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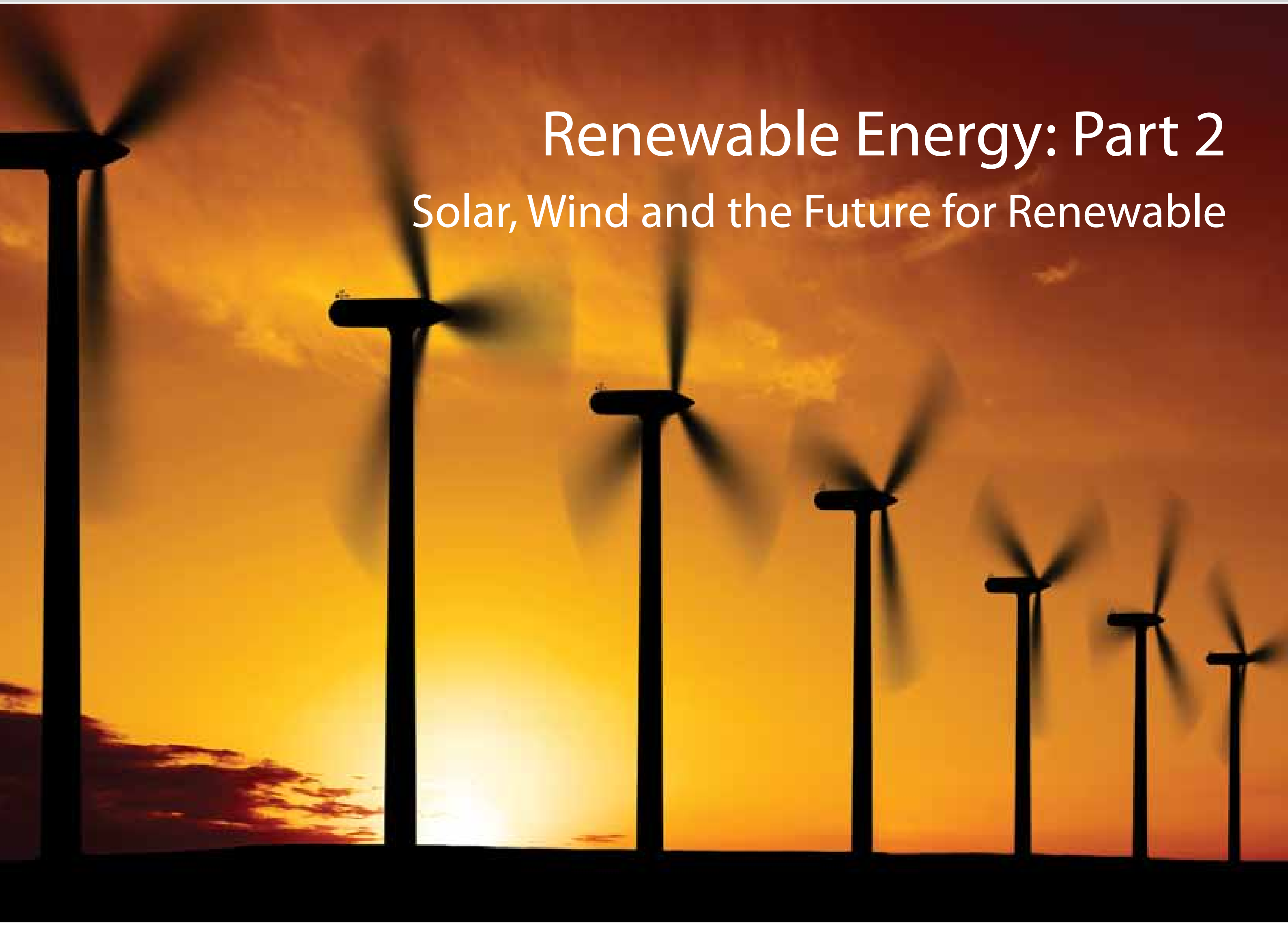
Technical News

INDUSTRIAL ELECTRICAL AND AUTOMATION PRODUCTS, SYSTEMS AND SOLUTIONS



Renewable Energy: Part 2

Solar, Wind and the Future for Renewable

Written by Damian Jones
Sustainability and Engineering Projects Manager

INTRODUCTION

In the last edition of technical news (issue #62) the difference between renewable and non-renewable sources of energy was discussed, with a variety of renewable energy sources highlighted including:

- Direct heating.
- Hydro-power generation.
- Bio-mass.
- Tidal power.
- Geothermal power.

In this issue of technical news, the discussion continues with:

- Photovoltaic solar energy.
- Wind energy

PHOTOVOLTAIC POWER - 15,000MW WORLD, 300MW AUSTRALIA, NOT SIGNIFICANT NEW ZEALAND

Unlike many other renewable energy sources, photovoltaic power is relatively new. The photoelectric effect was discovered by Alexander Bequerel in 1839. The word Photovoltaic describes the direct conversion of sunlight into electrical energy by means of solar cells.

Over 95% of all the solar cells produced worldwide are composed of the semiconductor material Silicon (1). As the second most abundant element in earth`s crust, silicon has the advantage of being easily available and its extraction is generally not an excessive burden to the environment.

To produce a solar cell the semiconductor is contaminated or "doped". "Doping" is the intentional introduction of chemical elements. Connecting two differently contaminated semiconductor layers forms a "p-n-junction" at the boundary of the layers. This is the same technology used to produce diodes and transistors.

The usable voltage from solar cells depends on the semiconductor material. Using silicon amounts to approximately 0.5 V. Terminal voltage is only weakly dependent on light radiation. It is the current intensity that increases with higher illumination. Figure 1 shows the typical voltage current curve for a solar module. Also shown is the output power for various operating conditions. The peak of the power curve is significant and it is known as the Maximum Power Point (MPP). Where maximum energy harvesting is required it is important to keep the solar modules operating at the MPP.

The power output of a solar cell is temperature dependent. Higher cell temperatures lead to lower output and hence to lower efficiency. The level of efficiency indicates how much of the incident light energy is converted into useable electrical energy.

There are three commonly available PV types and they all use similar chemical components. It is the technology used in their formation that defines their type:

Mono Crystalline

A single mono-crystalline rod ingot of silicon is extracted from a pool of molten silicon. This rod is a single crystal and is cut into wafers.

Poly Crystalline

A less expensive ingot is formed by casting molten silicon into a mould. The result is an amalgam of many different sized silicon crystals. This is then cut into wafers. The boundaries of the crystals interfere with the PV effect making these cells less efficient.

Amorphous or Thin Film

A silicon film is deposited on glass or another substrate material. This material can be curved or even flexible. The layer thickness amounts to less than 1µm (the thickness of a human hair is 50-100 µm). The production costs are lower due to the low quantity of materials used, with the efficiency of amorphous cells much lower than that of the other two cell types.

The three types of PV cells are easily identified by their appearance. As shown in Figure 2.

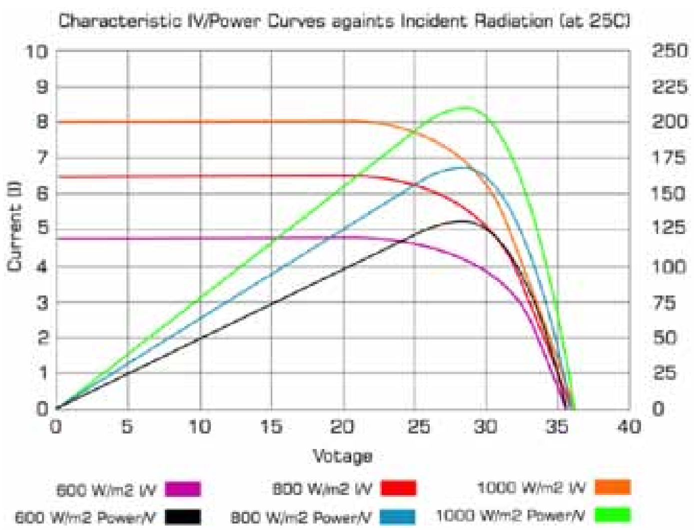


Figure 1: Typical voltage/current curve for a PV module

Typical efficiencies for the three cell types are shown in the table below:

PV Material	Efficiency at 1kW/m^2 25°C	Efficiency in service
Mono-crystalline Silicon	~24%	14 to 17%
Poly-crystalline Silicon	~18%	13 to 15%
Amorphous Silicon	~13%	5 to 7%

The table below gives a snapshot of real relative prices for silicon crystalline PV cells. Poly cells are about 13% less expensive than mono cells (4). The same source shows that the average price for thin film modules was $0.915/W. This was 22% less expensive than crystalline modules at $1.165/W.

Typical efficiencies for the two cell types are shown in the table below:

PV Material	Efficiency at 1kW/m^2 25°C	Efficiency in service
Mono-crystalline 125x125mm	$1.94	-
Poly-crystalline 125x125mm	$1.67	14% less expensive
Mono-crystalline 156x156mm	$3.22	-
Poly-crystalline 156x156mm	$2.84	12% less expensive

Individual cells are connected in series and parallel combinations to obtain useful voltage and current outputs. The interconnected solar cells are usually embedded in a semi-transparent plastic, fitted with an aluminium or stainless steel frame and covered with transparent glass. Typically this assembly is referred to as a "module".

The typical power ratings of such solar modules are between 10W and 250W. This rating is usually provided at the "standard" test conditions of 1000W/m^2 solar radiation at a cell temperature of 25°C. The reality is that in service solar cells operate at much higher temperatures. Temperatures as high as 60°C have been recorded at NHP's Sustainability Centre in Laverton, Melbourne. Depending on how the manufacturer rates their panels, the actual power produce may be less than the rated power. Most manufacturers offer a power output warranty on their panels. For example, Q-Cells (NHP's solar module supplier) warrants that the output of their Q.Pro range of crystalline panels will not fall below 83% of their nominal rating within 25 years.

Mono-crystalline modules have the highest efficiency, however, this is usually only when the module is perpendicular to the incidental sun light. At other angles the efficiency drops. In fact, the efficiency tends to drop faster than that of poly-crystalline panels. For fixed installations, the energy harvesting ability of poly-crystalline modules exceeds that of mono-crystalline modules, making them a better and more cost effective choice for most systems where total energy yield is more important than maximising power. This has been shown at the Desert Knowledge Solar Centre (5) in Australia's Northern Territory.

Figure 2: (top - bottom) Mono-crystalline, Poly-crystalline and thin film solar cells (3)

A typical crystalline solar module has an output voltage defined as 24V. This is somewhat misleading. Such a module might have an open circuit voltage of 45V and a maximum power point voltage of 33V. The 24V rating may be somewhat historic, meaning the module is suitable for charging a 24V battery bank. Solar Modules may be used singly or connected in "strings" of series and parallel combinations. This is done to achieve a voltage and current output to suit the application.

Broadly speaking, there are three common applications for solar modules: Off-Grid, Grid Connect and Hybrid Energy Systems.

Off-Grid

As the name suggests off-grid systems are not connected to the mains electricity grid. They are also called stand-alone systems. The DC energy from the solar modules may be used in a number of ways:

- The simplest method is directly as DC. For example, a water pump that only runs when the sun is shining.
- A bank of batteries can be charged to provide a "buffer" for when the sun is not shining. For example, a remote telecommunications tower that must function both day and night.
- A DC to AC inverter may be used in conjunction with batteries to create a mains voltage that is only used locally. Examples include a remote household without access to the electricity grid or a backup power system for critical installations that cannot tolerate black outs.

Perhaps the greatest advantages of off-grid PV systems are their immunity to supply interruptions and their ability to supply remote locations, where connection to the mains grid is impractical due to cost or terrain.

Perhaps the greatest disadvantages are the requirement for a battery pack and the risk of weather that results in complete discharge of the battery system and subsequent loss of supply. Regardless of the battery chemistry used, all batteries will likely need to be replaced several times within the life of the installation.

Batteries are also generally expensive. It is tempting to select the smallest possible battery pack, however, the deeper that a battery pack is discharged the shorter its life will be. Also, a small battery pack limits the system's ability to cope with extended periods without sun. A cost benefit analysis is definitely required when sizing battery systems. A compromise is often to include a backup internal combustion engine generator to cater for extended periods of poor weather.

Hybrid Energy System

As the name suggests hybrid energy systems share properties of both grid and off-grid systems. They are also referred to as energy management systems. A typical hybrid system is capable of providing a stable and reliable power supply in a manner similar to an uninterruptable power supply (UPS). Typically, solar modules are used to charge a bank of batteries. The energy from the batteries is converted into an AC supply to power the local installation. If the batteries do not hold enough charge to power the installation then energy is automatically imported from the electricity grid. If the batteries are fully charged the surplus energy from the renewable supply can be fed into the grid.

Advanced hybrid energy systems such as the Selectronic Sp-Pro unit at NHP's Sustainability Centre can be configured to start a back-up generator in cases where the grid is not available and the batteries are fully discharged. They can also be configured to take advantage of peak and off-peak tariffs by minimising energy imported from the grid at peak times.

Hybrid energy systems allow an installation to best utilise the available energy sources, be it grid, battery, solar or wind.

Grid connect

In grid connect systems the energy meter and mains electricity supply can be thought of as an "infinite battery". DC energy from the solar modules is fed into an inverter that creates an AC output that is then fed into the local electricity grid. When the system is exporting energy, the installation's energy meter "counts down" or "spins backwards", essentially "storing" energy in the grid. When energy is imported, the energy meter "counts up" or "spins forward", essentially recovering the energy from the grid. In a typical grid connect installation, locally connected loads use the generated energy before it is exported to the grid.

Perhaps the greatest advantage of grid connected PV systems is their simplicity relative to off-grid systems. There are no batteries. A further advantage is the possibility of receiving a "feed-in-tariff" from the power supply company. Until recently in Victoria it was possible to receive $0.66/kWh for energy exported to the grid. While the cost to import energy was $0.20. This feed-in-tariff incentive can significantly reduce the pay-back time for grid connected PV systems. However, for new installations in Victoria this feed-in tariff was recently reduced to $0.25.

Perhaps the greatest disadvantage for grid connect systems is the uncertainty surrounding feed-in-tariffs and the misconception that grid connect systems continue to produce power during a supply interruption.

The uncertainty regarding feed-in-tariffs has led to the perception that it is no longer worthwhile to install grid connect systems. This is a misconception. A reduction in feed-in-tariff will certainly increase the pay-back time for grid-connect systems, however, such a system will still produce power that is used locally at the installation and interact with the grid as an infinite battery. Of course the real cost of buying electricity will only increase. Relative to CPI, the price of electricity in Australia has increased by 40% since 2008 (6). The return on investment can be shown to be greater than current interest rates (7).

It is a requirement of Australian/New Zealand Standard AS/NZS 5033 that all grid connect systems do not export power in the absence of mains supply. This is known as "anti-islanding" and is a function of grid connect systems that is poorly understood by end-users who expect immunity to black outs, at least during the day.

WIND POWER - 194,000MWWORLD, 1,991MW AUSTRALIA, 320MWNEW ZEALAND.

Wind power is yet another ancient source of energy. The first recorded instance of a working windmill was built by Greek engineer Heron of Alexandria in the 1st century AD (8). The canvas and wood structures of earlier times have been replaced by more modern materials such as carbon fibre and superconductive magnets. However, as with the ancient windmills, modern wind turbines still simply convert the kinetic energy of moving air into mechanical motion. Typically, modern turbines are connected to a generator to then produce electrical energy.

Interestingly, all turbines or windmills are constrained by a theoretical upper limit of efficiency. That is, the fraction of energy that can be extracted from the kinetic energy contained in the moving air stream. Known as Betz's law, no turbine can capture more than 59.3% of the kinetic energy of the wind (9). The mechanism behind this limit is easy to understand. The air flow past the turbine must be continuous. If all the kinetic energy was removed from the air then the air flow would stop. So, some kinetic energy must be left in the air to keep it moving or the turbine would stop too!

Of course 59.3% is a theoretical figure. Real devices achieve significantly lower figures. The 3kW micro turbine at the NHP Sustainability Centre has a claimed (and confirmed) efficiency of approximately 40% at its rated power.

Modern wind turbines have two main configurations. This is defined by the orientation of their axis of rotation. They are known as Horizontal Axis Wind Turbines (HAWT) or Vertical Axis Wind Turbines (VAWT). Two examples of micro wind turbines are shown in Figure 3.

At the micro turbine scale, VAWT tend to be more consistent in their output. They do not need to track the wind direction and are somewhat more tolerant to turbulence. However, they are considerably more expensive.

Perhaps more so than with other renewable energy systems a site survey is critical prior to the installation of wind power systems. The NHP Sustainability Centre includes a 3kW Carlo Gavazzi HAWT. Visitors to the Centre, which is located behind NHP's National Manufacturing & Distribution Centre, commonly say "Laverton must be a great place for a wind turbine. It is so windy here." Laverton does indeed have windy days, however, consistency in the wind is required for an energy generation system.

Based on Australian Bureau of Meteorology data our 3kW system can only be expected to produce 400W averaged across a year. Furthermore, this assumes non-turbulent air flow. Turbulence results in the turbine constantly changing direction while trying to stay aligned with the air flow. For local council reasons the mast of our turbine was limited to 8m. This is lower than the surrounding structures meaning there is a large amount of turbulence. The average power generated by our turbine is expected to be considerably less than 400W.

All this once again highlights the importance of a site survey. There are certainly sites where micro wind turbines can perform very well. Typically sites overlooking broad areas of flat terrain, say, a cliff overlooking the ocean or a hill overlooking extensive areas of flat farm land.

Of course, larger scale wind turbines can and do find suitable sites for installation. In addition to the 1.991MW of installed wind turbines in Australia an additional 9,000MW of large-scale wind farm projects are proposed within Australia (10).

Figure 3: (left) the HAWT at the NHP Sustainability Centre (right) a VAWT courtesy of True Solar Time.

WHAT IS NEXT?

Renewable energy sources are expected to become more common and more economically feasible as the cost of energy, in particular electricity, increases. So what will happen next in the renewable energy fields? Below are some speculations:

PV Cells New Direction

Research continues on improving the efficiency of PV cells (1):

- Surface structuring to reduce reflection loss: for example, construction of the cell surface in a pyramid structure, so that incoming light hits the surface several times.
- New materials: for example, gallium arsenide (GaAs), cadmium telluride (CdTe) or copper indium selenide ($CuInSe^2$).
- Tandem or stacked cells: in order to be able to use a wide spectrum of radiation, different semiconductor materials, which are suited for different spectral ranges, will be arranged one on top of the other.
- Concentrator cells: A higher light intensity will be focussed on the solar cells by the use of mirror and lens systems. This system tracks the sun, always using direct radiation.
- MIS Inversion Layer cells: the inner electrical field are not produced by a p-n junction, but by the junction of a thin oxide layer to a semiconductor.
- Grätzel cells: Electrochemical liquid cells with titanium dioxide as electrolytes and dye to improve light absorption.

Co-Generation

This system involves generating electricity at the site of consumption. A readily available fuel such as natural gas or bio-methane is used to produce both heat for HVAC systems and electricity for the site. The gas may be burnt in a specially designed internal combustion engine. The engine turns a generator and waste heat is directed to HVAC services. Alternatively, the gas may be processed by a fuel cell as in the "Bloom Box" produced by a company called Bloom Energy.

Co-generation technology is already in place and is gaining momentum as more installations adopt the system

Electric Vehicles with Muscle

As battery technologies continue to develop, electric vehicles are becoming reality. Previously, electric vehicles have been perceived as slow, underperforming machines. The purely electric Tesla Roadster challenges this (Figure 4). With a 185kW motor it is capable of 0-100km/h in 3.8 seconds and has a range of 393km between charges.

"Range anxiety" is a common concern with electric vehicles. Diesel powered turbine engines are being developed as "range extenders" for electric vehicles. In particular for large transport vehicles. This technology is being investigated by the Capstone Turbine Corporation.

NHP is expanding its vehicle fleet to include Electric Vehicles and have agreed to participate in the Victorian Government's Electric Vehicle Trial (see breakout box). One of the vehicles currently on order is the much acclaimed General Motors Volt. Based on the Chevy Volt, this vehicle has an all-electric range of approximately 100km using a petrol engine as a generator to extend the range of the vehicle to 500km, if required. For the general commuter, this type of electric vehicle is as practical as a similar petrol engine car but runs at a fraction of the cost.

Figure 4: the author, Damian Jones, with the Tesla Roadster

Further to the General Motors Volt, NHP will be participating in the Victorian Government's Electric Vehicle (EV) Trial, which will run until mid-2014 and will help Victoria to better understand the process, time lines and barriers for transitioning to electric vehicle technologies.

The Electric Vehicle trial for fleet operators involves leasing one or more EV's from the Department of Transport, setting up a limited charging infrastructure and then using the EV within the organisation in a manner that best promotes the use of EVs.

Data is gathered about usage patterns, power consumption and other issues associated with EV use. This data will be used by the Department of Transport to guide government action on integrating EVs into the existing transport infrastructure.

More information is available at the EV Trial website:

http://www.transport.vic.gov.au/projects/ev-trial

THE NHP SUSTAINABILITY CENTRE

As the Centre design is finalised, NHP will begin to capture real data from the installation. For example, Figure 5 below is a screen capture from the EOS system installed at the Centre. This display shows the DC power output from two strings of solar modules. It clearly shows the difference in power output for a fixed string versus a tracking string.

The Centre will continue to evolve as new products and ideas become available. An advanced hybrid energy system based around the Selectronic SP-Pro device was recently installed. The design of a display to demonstrate the energy saving possibilities of variable speed drives (VSDs) in certain applications is also underway.

The Centre was officially opened in late November 2011 and is open to NHP customers and the general public by appointment. Please contact your local NHP representative or book a tour through NHP's website or by scanning the QR code.

Scan the QR code to Book a Live Tour.

(top) Damian Jones demonstrates the Grid Connect PV Small Scale in the NHP Sustainability Centre ***(bottom)*** Damian Jones and David Cheng discuss the Poly-crystalline solar modules.

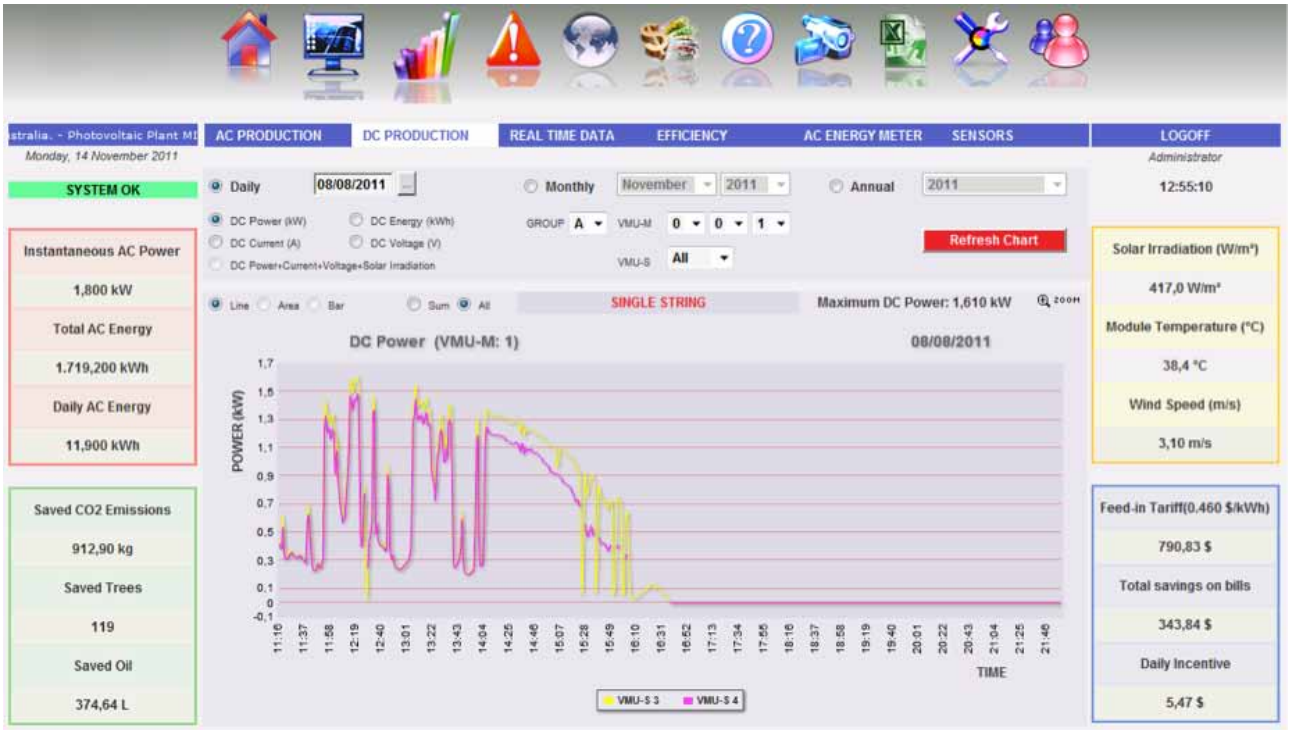


Figure 5: Screen capture from the EOS system at the NHP Sustainability Centre.

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