) Maintenance of Vegetation in Co-ordination with Ecologists

9.3 The remote monitoring is typically completed using a Supervisory Control and Data Acquisition ('SCADA') system which allows monitoring and remote operation of the solar park via satellite. The constant feed of data allows the O & M companies to see if issues have arisen or if certain areas of the solar park are under-performing which may be due to damage, a build-up of dust or a defect in some of the PV panels or some other equipment e.g. inverters/transformers may be under-performing. A decision on whether a site visit will be required is made once the data received has been analysed.

9.4 Scheduled site visits would typically be undertaken once every 3 months to inspect the PV panels, mounting structures and electrical infrastructure and connections. Other site visits may be required if operational issues are encountered at any time.

9.5 PV panel cleaning methods have advanced and depending on the size of the solar park may be completed using a small, tracked machine similar to the one in Figure 13 below.

Figure 13

10. WHAT HAPPENS TO THE PV SOLAR PANELS, ASSOCIATED ELECTRICAL INFRASTRUCTURE AND THE BATTERY ENERGY STORAGE SYSTEM WHEN THE SOLAR PARK IS DECOMMISSIONED?

10.1 When the time comes to decommission a PV Solar park the physical process of removing the equipment will begin. As the majority of the equipment is classed as electrical it will fall under the Waste from Electrical and Electronic Equipment Regulations 2013 ('WEEE'). WEEE was introduced to reduce the amount of waste electrical equipment sent to landfill/incinerated and to promote re-use, recovery and recycling of electrical equipment.

10.2 The electrical equipment used in a solar park and its suitability for recycling are listed below:

(i) PV Solar Panels: Whilst PV solar panels have been around for decades their deployment on a global scale only commenced in the last 15 years. In light of this the decommissioning/recycling of panels is only starting to gather pace.

Silicon based PV panels similar to those proposed for Little Crow Solar Park consist of approximately 76% glass, 10% polymer (encapsulant and backsheet foil), 8% aluminium, 5% silicon semiconductor, 0.9% copper (interconnectors) and 0.1% other metals silver, tin and lead (contact lines).

The recycling process involves the following processes:

- physical disassembling of the panels (removal of frame and connection box) with the aluminium frames removed for recycling
- cutting of the solar cells into small pieces
- stripping of the semi-conductor films (silicon) from the glass in a rotating drum with the glass and polymer cleaned and removed for recycling
- the remaining metal compounds are processed for re-use in the manufacturing of PV panels

There are a number of avenues open to the operators with regard to recycling of the panels:

- PV Cycle (www.pvcycle.org.uk) is a global not-for-profit organisation that offers waste management services for operators of solar parks.

Initially set up to recycle PV solar panels it has expanded its services to include batteries and inverters. PV Cycle has achieved a 96% recycling rate for silicon based PV solar panels.

- Recycle Solar (www.recyclesolar.co.uk) is based in Scunthorpe and specialises in the recycling of PV solar panels and inverters.

(ii) Battery Energy Storage Systems: The Battery Energy Storage System will comprise of a series of steel containers which contain the Lithium-ion battery cells in addition to switchgear, inverters and transformers. The facilities required for large scale recycling of Li-ion batteries do not currently exist in the UK although this is likely to change in the future with large - scale deployment of Li-ion batteries in the both the electricity storage and car industries expected over the coming years. In light of this Li-ion batteries are currently sent to recycling facilities in Europe and Asia where recycling rates of c90% are achieved with Li-ion batteries. As part of the supply contract the suppliers of Li-ion batteries for Battery Energy Storage Systems arrange the recycling of the Li-ion batteries.

(iii) Substation: Substation compounds contain the infrastructure (switchgear, transformers, circuit breakers etc) that allows the safe export/import of electricity to/from the local electricity network. The switchgear that controls the flow of electricity is located within the control rooms and the transformer 'steps' up the voltage of the electricity from the low voltage that is produced by the solar panels to the high voltage required to allow export to the local electricity network. Dismantling of substations is completed by specialist contractors in the UK such as C. Soar and Sons (www.csoarandsons.co.uk), C. K. Beckett (www.ckbeckett.co.uk) and John Robson Metal Ltd (www.johnrobsonltd.co.uk). Recycling rates in excess of 95% are standard in the dismantling of the electrical equipment.

(iv) Powerstations (Inverters/Transformers): Powerstations are located throughout the solar park and it is here that the low voltage electricity produced by the PV solar panels is converted from DC to AC and the process of stepping up the voltage commences.

The inverter converts the electricity from DC to AC. The components of a typical inverter are transistors, capacitors, semi-conductors, inductors and circuit boards. Recycle rates of greater than 95% are standard when recycling inverters.

Transformers step up the voltage to the required level and depending on the steps required a series of transformers may be used throughout the solar park. Transformers are made from steel with internal aluminium/copper coils, ceramic bushings, insulation and are typically oil filled. The oil is used to cool down the transformer during operation and also as an insulator and this requires specialist handling when the transformer is being de-commissioned. Transformers are often completely stripped down after use and re-built again to enter the market as a re-furbished transformer.

(v) Switchgear: Switchgear is composed of a switches, fuses, relays and circuit breakers which allows the control, protection and isolation of the solar park. Switchgear recycling services are widely available throughout the UK.

(vi) Cables: The cables used in solar parks will utilise either copper or aluminium as the conducting material. Cable recycling services are widely available throughout the UK.

(vii) Mounting Structure: The mounting structure which is the framework that supports the panels is formed using galvanised steel and/or aluminium both of which are widely recycled in the UK.

APPENDIX 1 - SOLAR IRRADIATION MAP FOR THE UK

APPENDIX 2

PVSYST REPORT FOR THE CANDIDATE DESIGN USING 420Wp PANELS

Grid-Connected System: Simulation parameters

Project :	**Little crow**			
Geographical Site	**Broughton**		Country	**United Kingdom**
Situation	Latitude	53.58° N	Longitude	-0.58° W
Time defined as	Legal Time	Time zone UT	Altitude	50 m
	Albedo	0.20		
Meteo data:	**Broughton**	SolarGIS Monthly aver. , period not spec. - Synthetic		

Simulation variant : **Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.1**

Simulation date 10/05/21 11h05

Simulation parameters	System type	**Ground system (tables) on a hill**		
Collector Plane Orientation	Tilt	15°	Azimuth	3°
Sheds configuration	Nb. of sheds	6873		
	Sheds spacing	10.6 m	Collector width	7.55 m
Shading limit angle	Limit profile angle	30.8°	Ground cov. Ratio (GCR)	71.2 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	According to module strings		Electrical effect	100 %
User's needs :	Unlimited load (grid)			
Grid power limitation	Active Power	99.9 MW	Pnom ratio	1.500

PV Array Characteristics

PV module	Si-mono	Model	**LR4-72 HIH 420 M**		
Original PVsyst database		Manufacturer	Longi Solar		
Number of PV modules		In series	27 modules	In parallel	13210 strings
Total number of PV modules		Nb. modules	356670	Unit Nom. Power	420 Wp
Array global power		Nominal (STC)	**149801 kWp**	At operating cond.	135907 kWp (50°C)
Array operating characteristics (50°C)		U mpp	975 V	I mpp	139451 A
Total area		Module area	**793584 m²**	Cell area	707747 m²

Inverter	Model	**Sunny Central 4600 UP (Preliminary)**		
Custom parameters definition	Manufacturer	SMA		
Characteristics	Operating Voltage	1003-1325 V	Unit Nom. Power	4600 kWac
Inverter pack	Nb. of inverters	26 units	Total Power	119600 kWac
			Pnom ratio	1.25

PV Array loss factors

Array Soiling Losses			Loss Fraction	1.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	0.039 mOhm	Loss Fraction	0.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC
LID - Light Induced Degradation			Loss Fraction	1.5 %
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Grid-Connected System: Simulation parameters

Incidence effect (IAM): User defined profile

0°	25°	45°	60°	65°	70°	75°	80°	90°
1.000	1.000	0.995	0.962	0.936	0.903	0.851	0.754	0.000

System loss factors

AC wire loss inverter to transfo	Inverter voltage	690 Vac tri		
	Wires: 3x30000.0 mm²	39 m	Loss Fraction	0.7 % at STC
External transformer	Iron loss (24H connexion)	147134 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive losses	0.016 mOhm	Loss Fraction	0.5 % at STC

Auxiliaries loss Proportionnal to Power 1.0 W/kW ... from Power thresh. 0.0 kW

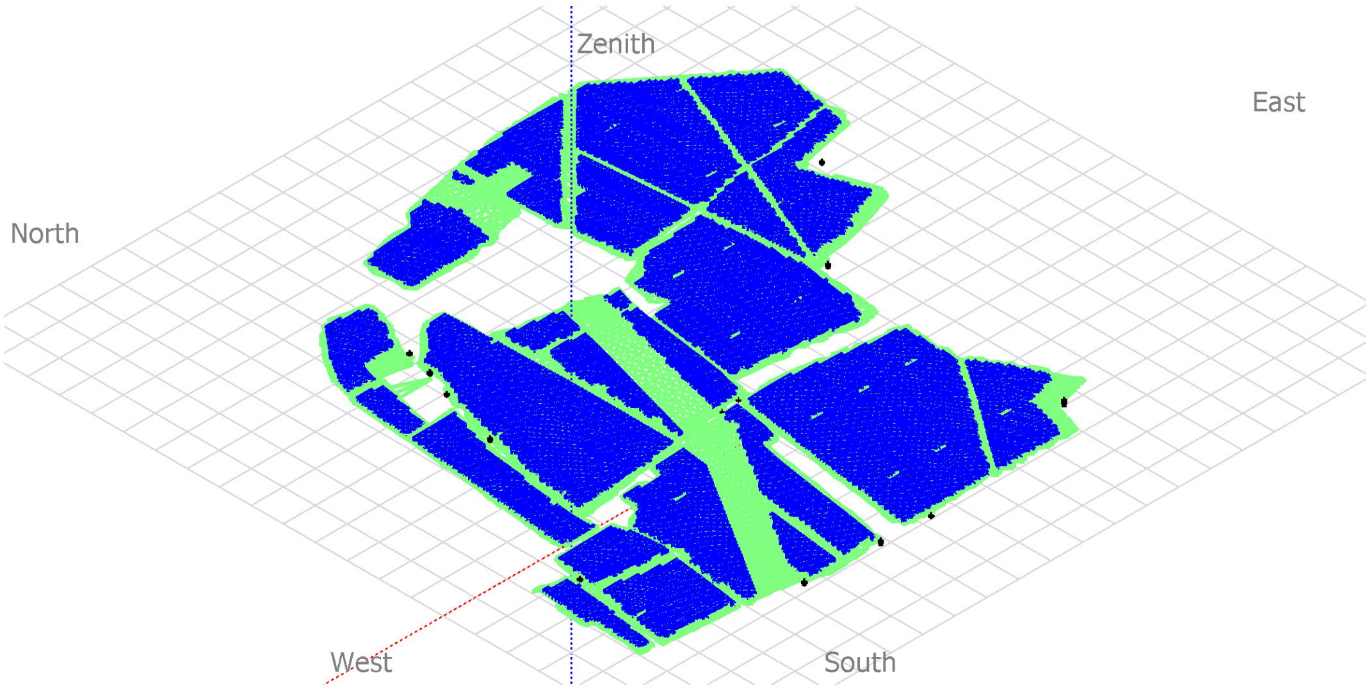
Grid-Connected System: Near shading definition

Project : **Little crow**

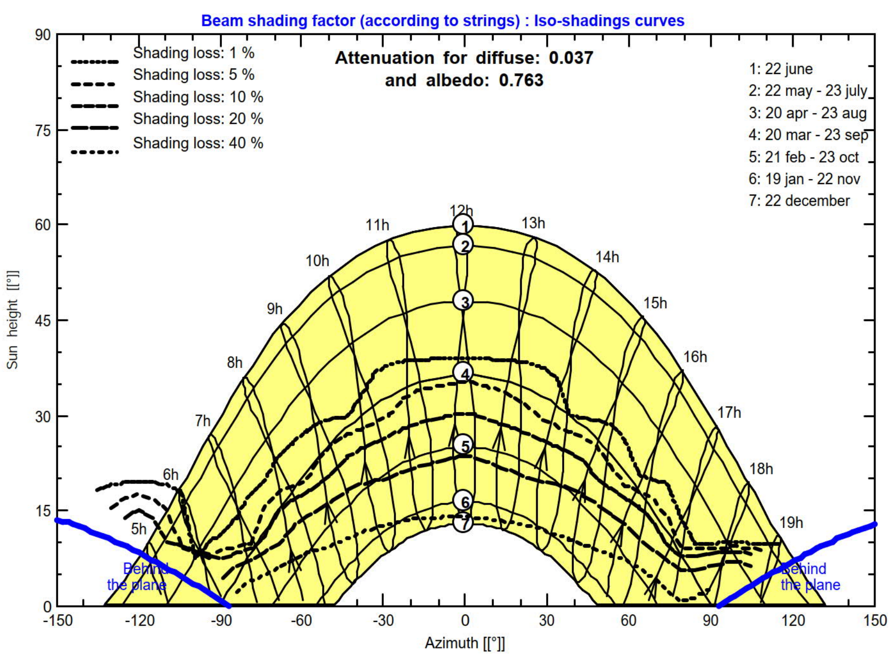
Simulation variant : **Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.1**

Main system parameters	System type	**Ground system (tables) on a hill**		
Near Shadings	According to module strings		Electrical effect	100 %
PV Field Orientation	tilt	15°	azimuth	3°
PV modules	Model	LR4-72 HIH 420 M	Pnom	420 Wp
PV Array	Nb. of modules	356670	Pnom total	**149801 kWp**
Inverter		Sunny Central 4600 UP (Preliminary)	Pnom	4600 kW ac
Inverter pack	Nb. of units	26.0	Pnom total	**119600 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



Grid-Connected System: Main results

Project : **Little crow**

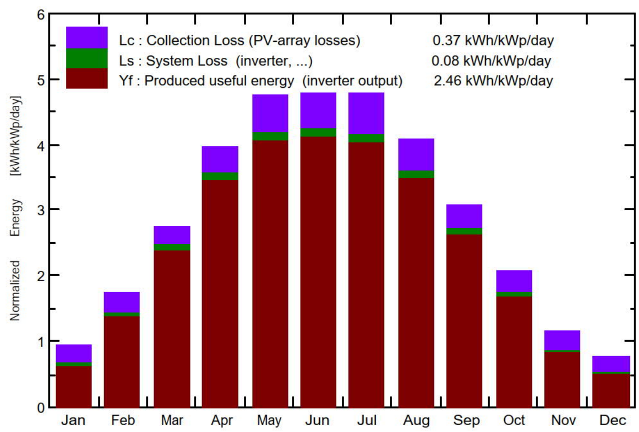
Simulation variant : **Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.1**

Main system parameters System type **Ground system (tables) on a hill**

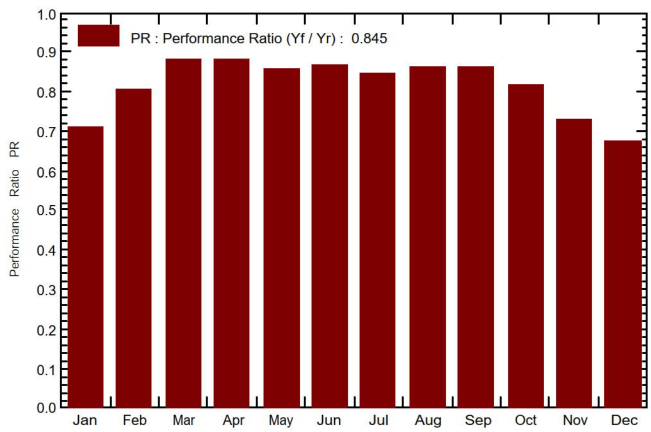
Near Shadings According to module strings Electrical effect 100 %
PV Field Orientation tilt 15° azimuth 3°
PV modules Model LR4-72 HIH 420 M Pnom 420 Wp
PV Array Nb. of modules 356670 Pnom total **149801 kWp**
Inverter Sunny Central 4600 UP (Preliminary) Pnom 4600 kW ac
Inverter pack Nb. of units 26.0 Pnom total **119600 kW ac**
User's needs Unlimited load (grid)

Main simulation results
System Production **Produced Energy** **134529 MWh/year** Specific prod. 898 kWh/kWp/year
Performance Ratio PR 84.46 %

Normalized productions (per installed kWp): Nominal power 149801 kWp



Performance Ratio PR



Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.1

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	20.0	13.00	4.70	29.2	23.1	3283	3092	0.708
February	37.0	22.00	4.80	49.1	42.8	6151	5915	0.804
March	73.0	44.00	6.10	85.0	79.6	11627	11247	0.883
April	108.0	63.00	7.90	118.4	111.4	16129	15650	0.882
May	141.0	80.00	11.00	147.3	138.7	19508	18944	0.859
June	140.0	82.00	13.80	143.5	135.1	19107	18570	0.864
July	144.0	82.00	16.20	148.3	139.6	19304	18757	0.844
August	118.0	71.00	16.50	126.4	119.0	16770	16288	0.860
September	82.0	50.00	13.90	92.4	86.7	12285	11903	0.860
October	51.0	31.00	10.70	64.6	57.7	8175	7886	0.815
November	25.0	16.00	7.40	35.3	28.8	4064	3863	0.731
December	16.0	11.00	4.80	23.9	18.3	2593	2415	0.675
Year	955.0	564.99	9.85	1063.3	980.5	138995	134529	0.845

Legends:
- GlobHor: Horizontal global irradiation
- DiffHor: Horizontal diffuse irradiation
- T_Amb: T amb.
- GlobInc: Global incident in coll. plane
- GlobEff: Effective Global, corr. for IAM and shadings
- EArray: Effective energy at the output of the array
- E_Grid: Energy injected into grid
- PR: Performance Ratio

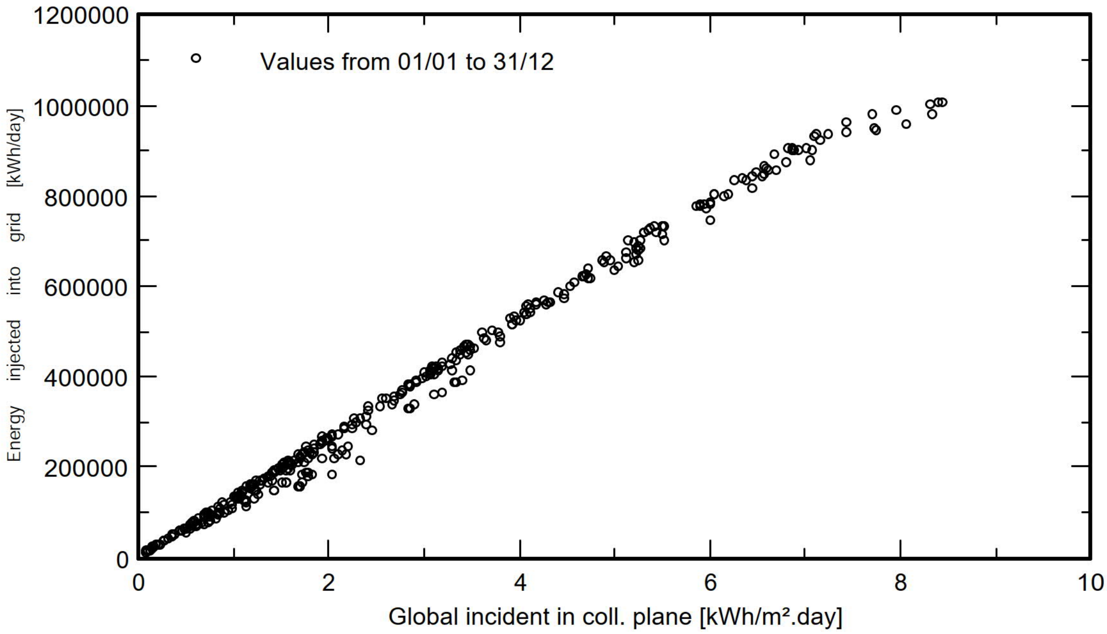
Grid-Connected System: Special graphs

Project : **Little crow**

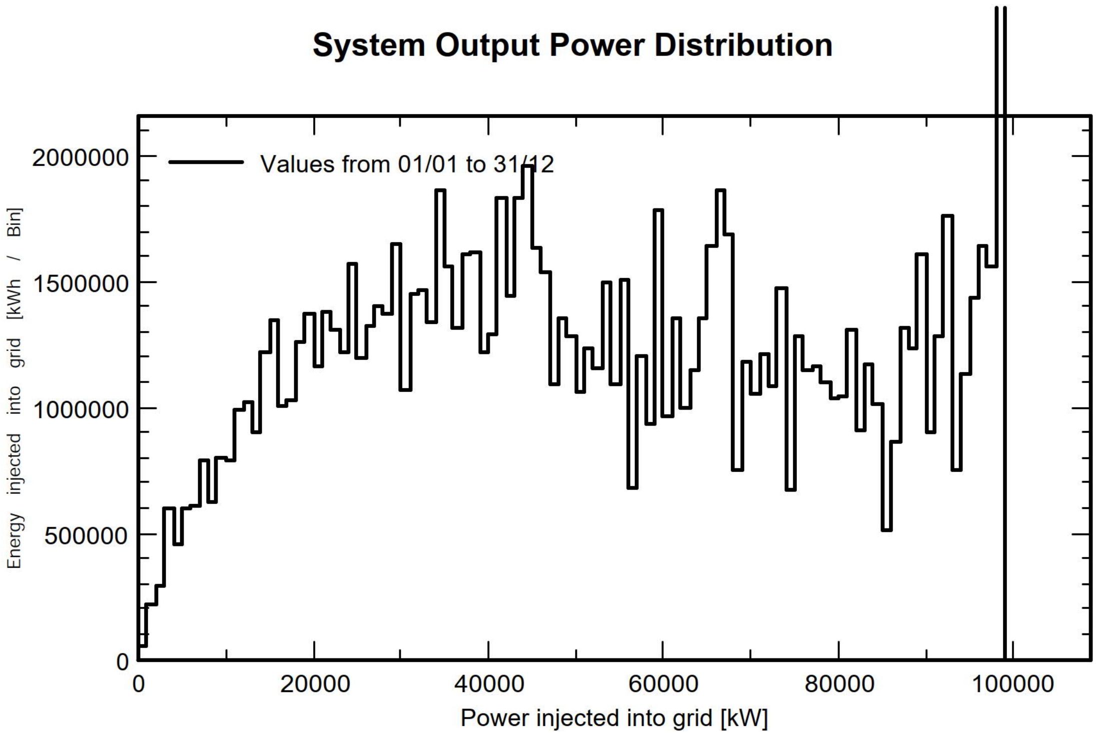
Simulation variant : **Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.1**

Main system parameters	System type	**Ground system (tables) on a hill**		
Near Shadings	According to module strings		Electrical effect	100 %
PV Field Orientation	tilt	15°	azimuth	3°
PV modules	Model	LR4-72 HIH 420 M	Pnom	420 Wp
PV Array	Nb. of modules	356670	Pnom total	**149801 kWp**
Inverter		Sunny Central 4600 UP (Preliminary)	Pnom	4600 kW ac
Inverter pack	Nb. of units	26.0	Pnom total	**119600 kW ac**
User's needs	Unlimited load (grid)			

Daily Input/Output diagram



System Output Power Distribution



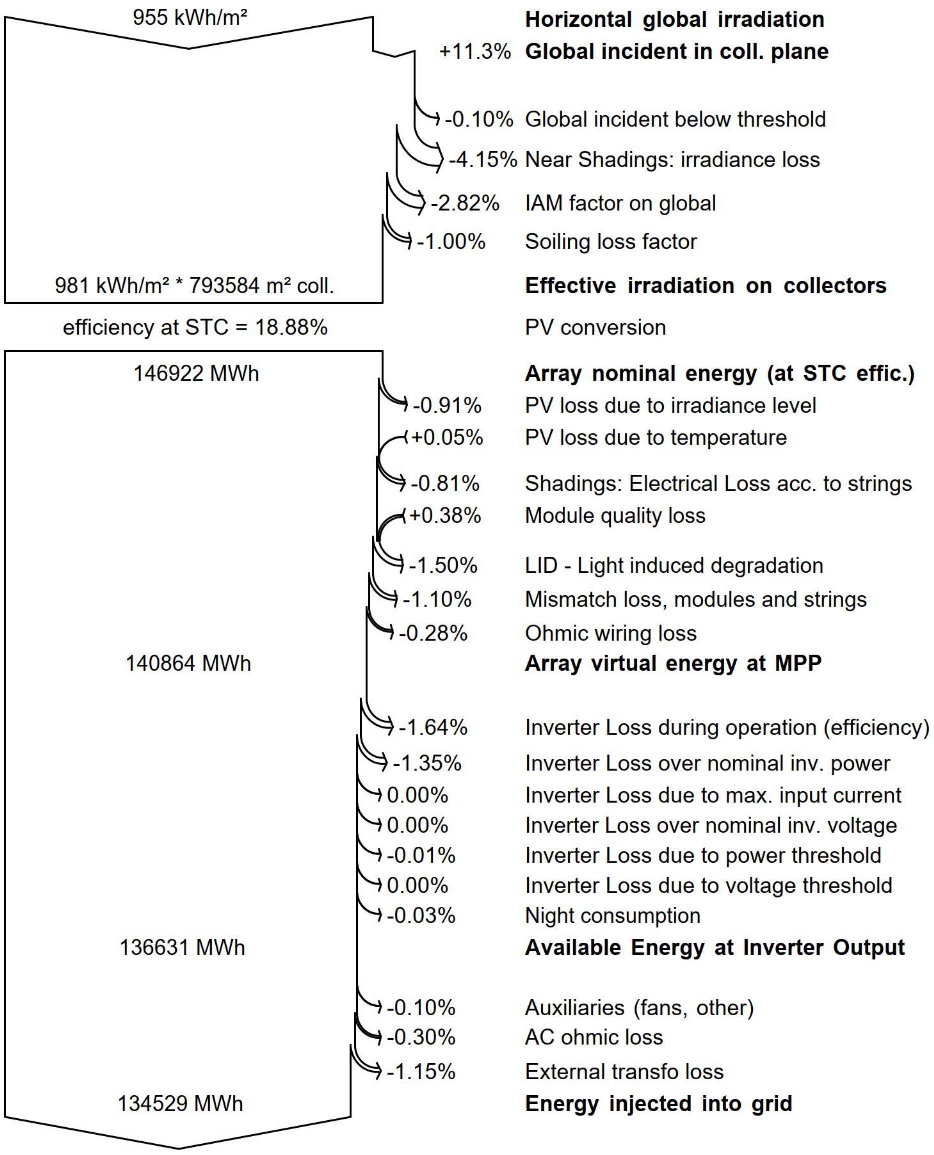
Grid-Connected System: Loss diagram

Project : **Little crow**

Simulation variant : **Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.1**

Main system parameters	System type	**Ground system (tables) on a hill**		
Near Shadings	According to module strings		Electrical effect	100 %
PV Field Orientation	tilt	15°	azimuth	3°
PV modules	Model	LR4-72 HIH 420 M	Pnom	420 Wp
PV Array	Nb. of modules	356670	Pnom total	**149801 kWp**
Inverter		Sunny Central 4600 UP (Preliminary)	Pnom	4600 kW ac
Inverter pack	Nb. of units	26.0	Pnom total	**119600 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



APPENDIX 3

PVSYST REPORT FOR THE CANDIDATE DESIGN USING 535Wp PA

Grid-Connected System: Simulation parameters

Project :	**Little crow**			
Geographical Site	**Broughton**		Country	**United Kingdom**
Situation	Latitude	53.58° N	Longitude	-0.58° W
Time defined as	Legal Time	Time zone UT	Altitude	50 m
	Albedo	0.20		
Meteo data:	**Broughton**	SolarGIS Monthly aver. , period not spec. - Synthetic		

Simulation variant :	**Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.3**			
	Simulation date	10/05/21 14h51		

Simulation parameters	System type	**Unlimited sheds**		
Collector Plane Orientation	Tilt	15°	Azimuth	0°
Sheds configuration	Nb. of sheds	125	Unlimited sheds	
	Sheds spacing	10.6 m	Collector width	8.00 m
Inactive band	Top	0.02 m	Bottom	0.02 m
Shading limit angle	Limit profile angle	36.0°	Ground cov. Ratio (GCR)	75.5 %
Shadings electrical effect	Cell size	15.6 cm	Strings in width	6
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Mutual shadings of sheds	Electrical effect		
Bifacial system	Model	Unlimited sheds, 2D calculation		
	Sheds spacing	10.60 m	Sheds width	8.04 m
	Limit profile angle	36.3°	GCR	75.8 %
	Ground albedo	25.0 %	Height above ground	0.80 m
	Module bifaciality factor	70 %	Rear shading factor	5.0 %
	Module transparency	0.0 %	Rear mismatch loss	10.0 %
User's needs :	Unlimited load (grid)			
Grid power limitation	Active Power	99.9 MW	Pnom ratio	1.910

PV Array Characteristics

PV module Si-mono	Model	**18X-LR5-72HBD-535M**		
Custom parameters definition	Manufacturer	Longi Solar		
Number of PV modules	In series	27 modules	In parallel	13210 strings
Total number of PV modules	Nb. modules	356670	Unit Nom. Power	535 Wp
Array global power	Nominal (STC)	**190818 kWp**	At operating cond.	174362 kWp (50°C)
Array operating characteristics (50°C)	U mpp	1006 V	I mpp	173382 A
Total area	Module area	**911666 m²**	Cell area	845907 m²
Inverter	Model	**Sunny Central 4600 UP (Preliminary)**		
Custom parameters definition	Manufacturer	SMA		
Characteristics	Operating Voltage	1003-1325 V	Unit Nom. Power	4600 kWac
Inverter pack	Nb. of inverters	33 units	Total Power	151800 kWac
			Pnom ratio	1.26

PV Array loss factors

Array Soiling Losses			Loss Fraction	1.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	0.032 mOhm	Loss Fraction	0.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.1 % at STC

Grid-Connected System: Simulation parameters

LID - Light Induced Degradation	Loss Fraction	1.5 %
Module Quality Loss	Loss Fraction	-0.2 %
Module Mismatch Losses	Loss Fraction	1.0 % at MPP
Strings Mismatch loss	Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	40°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	0.998	0.992	0.983	0.961	0.933	0.853	0.000

System loss factors

AC wire loss inverter to transfo	Inverter voltage	690 Vac tri		
	Wires: 3x30000.0 mm²	20 m	Loss Fraction	0.5 % at STC
External transformer	Iron loss (24H connexion)	187666 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive losses	0.013 mOhm	Loss Fraction	0.5 % at STC

Auxiliaries loss Proportionnal to Power 1.0 W/kW ... from Power thresh. 0.0 kW

Grid-Connected System: Main results

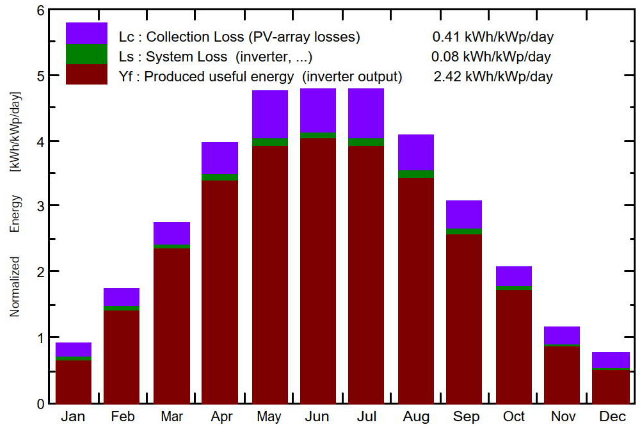
Project : **Little crow**

Simulation variant : **Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.3**

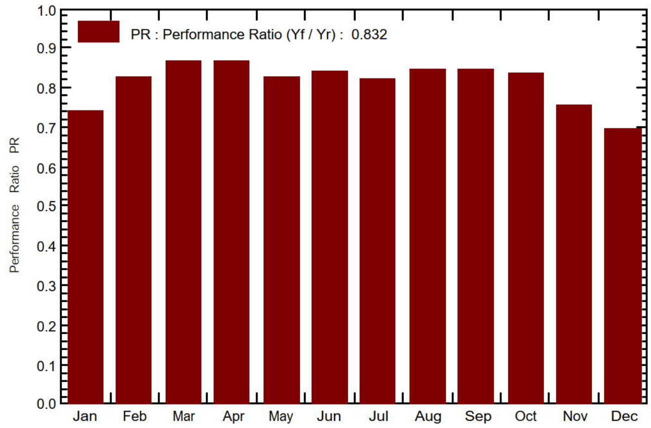
Main system parameters System type **Unlimited sheds**
PV Field Orientation Sheds disposition, tilt 15° azimuth 0°
PV modules Model 18X-LR5-72HBD-535M Pnom 535 Wp
PV Array Nb. of modules 356670 Pnom total **190818 kWp**
Inverter Sunny Central 4600 UP (Preliminary) Pnom 4600 kW ac
Inverter pack Nb. of units 33.0 Pnom total **151800 kW ac**
User's needs Unlimited load (grid)

Main simulation results
System Production **Produced Energy** **168708 MWh/year** Specific prod. 884 kWh/kWp/year
Performance Ratio PR 83.20 %

Normalized productions (per installed kWp): Nominal power 190818 kWp



Performance Ratio PR



Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.3

Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	
January	20.0	13.00	4.70	29.0	23.0	4331	4085	0.738
February	37.0	22.00	4.80	49.0	42.5	8006	7705	0.825
March	73.0	44.00	6.10	84.9	80.7	14464	14006	0.864
April	108.0	63.00	7.90	118.4	113.3	20114	19545	0.865
May	141.0	80.00	11.00	147.3	141.0	23927	23267	0.828
June	140.0	82.00	13.80	143.6	137.3	23734	23094	0.843
July	144.0	82.00	16.20	148.3	141.9	23862	23211	0.820
August	118.0	71.00	16.50	126.4	120.9	20993	20406	0.846
September	82.0	50.00	13.90	92.3	88.1	15359	14894	0.846
October	51.0	31.00	10.70	64.4	57.6	10617	10249	0.834
November	25.0	16.00	7.40	35.2	28.7	5337	5079	0.756
December	16.0	11.00	4.80	23.8	18.3	3397	3168	0.697
Year	955.0	564.99	9.85	1062.6	993.4	174140	168708	0.832

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

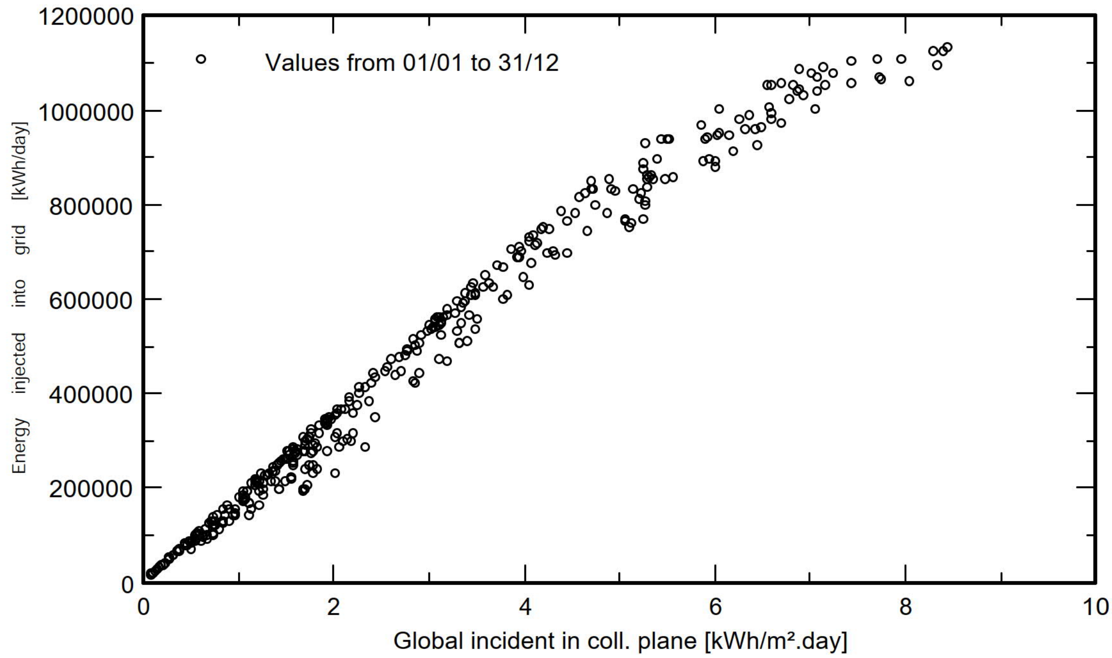
Grid-Connected System: Special graphs

Project : **Little crow**

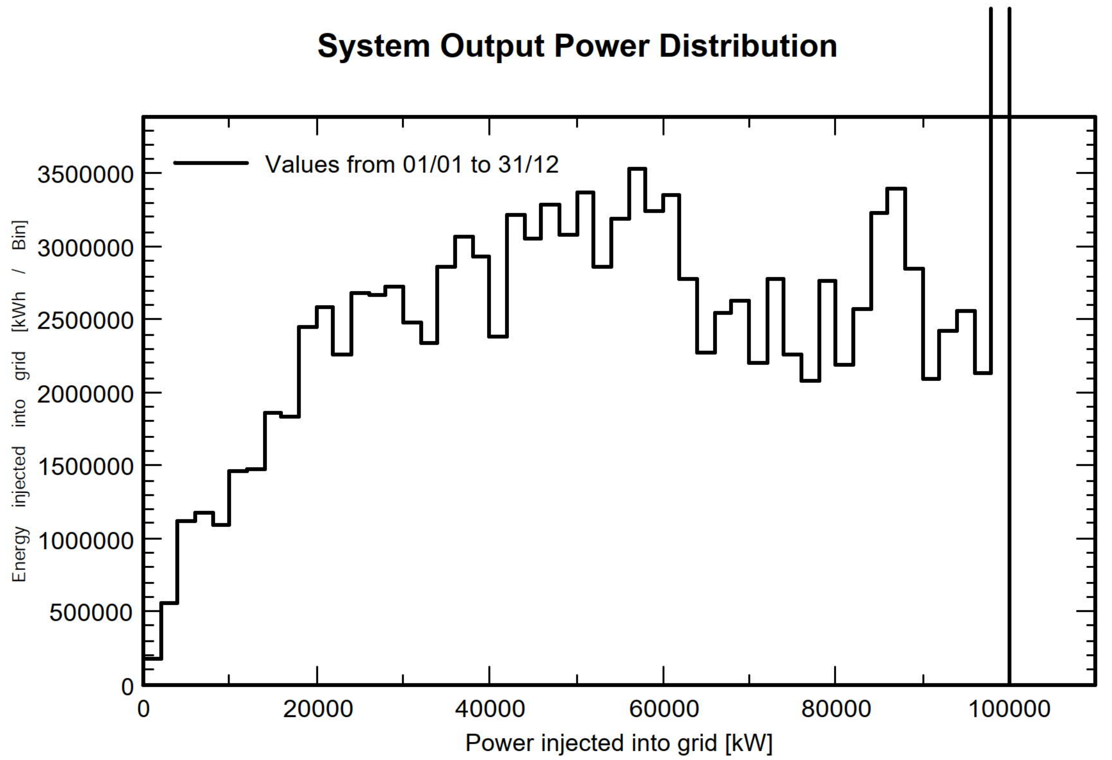
Simulation variant : **Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.3**

Main system parameters	System type	**Unlimited sheds**		
PV Field Orientation	Sheds disposition, tilt	15°	azimuth	0°
PV modules	Model	18X-LR5-72HBD-535M	Pnom	535 Wp
PV Array	Nb. of modules	356670	Pnom total	**190818 kWp**
Inverter		Sunny Central 4600 UP (Preliminary)	Pnom	4600 kW ac
Inverter pack	Nb. of units	33.0	Pnom total	**151800 kW ac**
User's needs	Unlimited load (grid)			

Daily Input/Output diagram



System Output Power Distribution



Grid-Connected System: Loss diagram

Project : **Little crow**

Simulation variant : **Littlecrow_PVsyst_A01B0C0_10.05.2021_Simulation.3**

Main system parameters	System type	**Unlimited sheds**		
PV Field Orientation	Sheds disposition, tilt	15°	azimuth	0°
PV modules	Model	18X-LR5-72HBD-535M	Pnom	535 Wp
PV Array	Nb. of modules	356670	Pnom total	**190818 kWp**
Inverter		Sunny Central 4600 UP (Preliminary)	Pnom	4600 kW ac
Inverter pack	Nb. of units	33.0	Pnom total	**151800 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year