



**Murdoch**  
UNIVERSITY

School of Engineering and Information Technology

ENG 470 Engineering Thesis

# Upgrade and Performance Evaluation of REPS Facility

Scott James Mokrzycki

Renewable Energy and Power System facility

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**Commerce**

## Declaration

The following dissertation is based on the author's own research and findings. The research and work performed throughout the report relied on others of whom acknowledgment is given.

## Acknowledgements

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I would like to thank Daniel Jones from Pure Engineering with allowing me to document the maintenance of the Fortis Wind Turbine on campus.

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## Abstract

Murdoch University's Renewable Energy Power Systems (REPS) Facility is designed to give students a practical understanding of how a stand-alone power system operates. The facility allows students and faculty to monitor, adjust and observe a range of system components in the energy generation process.

The facility is designed to manage the power generation of two wind turbines with the option of isolation through a switch located on the main wall of the facility. The Soma 1kW wind turbine has been erected and placed on top of the previous Ginlong WT tower and requires integration into the facility. This involved the current WB inverter to be checked for compatibility as well as its existing parameters to be changed to allow for the new turbine to be compatible.

The SOMA turbine's controller and dump load location inside the facility needed to be connected (Fig 3). The housing for the controller remained in its position on the main wall of the facility whilst the dump load was removed from the controller and secured inside the previous Ginlong dump load housing on the outside wall of the building. The separation of the dump resistor was needed for it posed a safety concern in its previous location. The controller and dump load were then connected via 2.5mm diameter wires to the main wall and turbine.

The Fortis Passaat turbine located to the West of the SOMA required various wind data for the creation of a power curve. The Wind Monitoring tower (WMT) located north of the turbine was recording data on the system however was not logging information over the

required intervals needed to perform an adequate test which adhered to International Standards. The LabVIEW system that monitored the wind data was modified and adjusted to allow the data to be recorded to the needed specification to perform the test.

This report delves into the work required in integrating a new turbine into an existing system and the steps taken in the upgrade of the existing system. The system now allows for monitoring data to be collected in a user friendly table based on ten minute averages. A risk assessment document was compiled suggesting the possible improvements to the current maintenance of the wind turbines. The changes made to the system and investigation into the integration of a new turbine are shown in detail throughout this paper.



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## 1. Introduction

### 1.1 Statement of the Problem

The world currently is being confronted with various issues in the traditional methods for power generation. Fossil fuels, environmental factors and high costs are allowing for attention to alternative non-conventional energy generation sources. Renewable energy resources such as wind, solar, micro-hydro, ocean wave and fuel cells are becoming the focus of a viable alternative for power generation. One scheme that is being used is the hybrid Remote Area Power Supply (RAPS) system. RAPS systems are usually used because the remote area is off the grid. This system usually involves off grid applications depending on the available technologies. Generally a hybrid RAPS system is equipped with a primary energy source (wind or solar), secondary energy source (diesel generator) and an auxiliary components (battery storage, flywheel, dump load)[1].

The selection of specific components for use in different stand-alone situations is crucial in creating the most efficient system. The primary energy sources usually wind and solar devices need to be selected carefully with power rating and capacity factors imperative in constructing an appropriate system. In stand-alone systems the usual wind energy source selected is a variable speed wind turbine generator. Their ability to provide adequate frequency and voltage regulation is more appealing when compared to constant speed generators. This suggests a Permanent Magnet Synchronous Generator (PMSG) as the logical choice of wind energy sources.

## 1.2 Aim of the research work

The purpose of this research is performed to show how stand-alone power systems operate and perform under specific conditions relating to the individual environment. The inclusion of a new primary energy source and the related tasks involved are provided to give a more realistic point of view regarding these systems. The performance and improvement of the Murdoch Renewable Energy Power Systems Facility (REPS) is investigated for improvement in the future for students and faculty involved in the stand-alone system. This paper ultimately shows a real world example of an stand-alone hybrid power system and documents in detail the specific steps involved when trying to alter the existing system.

The turbines investigated consist of the SOMA 1KW and the Fortis Passaat (FP) 1.4kw wind turbine. Only one turbine is connected at any one time (via individual protection boxes with rectifiers and dump load controllers). The work performed in this thesis concerns the integration of the SOMA turbine into the system and the issues involved in the process. The FP turbine is presented highlighting the changes and system parameters affected in the test procedure. The two turbines and specific components like the wind monitoring tower (WMT), windy boy inverter and LabVIEW program are investigated in detail in this stand-alone application.

## 1.3 Research Objectives and Methodologies

The main objective of the thesis is to perform and evaluate the current REPS facility on the Murdoch Campus with particular attention on the performance of the current wind turbines. To achieve this it is necessary to present and discuss the results of measurements from specific components of the REPS system concerning the wind system, energy produced

from the FP turbine, inverter system changes, LabVIEW control system interface and monitoring system. The following are presented as the main research objectives:

1. *Murdoch Renewable Power System Evaluation and Condition*

This objective focuses on describing the current system and evaluating its performance for off-grid applications involving a learning perspective. The literature will focus on hybrid systems described in studies such as PV/Wind only and PV/Wind/Battery both experimentally and numerically. This selection process involved for analysis of an AC hybrid power source at a site is dependent upon various factors from IEC Standards, component operations, data collection and control system connections.

2. *Integration of the SOMA 1KW Wind Turbine into the REPS facility.*

This objective is focused on the new SOMA wind turbine being connected to the current system. This objective presents a guideline to the steps taken in the integration process of a 1KW wind turbine in a hybrid stand-alone system. This is achieved by documenting the process taken in this procedure.

3. *Fortis Passaat Upkeep and Wind Monitoring System.*

This objective focused on the Fortis Passaat turbine upkeep and maintenance as



well as the wind data being shown through the LabVIEW program. This involved documenting the current system and implementing various changes in regards to the data recording program which will help in the data collection process for future testing. This was done by averaging the data into timed averages following information by the International Electrical Commission (IEC) and Australian testing standards. The FP maintenance and inspection was documented and photographed allowing for a risk assessment to be compiled suggesting improvements to the current process.

#### 1.4 Outline of Thesis

This thesis is comprised of 3 sections. In each section a background, literature review, results/discussion and conclusion are presented. This structure allows the relevant objectives to be described in detail in which the reader can understand the experimental process involved.



## 2 Renewable Energy Power System Evaluation and Condition

### 2.1 Background

The REPS has been previously evaluated for its performance in different weather conditions. The last performance evaluation was conducted in Semester 2 2014 as a research project[2] which outlined the systems efficiency and capabilities in regards to the different renewable energy sources and devices.

In the previous project some of the tasks performed included overview of equipment, FP turbine power curve and monitoring system breakdown. This evaluation is expanded and compared to in this paper in specific regards to upkeep of the facility on the system.

### 2.2 An Overview of Hybrid Renewable Energy Systems

With the increase in the global population and energy consumption the use of RAPS are becoming more common. These systems are used for energy production in areas that have no access to the grid or for long-term economic gain. The typical hybrid RAPS system consists of various energy generation sources for example wind, solar, hydro, battery and diesel.

When designing a suitable RAPS system the energy sources and components chosen are dependant on the specific location investigated. An example of typical hybrid stand-alone system dominated by a wind power source is shown in Figure 1. It consists of a wind turbine, battery bank or energy storage system, inverter, dump load, diesel generator, AC bus and relevant load.

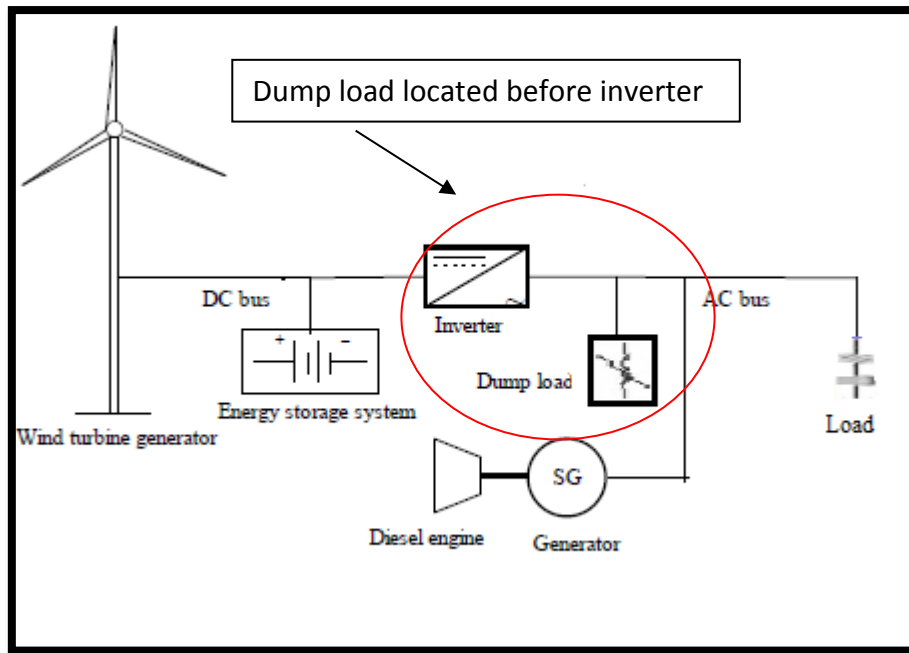


Figure 1-Hybrid RAPS System

### 2.2.1AC- Coupled Hybrid Energy Systems

An AC-coupled hybrid system consists of different energy sources which are integrated through their own power electronic circuits to an AC bus. This arrangement requires coupling inductors between the power electronic interfacing circuits and power frequency AC bus to achieve the desired power flow management[3].

With the presence of DC energy sources and loads combined with the long existing AC power systems, an interest on hybrid ac/dc systems is growing. One of the advantages of having a hybrid system is the control strategy and power management scheme allowing for efficient operation in stand-alone and grid-connected operation modes. In ac-coupled systems the control strategy and power production schemes is

mostly concerned with power generation/consumption balance and the ac bus voltage/frequency control, especially concerning stand-alone systems[4].

In stand-alone systems power management and control schemes focus is on the ac bus voltage and frequency control. The droop method is the most common method used in this system where the voltage and frequency vary with the output real and reactive power of a generator.

### 2.3 Renewable Energy Power System Facility Murdoch University Campus

The Renewable Energy Power System Training Facility (REPS) is a single phase hybrid generator system consisting of a battery bank, inverter, photovoltaic panels, wind and diesel generator system with programmable loads. This facility is located in the Renewable Outdoor Testing Area (ROTA) of Murdoch University. The REPS facility is a stand-alone hybrid system which uses different renewable energy technologies to generate power for different components within the housing of the facility e.g. Refrigerator. This system is incorporated into the (RAPS) systems within the ROTA test area. The facilities main function is to provide students an opportunity to work on a real off-grid power system as well as the opportunity to simulate different conditions for a wide range of testing conditions in a safe environment.

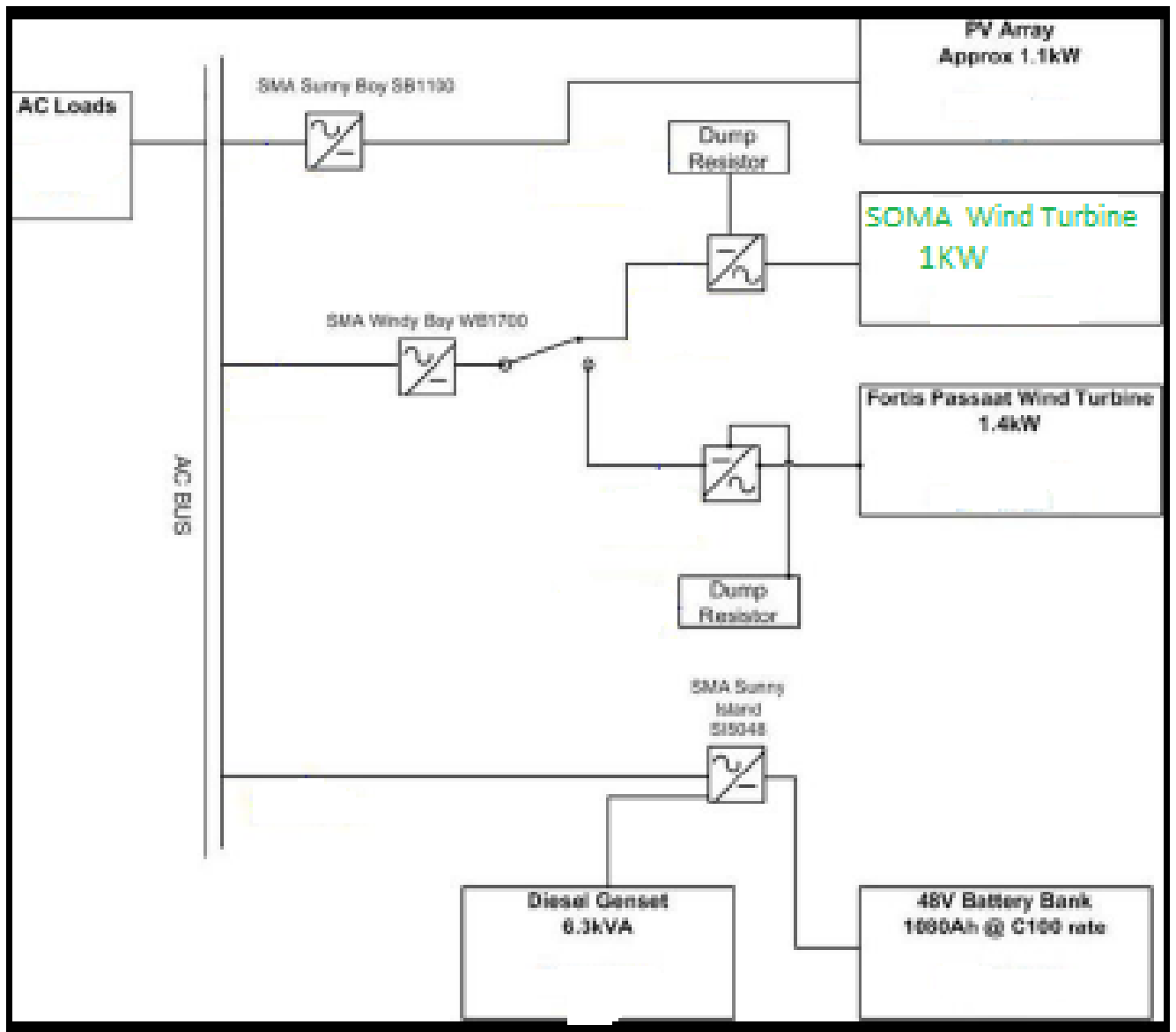


Figure 2- REPS System

The main control wall of the facility shown in Figure 2 shows the system easily visible and accessible. The wall holds the following components[5]:

- A SMA 'Sunny Boy' SB1100 inverter which is used to convert the DC power given from the PV array to AC power. This inverter has a PV start up voltage of 180V with an input current and power of 10A and 1210W respectively
- A SMA 'Windy Boy' SB1700 inverter for the wind component. Only one turbine is connected at any one time (via individual protection boxes with rectifiers and dump

load controllers).This inverter has a maximum input DC voltage of 400V and current of 12.6A

- The Sunny Island 5048 inverter.This inverter has an input power of 12.8kW and an output power of 7200W at 25 degrees Celsius
- SOMA Controller Box



Figure 3-Soma Controller

- Data monitoring and logging system consisting of a SMA Sunny Webbox and Sensorbox

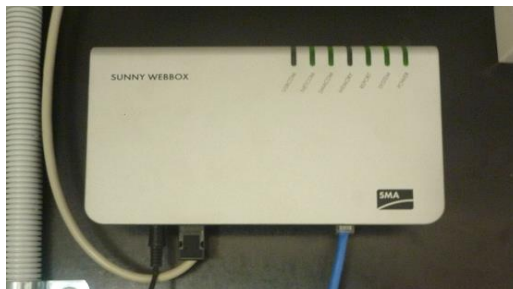


Figure 4-SMA Sunny Webbox

The load bank which is located inside the REPS facility, can apply various ac loads of any multiples of 5W.





## 3 Integration of SOMA 1KW Turbine into the System

### 3.1 Introduction

The introduction of a new SOMA 1KW wind turbine has been included into the REPS facility. The integration of the SOMA turbine into the REPS was needed in order to replace the previous Ginlong WT which had burnt out its generator windings. The integration process performed documents the process and issues faced when adding a new component to a stand-alone system. 3.2 Literature Review

### 3.2 Literature Review

The connection of the Soma system to the grid is motivated by the Murdoch interest in securing a fully functional wind grid connect system. This procedure involves various steps and needs to adhere to the IEC 61400-2 standards for grid connection. The Murdoch system required information to be gathered as to the processes in which the University must take in completing this task. The system is currently connected to an isolated grid.

A wind turbine to be connected to the grid must comply with the IEC 61400.2 Standards specifically the requirements in sections 10.7.3.2-10.7.3.3 {Appendix (A)}. This task involves a detailed analysis of the wind turbines structure, power output, connections, foundation, load requirements, support structure and installation. The standard also provides a general safety requirement for the power system. A power performance test of the FP turbine must also be performed according to the IEC 61400-12-2 requirements before grid connection.

IEC61400-2 standard classifies a small wind turbine (SWIND TURBINE) as having a swept area of less than 200m<sup>2</sup> with a power capacity >50kw. The international standard relevant

to power performance testing of wind turbines is IEC61400-12-1. Annex H deals specifically with the power performance testing of SWIND TURBINES, and states that 1-minute averaged power and wind speed data are to be logged and binned to form the wind turbine power performance curve. The wind speed data are measured at a height within  $\pm 2.5\%$  of the turbine hub height and, for grid-connected SWT, the A.C. turbine power data are measured at the connection to the load after the inverter. For the binning of data, wind speed bins are created with width  $0.5 \text{ m s}^{-1}$ , centred on integer multiples of  $0.5 \text{ m s}^{-1}$ .

### 3.3 SOMA Components and Current System

The Soma WT is a 2-bladed, horizontal-axis, furling wind turbine. It has wind at a rated speed of  $10 \text{ m/s}$  at a rated instantaneous power of  $1000 \text{ W}$  and a peak output of  $1200 \text{ W}$  according to the manufacturer's power curve [6]

#### Turbine Characteristics

##### **Generator**

The WT for the Soma system is a brushless, directly-driven, alternating current generator which utilises a rotating permanent magnet field [6]. Permanent magnet machines are self-excited operating at a high power factor and efficiency. The use of permanent magnet excitation requires the use of a full-scale power converter to adjust the voltage and frequency of generation to the transmission. The permanent magnet synchronous generator (PMSG) has a wound stator with the rotor having a 14-pole system. The use of Permanent Magnets (PM) mean there is no need for slip rings or brushes and the rare earth

magnets are very high strength generally ferrite. The PM are located on the inside of the rotating drum.

The SOMA turbine is directly driven which generates 'wild' AC. It produces a variable voltage and frequency [7]. This allows for the generator to have no gearbox. The SOMA turbine also has a protection/ control which involves passive furling. This is an over-speeding protection method used to avoid the generator burning out. Furling involves offsetting the pressure on the rotor from the axis of rotation of the nacelle creating movement which reduces the angle between rotor axis and tail fin axis. This reduces the projected area of the rotor and limits power [7].

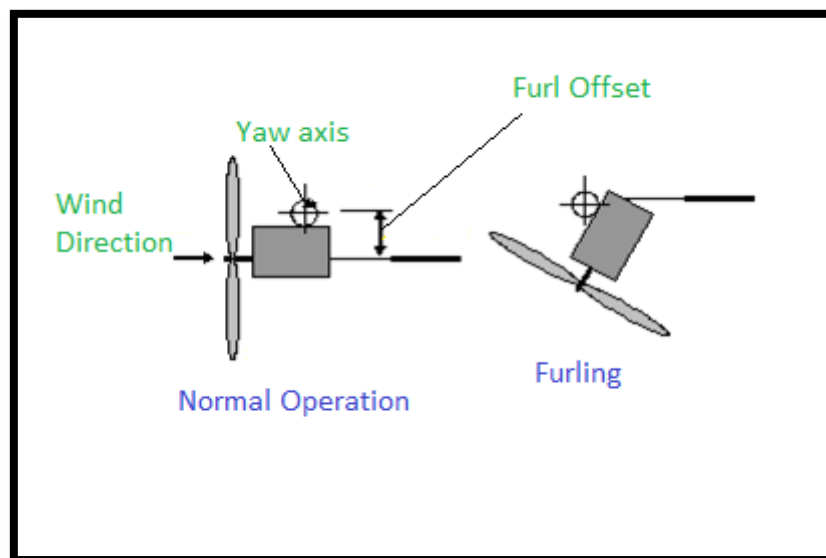


Figure 5- Furling Turbine

### Blade Characteristics

The blade is made up of a combination of high tensile glass fibres and marine grade resins resulting in a modulus. The blade is designed in one piece and is placed over the rotor hub.

Blade Characteristics	SOMA 1KW
Rotor Diameter	2.7m
Pitch at tip	2 degrees
Twist	7 degrees
Tip speed ratio	10:1

Table 1- SOMA Blade Characteristics

### Tilt-up Feathering Method

This method limits the rotor speeds in excess of 15m/s. This is another over-speed protection method to reduce blade wear and generator loads [6]. When the wind speeds exceed the rated wind speed (15m/s) power output can be regulated by ‘feathering the blades in order to control the power output [8]. The SOMA turbine has its rotor above the pivot point of the stator which causes the wind pressure to tilt-up. The stronger winds cause the rotor to tilt back further, with speed is controlled by a stainless steel hydraulic dampener reducing gyrational action [6].

### Tower

The Soma 2-bladed turbine is positioned on top a galvanised pipe winch-tilt tower at 19.5m which was used as an adaption from the previous Ginlong tower. The tower sits on a concrete foundation and can pivot at the base allowing it to be lowered. The tower tilts down to the ground using a pulley winch mechanism which can be attached to the gin pole for leverage.



Figure 6-Soma Wind Turbine

### SOMA Controller and Dump Load

The Soma WT controller is located on the wall of the REPS facility shown in Figure 7.



Figure 7- REPS Main wall



Figure 8- Controller Connections

The Soma WT controller is essentially a voltage regulator, the purpose of which is to provide protection to the inverter from over-voltage from the WT. The SOMA controller is located on the REPS facility on the main wall. The controller has a dump load attached to the top of the main casing. The dump load contains a resistor measured at 50Ω and is set to operate at 300V. The dump loads purpose is to prevent the power output from the WIND TURBINE rising too high while the inverter attempts synchronisation with the grid or if grid connection is lost. This results in the dump load becoming very hot due to the resistor absorption of voltage. The dump load needed to be removed from inside the facility where heat from the resistor could affect the electrical components and people.

### Activities and Changes performed

The following changes to the SOMA system were performed and documented.

#### **Controller and dump load re-Location**

The dump load was removed from the controller housing and the resistor was attached to a specially designed bracket. This bracket allowed the dump load resistor to be secured to the

facility wall while remaining within the protection casing. The casing for the dump load was re-used from the previous Ginlong turbine and required holes to be screwed into the metal base allowing the bracket to be firmly secure.



Figure 9-Bracket Made to Hold Dump Resistor



Figure 10- Bracket Bolted onto Facility Wall





Figure 11- Protection Housing for Resistor

The dump load was then wired through a junction box and into the main wall of the REPS facility. The wires were then connected to the controller box using 2.5mm wires.



Figure 12-Wiring to Controller Box

### Windy Boy Inverter Proposed Changes

In order to change the parameters of the inverter to the new turbine the inverter must be changed to OFF-Grid via the default operation. The next step involves programming the power curve depending on the DC input voltage. The following parameters need to be changed on the PC with the windy boy setup tool:

1.  $V_{pv}$ —Start
2. UdcWind Start
3. Wind  $a_0$ ... Wind  $a_3$
4. Pmax
5. P-Wind –Ramp
6. KP-Wind-Reg
7. KI-Wind-REg
8. T-Stop

The manufacturers programming parameter for safe operation with the SOMA 1000 turbine are shown in Table 2.

Soma Inverter Parameters	Manufacturers Values
<b>UdcWind Start</b>	150V
<b>Tstop</b>	120seconds
<b>V pv Start</b>	150V
<b>Wind a0</b>	6576.971
<b>Wind a1</b>	-107.054
<b>Wind a2</b>	530.22 E-3
<b>Wind a3</b>	-732.68 E-6

Table 2- Windy Boy 1700 Settings for SOMA Turbine

## Discussion

The integration of the SOMA WIND TURBINE encountered many issues relating to positioning the controller/dump load and compliance of the WB inverter in accordance to Clean Energy Council CEC standards. These issues halted the project temporarily until a resolution can be finalised.

The controller positioning inside the facility shown in Figure (7) was deemed inadequate. The main safety issue with its location is the dump resistors above the controller. They get very hot and pose a fire risk. The manufacturer recommends it should be located at least 1 metre below any horizontal surface such as a ceiling or cabinet top. Sideways clearance to left and right should be 300mm from any other object. It should not be fastened to a flammable surface such as wood. The enclosure should be adequately ventilated to allow

the heat from the dump resistors to escape. Where a separate dump resistor box is supplied, the same installation requirements apply to it[6].

The WB 1700 inverter was found to not be approved by the CEC as of the 31<sup>st</sup> of July 2015. The CEC presented its list of approved inverters on the 11<sup>th</sup> of July and the WB 1700 inverter not was found to be included. This caused a halt to project while a solution was finalised regarding this issue.

The solution that was decided was to grid-connect the SOMA 1KW turbine by raising its connectivity. We met with Gary Higgins the Murdoch University facilities manager in charge of electrical supply demand. He responded by having no issues in the grid-connect of this turbine. This solution is now in the process of being finalised with relevant personal.

The ABB Power One Inverter was selected as a replacement being on the CEC approved list and it has up to 400VAC from the turbine, Rectified 400VDC, as well as the 240VAC from the grid.

This prompted a grid-connection plan to be investigated in regards to the REPS building. The new connection allowed for:

1. Grid-connection of the SOMA 1KW WIND TURBINE for teaching and research purposes
2. Grid power for computer/data acquisition infrastructure and engineering lab experiments (air conditioner power)

The inverter replacement is yet to be finalised and will not be purchased until the current project has been completed and the new system agreed upon by the appropriate personal.

The current system RAPS system is connected to an isolated grid on the grounds of Murdoch University.

## Wiring Diagram Changes

The wiring diagrams that were previously available needed to be changed in order to incorporate the relevant changes to the system that had been implemented. The previous wiring diagram was located in the Engineering Shared folder which was on most computers found in the Engineering areas at Murdoch Campus.

The diagram was then upgraded to incorporate the changes made to the system shown in Figure 13. The wires that were used to incorporate the dump load were 2.5mm<sup>2</sup> in size. This wiring size was used based on the manufacturer's maximum diameter recommendations in the Soma manual.

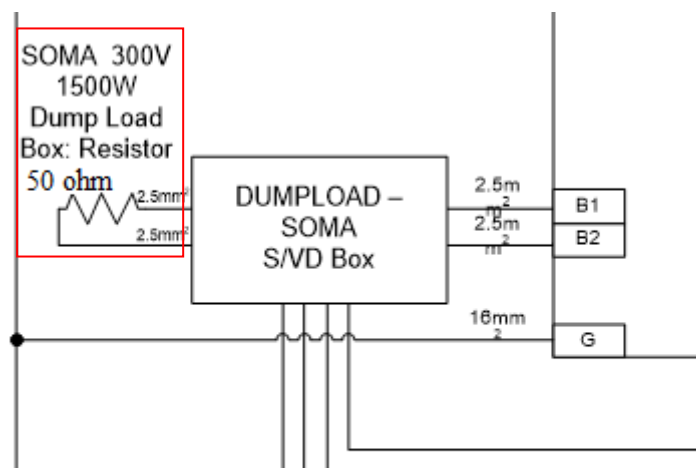


Figure 13-Dump Load Changes

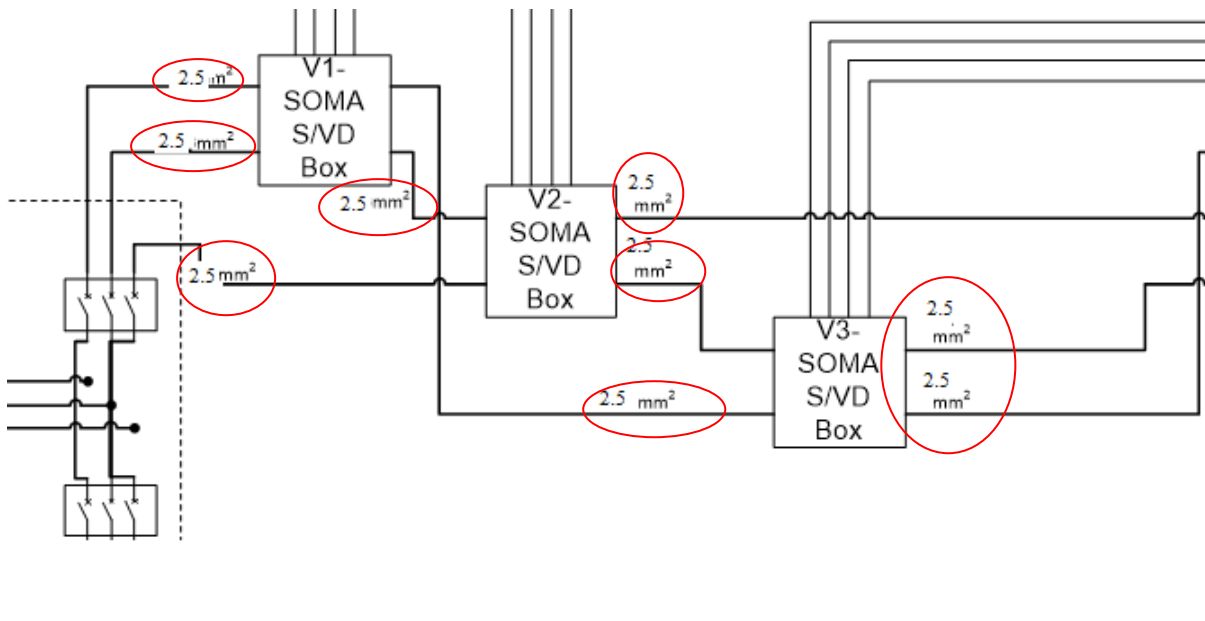


Figure 14- Wiring Connection

These new wiring alterations then were uploaded to the SOMA project file located in the Eng-Shared desktop short cut.

## Fortis Passaat 1.4kW Turbine Evaluation & Wind Monitoring Tower Analysis

Wind turbine power curves or simulation programs as well as the sites wind data may be used to determine the power output from a wind turbine. Different data analysis options require different types of data. Once the techniques have been selected, the types of wind data needed and the most convenient form for the data can be determined. If the data uses are clearly specified, time and expense in the data analysis can be reduced[9].

### Background

#### Fortis Passaat Wind Turbine

The FP 1.5kW turbine is currently the only wind energy source that is connected in the REPS facility. The FP is a controlled horizontal axis, furling wind turbine consisting of 3 blades. It is positioned on top an 18m high tower with a cut-in speed of 2.5m/s. According to the manufacturers data it has a nominal output power of 1400W at rated wind speed of 16m/s.



Figure 15- FP 1.4KW Wind Turbine

### **Generator**

The FP turbine has a 12-pole brushless permanent magnet synchronous generator. The PMSG uses a rotating magnetic field around the stator to eliminate the need for brushes. It operates between 180-775 RPM with a frequency between 0-70Hz.



Figure 16- FP Slip Rings

## Blades

Rotor Blades	
Number	3
Diameter	3.12m
Area	7.64m <sup>2</sup>
Air foil	E387
Tip Speed Ratio	6.9
Material	Glass-fibre reinforced epoxy

Table 3



Figure 17- Blade Check

## Tower

The tower for the FP is guyed steel tubular at height of 18m.

## Maintenance Procedure and Documentation

The manufacturer maintenance report, used in previous inspections, and provided by Fortis Wind Energy is shown in Appendix (B). After documenting the Daniel Jones maintenance inspection an alternative report has been designed to help visually show the procedure.



## Fortis Passaat Turbine Maintenance and Inspection

The Fortis Passaat WT maintenance was conducted on the ROTA premises on Thursday the 29<sup>th</sup> of October at 12.30pm. The inspection was carried out by Daniel Jones from Pure Engineering.

The maintenance procedure was carried out incorporating an ENG 352 Laboratory where students were allowed a firsthand look at how a WT is serviced and inspected. Student involvement in this laboratory/maintenance, although very beneficial, did raise some safety concerns that will be mentioned later.

The maintenance procedure was documented in detail from start to finish with photos highlighting the steps and procedure involved, in order to provide input into a risk assessment of the procedure.

### 3.3.1 Fortis Passaat Maintenance & Inspection Report Improvements

#### **1. Safety Induction and Planning**

The safety induction was conducted by Martina Calais and Daniel Jones inside the REPS facility. Both instructors went over the importance of safety in this laboratory also the potential risks associated with the lowering of the turbine. Martina then ensured the students were wearing Personal Protective Equipment (PPE) which included foot protection, eye protection, head protection and sun protection.

If any students did not have any of the appropriate protection items they were supplied one for the purpose of the laboratory. A brief background was then given on the relevant equipment and facilities.

## **2. Shutting down the Turbine**

Daniel Jones then shut down the turbine by shorting it out at its base therefore not allowing it to still generate power. This shut down causes a danger when the wind speed is too high so it is recommended that this is only done during times of low wind speed.

## **3. Pre-Lowering Checks and Application**

The following steps were checked by Daniel Jones and deemed acceptable if a green tick is indicated:

- ✓ Firstly observe the turbine in operation and take note of any unfamiliar noises and vibrations



Figure 18- FP Turbine Upright position

- ✓ All four sheaves/pins greased and both grip clips fitted. Sheaves must turn freely;



Figure 19- Attached Pullies and cable to gin pole



Figure 20-Apply grease to the cable

- ✓ Tower hinge pin has grip clips(s) fitted;
- ✓ Check conditions of tow-up cable and associated rigging. Coat with corrosion inhibitor if necessary;
- ✓ Check tow-up cable is correctly routed through sheaves and safely attached to foundation block;
- ✓ Check all turnbuckles have safety splint pins or locknuts fitted;
- ✓ Check condition of gin-pole stay wires, and;



Figure 21-Support Cable

- ✓ Ensure gin pole stay wires are correctly fitted and do have visible slack
- ✓ Check condition of guy wires. Coat guys with corrosion inhibitor if necessary;
- ✓ Check condition of tower galvanizing. Touch-up any corrosion with zinc rich paint;
- ✓ Check condition of earthing cables/stakes- if installed, and; check tower fasteners (lock nuts tight) and condition. (Note if any bolts have come loose).
- ✓ Check electrical connections in tower base
- ✓ Check electrical connections in tower upper terminal box for condition and tightness;
- ✓ Check that tower cable suspension strap is in good condition and supporting cable



Figure 22-Side guys and Gin pole side stray wires always have slack

**Note: All side guys and gin pole side stray wires always have some slack while lowering the tower.**



Figure 23-Pully Connection

The procedure shown in figures (19-23) displays the shutdown and system check before the lowering of the tower. This procedure shows Daniel Jones shortening the generator, attaching pulleys and cable to gin pole, attaching pulley to guy wire in dropping direction,

attaching cable to the 4 wheel drive, releasing fasteners restraining the tower erect position, loosening gin pole and slowly driving 4WD forward).

Daniel then made sure the 4WD pulley is connected correctly. After all the pre-checks and cables are fastened the turbine is then ready for lowering.

#### **4. Lowering of turbine**

The 4WD is then reversed pulling the turbine while the connection and pulley rope was held by a student.



Figure 24-4WD Rope

The turbine is lowered slowly onto a metal bracket, which the turbine is rested upon using thick area of the pole. Pictures shown in figure (25) clearly indicate how the turbine is rested on the metal bracket.





Figure 25-Lowered on Bracket

## 5. Checking of blades and repairs

After turbine is lowered and secured on the bracket the following checks are performed.



Figure 26- Turbine Inspection

- ✓ Check overall condition of blades, in particular the mounting area and leading edge;





Figure 27-Blade Inspection

- ✓ Check blade bolt/nut torque;
- ✓ Check condition of leading edge tape and replace if necessary;
- ✓ Check condition of blade fasteners, and;
- ✓ Nose cone installed.
- ✓ Remove cover and inspect slip rings and brushes, clean if necessary;

#### **6. Bolt check of MAINFRAME/TAILBOOM/TAILFIN and Turbine**

The bolts are then all checked to see if they are corroded or damaged and need replacement. The bolts are all tightened and checked to make sure the threading is not damaged which allows for secure bolt connection.

- ✓ Check tail boom dampers for condition and operation;
- ✓ Check for overall condition of tail boom, and;
- ✓ Check for overall condition of tail fin.



Figure 28- Tail Fin

## 7. Checking & Servicing of the Slip rings and Brushes



Figure 29- Opening to check slip rings



Figure 30- slip rings

- ✓ Remove any build-up of brush dust under brushes;
- ✓ Check electrical connections for condition and tightness;
- ✓ Check operation of brushes;

- ✓ Check for overall condition of mainframe/generator;



Figure 31



Figure 32

- ✓ checking the junction box for any problems

## 8. Raising the tower

## 9. Reconnection check of the tower

- ✓ Guy tensions correct and tower straight and vertical;
- ✓ Chain or gin pole tie-bar fitted correctly below gin pole and shackle tight and wired;
- ✓ Turnbuckles wired together to prevent unscrewing and locknuts tightened on adjustment threads, and;
- ✓ Remove tow-up cable, sheaves, gin pole strays in a dry place if possible.

## *Operational tests*

- ✓ Wind turbine spins smoothly both off-line and under load (if enough wind)

#### Notes;

- Wind strength approximately 2-4m/s. Turbine rotating smoothly;
- Blade condition is good, the addition of leading edge tape may be included in the next service to extend the life of the blades;
- All fixings were found to be tight and secure;
- Tail boom bushes show a little wear, their condition will be monitored, considerable life remains, and;
- Slip rings in good order, the nuts on the top of the slip ring assembly have been rubbing on the top inside edge of the enclosure. This is due to wear of the thrust washer in the yaw bearing assembly. Preventative measures undertaken at the previous maintenance service have proven sufficient to prevent further wear of the thrust washer and so further action was not required.
- The thimble and wire rope grips for this tower tow up cable are still a missing component.

### Risk Assessment Turbine Maintenance Laboratory

#### New Ideas to be implemented:

- 1. During induction students sign a form acknowledging the risks and hazards that they will be exposed to during this activity.**
- 2. The designated cordoned off areas are more strictly adhered to in regards to students not crossing the tape barrier.**
- 3. A trained person (not student) is required to lower the tower via the pulley rope**
- 4. If a student/s misses this safety induction, held at the start of the maintenance work, they will be excluded from participating in the laboratory.**

5. The unit co-ordinator or relevant person expresses via LMS that students who are not present at the start of the laboratory will be excluded from participating in the maintenance laboratory.
6. The area where the turbine is to be lowered needs to be cleared for hazards prior to commencing the procedure.
7. Dangerous items around the clearance zone need to be noted or eliminated prior to commencement. This applies to metal parts exposed from near buildings or trip hazards on the ground around the clearance area.

**Table altered from Pure Engineering Safe Work Method Statement[10]**

**Laboratory Perspective:**

Hazards	Risks	Control Measures
<b>Wind Turbine- Parts and Cables for moving the turbine</b>	<b>Struck by the object when moving for maintenance</b>	<b>Pre-start check has to be complete before commencement of Lab</b>
<b>Objects around the barrier</b>	<b>Hurt by exposed objects (metal poles, concrete bases).Cuts, lacerations</b>	<b>Object must be cleared or made aware by danger tape or visible sign</b>
<b>Pedestrians</b>	<b>People entering the exclusion zone</b>	<b>Unauthorised personnel may not under any circumstance enter the exclusion zone</b>
<b>4WD movements and Pulley support cable</b>	<b>Falling over causing injury, muscular stress, turbine support could fail causing fast decline of turbine</b>	<b>Only an authorised person may be inside the exclusion zone when required to use the 4WD support pulley. Students are not permitted to participate in this activity</b>
<b>Tower lowering/ Raising: Large falling objects, pedestrians in the area,</b>	<b>Injury from falling objects (tower, turbine, blades) Person/s entering the</b>	<b>All students and spectators should stand well clear of the turbine when being</b>

<p><b>slippery terrain or exposed objects</b></p>	<p><b>exclusion zone while turbine is being lowered causing serious injury.</b></p> <p><b>Entanglement from turbine support cables causing cuts, bruising or lacerations</b></p>	<p><b>lowered with no person being inside the exclusion zone. The bracket (Figure 2) or turbine support shall be positioned by the authorised personal before lowering commences.</b></p>



**Exposed Metal Hazard**

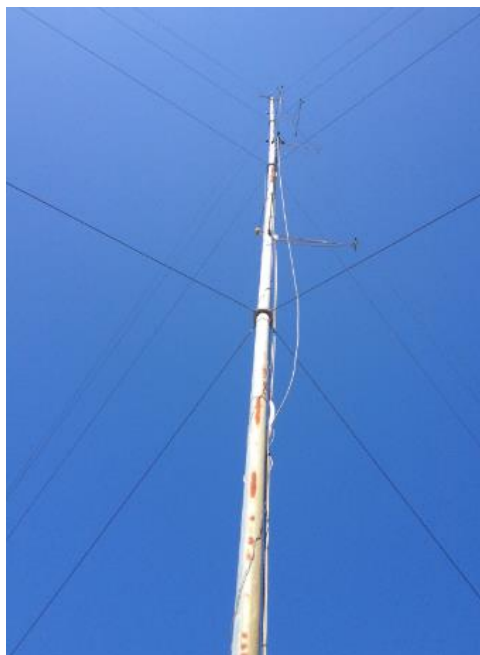




Turbine Bracket

## Wind Monitoring Tower

The wind monitoring tower (WMT) is a 30m high tower consisting of sensors and anemometers with which the wind speed, wind direction and ambient temperature are monitored. This tower is located within the REPS compound and has sensors positioned at heights of 3m, 10m, 18m, 24m and 30m.



### Figure 33-Wind Tower

For the selected data sets wind speeds shall be corrected for flow distortion from site calibration and air pressure shall be corrected if measured at a height other than close to hub height.

### Measurement Devices and System Literature Review

An adequate wind measurement system is needed in order for accurate and reliable data is recorded for test use. The current wind monitoring system (WMT) is located within the REPS facility consisting of various sensing devices located at heights 3, 10, 18, 24 and 30m this allows the determination of wind shear characteristics. These devices include wind direction sensors, temperature sensors, anemometers and air pressure sensors. The tower is approximately 30m high with the wind sensor located at 18m which correspond with the 2 wind turbine towers.

Wind measurement systems usually comprise of 3 primary parts [9]:

1. Sensors-measures the wind parameter and produces a signal that is directly related to the wind characteristic.
2. Signal Conditioning-Converts signal from sensor that can be used in the recorder/display.
3. Recorders / Displays-provides information in a useable form.

### **Meteorological Sensors**

The WMT displays the information from the following [9]:

1. anemometers to measure wind speeds;
2. wind vanes to measure wind direction;

When testing the site for its wind resource it requires all four information values. The WMT has all the values needed for a wind test to take place.

### **Anemometers**

Anemometers are wind speed sensors classified by their mode of operation. The anemometer used on the tower is a cup anemometer. They are designed to measure the wind speed by the cup rotation. Figure 34 shows the 10m anemometer on the WMT in the RAPS area.



Figure 34- Anemometer

### **Wind Vane**

Wind direction is normally measured by a wind vane, essentially a device mounted on and free to turn about a vertical axis, so that it can turn as the wind direction changes. The WMT has a wind vane to measure the wind direction as shown in figure 35:



Figure 35- Wind Vane

The device is mounted on a vertical axis which is free to turn allowing it to point in the direction from which the wind is coming [11]. During gusty winds, the wind vane may lag behind the direction as it changes, but the average direction should be correct.

### Data Loggers

Generally an electronic device compatible with all sensors. The REPS facility is connected with remote data transfer. The data is collected by either data logger-initiated action or by user-initiated action[7].

### Previous Work Performed

When starting the project the WMT had sensors that were not working or recording accurate data. The status of the previous system is shown below:

Sensor	Height(m)	Status
Pressure	0	Working

<b>Temperature</b>	3	Working
	10	Working
	18	Not Working
	24	Working
	30	Wrong Temperature Displayed
<b>Relative Humidity</b>	30	Not Working
<b>Wind Speed</b>	10	Working
	18	Working
	24	Working
	30	Working
<b>Wind Direction</b>	10	Not Working
	18	Connected but not accurate data
	24	Connected but not accurate data
	30	Working

Table 5

The figure 37 shows the configuration of the REPS system. It represents the points at which the voltage dividers and current shunts are placed to acquire the reading for the DAQ.

Figure (36) shows the current environmental display of the values calculated from the WMT.

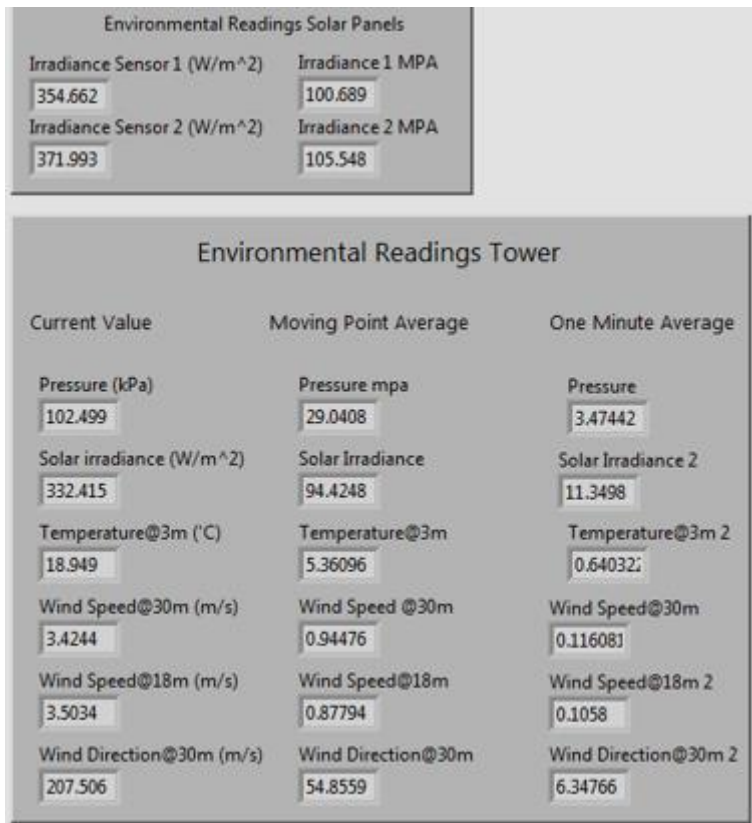


Figure 36-Environmental Reading Window

Figure (36) shows the 24\_7 program for REPS display:

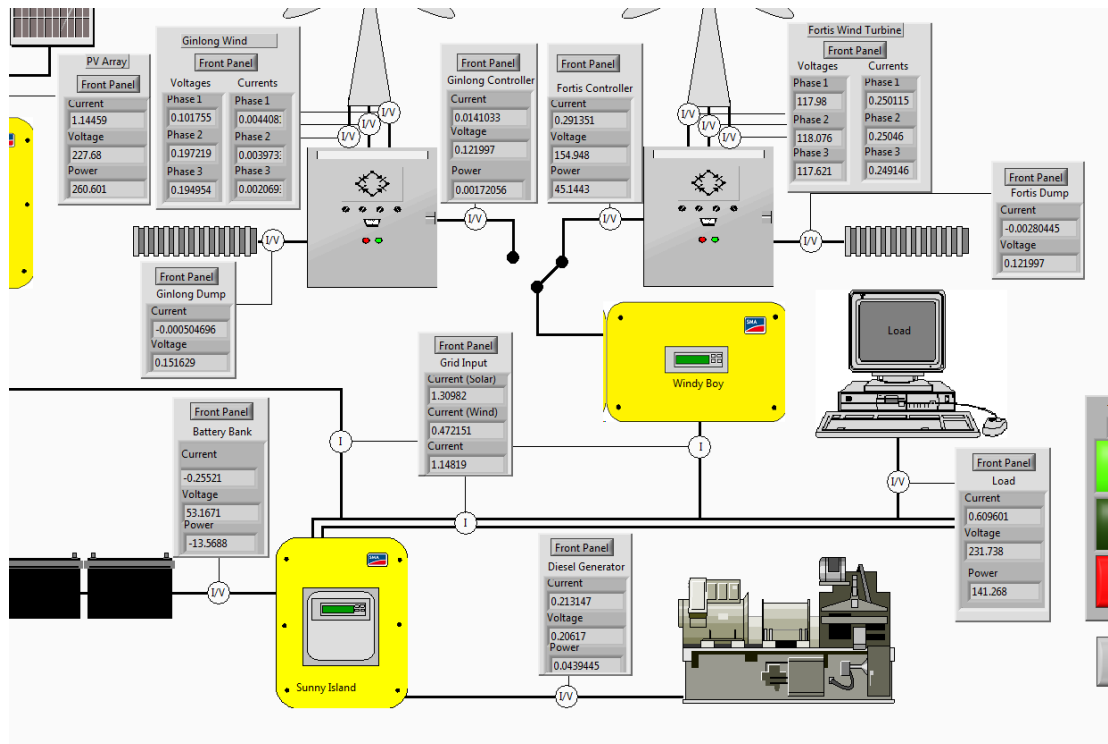


Figure 37-System Display Window

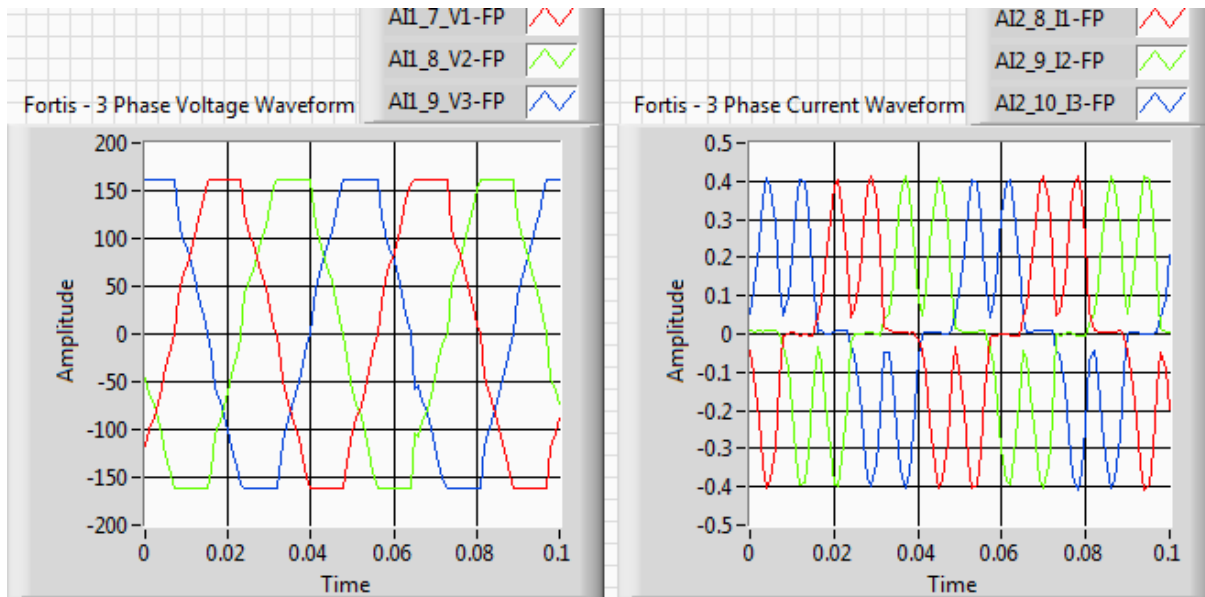


Figure 38- Voltage and Current Waveform from Fortis

Wind turbine power curves or simulation programs may be used to determine the power output from a wind turbine. Different data analysis options require different types of data. Once the techniques have been selected, the types of wind data needed and the most convenient form for the data can be determined. If the data uses are clearly specified, time and expense in the data analysis can be reduced [10].

#### Wind Data assessment

The WMT nearby was used for nearby accurate measurements from 10-30m. The assessment of errors by compounding errors in wind speed, presumably the impact of wind speed error on estimate of power output from turbine or the approximate wind speed distribution using a statistical probability function (Weibull Distribution).

The general System checks[11] include the integrity of data records (does each row have the requisite number of measurements?) and time sequence (is the data continuous in time? Are there any missing times/dates?)

## Logging and Monitoring Changes

### Measurement Sampling and Data collection

The data acquisition system needs to store data sets as follows:

- Mean value
- Standard Deviation
- Maximum value
- Minimum value

The recording interval shall be based on 10 minute periods derived from contiguous measured data.

The maximum sampling interval for all averaged parameters should be set at 1s. The data then can be logged over the 10 min. If the power measurements are calculated from voltage and currents the sampling interval needs to be significantly shorter than 1 second.

The data should include ten minute average, standard deviation, maximum and minimum values per time stamp and recorded the following parameters; power (kW), power factor (%), rotor speed (rpm), temperature (°C), primary and secondary wind speeds (m/s), turbine voltage (V), pressure (kPa), dry or wet weather conditions (dry or wet), wind direction (°), turbines brake condition (on or off), controller (on or off) and current (A).



## Recording and Monitoring Intervals

All parameters should be continuously sampled at the sample interval rate during the specified recording interval. The sampled data for each measured parameter should be processed into time-weighted averages.

**Average-** The average value should be calculated for all parameters on a ten-minute basis, which is now the international standard period for wind measurement. Except for wind direction, the average is defined as the mean of all samples. For wind direction, the average should be a unit vector (resultant) value. Average data are Basic and Optional Parameters used in reporting wind speed variability, as well as wind speed and direction frequency distributions.

**Standard Deviation-** The standard deviation should be determined for both wind speed and wind direction and is defined as the true population standard deviation ( $\sigma$ ) for all one or two second samples within each averaging interval. The standard deviations of wind speed and wind direction are indicators of the turbulence level and atmospheric stability. Standard deviation is also useful in detecting suspect or erroneous data when validating average values.

**Max and Min-** Maximum and minimum values should be determined for wind speed and temperature at least daily. The maximum (minimum) value is defined as the greatest (lowest) one or two second reading observed within the preferred period. The coincident direction corresponding to the maximum (minimum) wind speed should also be recorded.

## .LabVIEW Changes Incorporating Data Collection Design- System Set Up

The following changes were updated from the previous program to log the wind data calculated from the WMT. The new program compiles the wind speed from all heights and, temperature into 10 minute averages. Figure 39 shows the new environmental and system display windows.

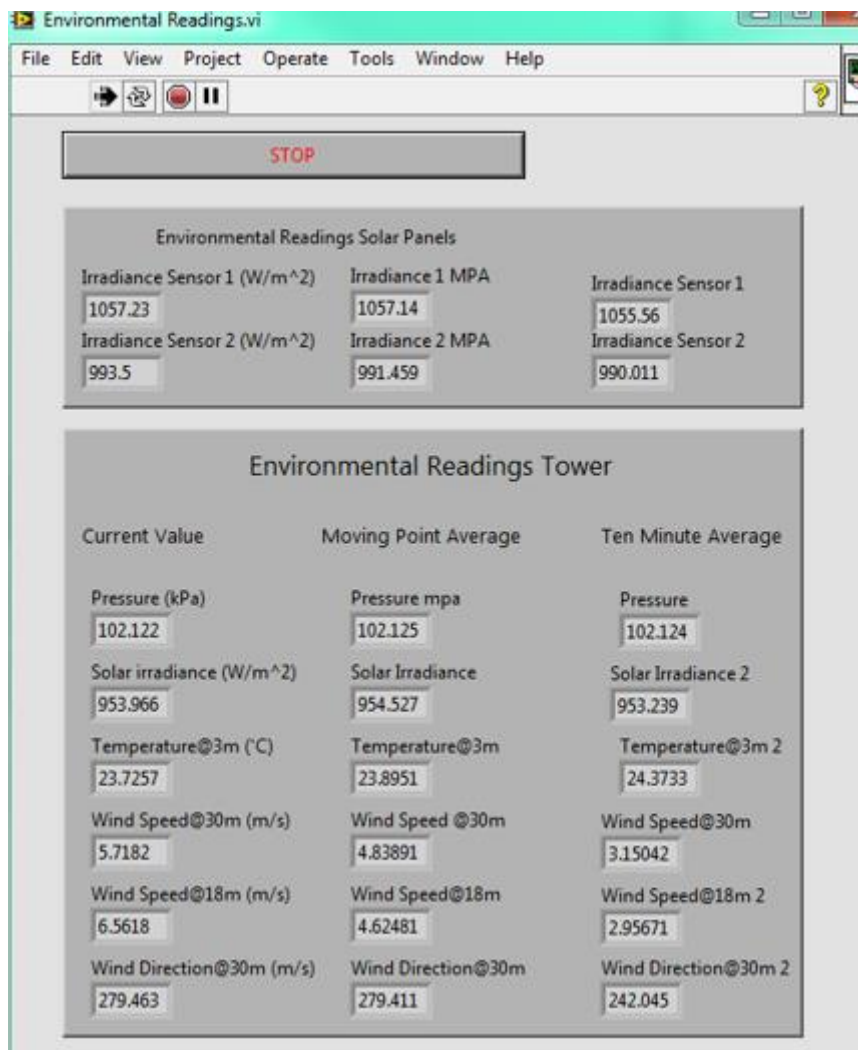


Figure 39- Ten Minute Average of Wind Speed

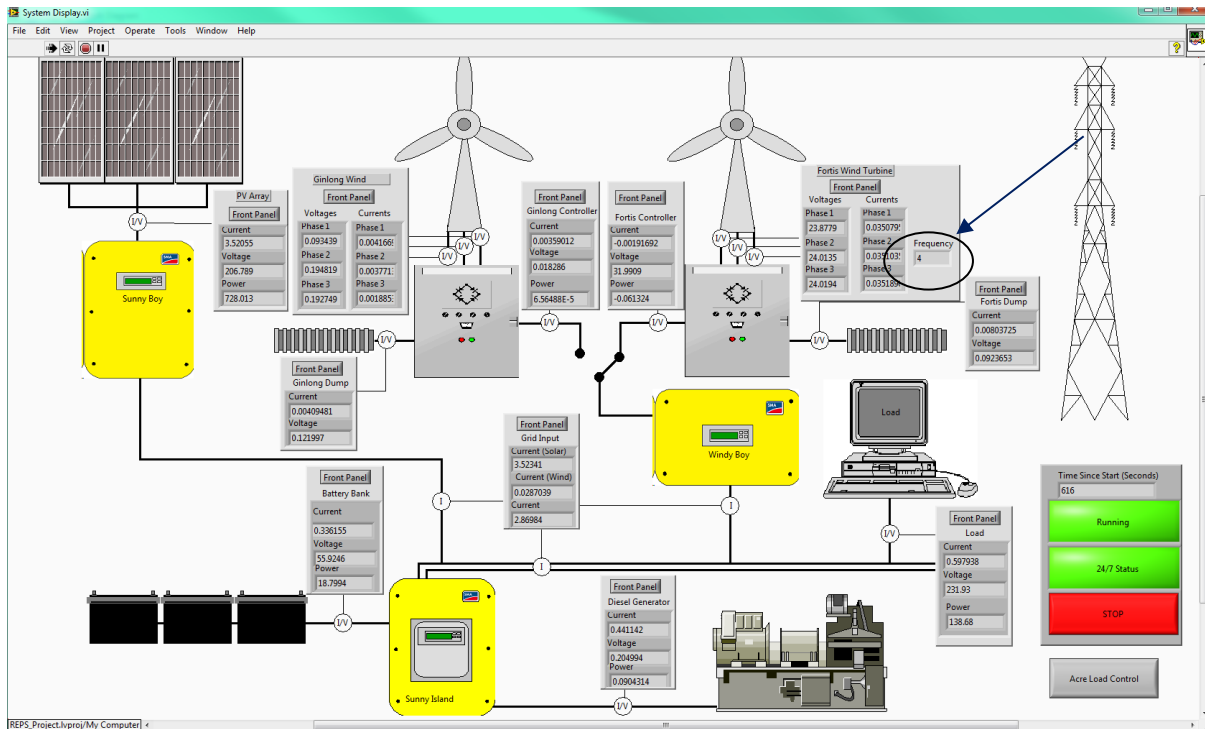


Figure 40- Frequency Addition

In figure (40) shows the frequency was added to the display which allows for more variety of tests that can be performed.

From the values being recorded into the environmental display a new logging system was programmed allowing for the 10 minute averages to be inputted into a table. This new alteration has some constraints such as restriction of access and continuous operation. In its current state the table of data values can only be accessed and logged from inside the REPS facility by running the main 24\_7, environmental window, front panel display and data logging LabVIEW programs. The SQL Management server also has to be running and opened to gain access into the logged results. This server is restricted certain to personal. Refer to Appendix C for logging into the system steps.

## Fortis Passaat Testing Procedure

The FP testing of power output against wind speed was the test that was to be conducted.

The test did not take place due to time constraints and logging system issues in regards to data collection.

The logging results that were displayed in a table could not be accessed on my individual user name. In order to gain access I had to use the ENG 550 student's user name and password on the REPS computer to gain access to the logged results. This logging program was also completed in the last week before this paper was due so could not be completely explored.

## Test Design

The parameters that are needed to accurately test the FP system for validation are the wind speed, air temperature and power output. The power would also need to be examined in the dump load. The parameters therefore that need to be examined are output power as a function of time, power to dump load, power to load and output power of turbine. Figure 40 shows the display of the power parameters on the screen shot.

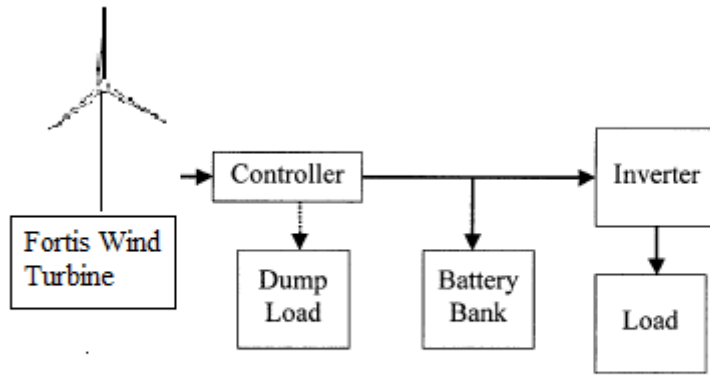


Figure 41-FP System Validation Layout

### Discussion

This simulation program data validation procedure for the REPS Facility was not conducted due to the time restrictions held on this project.

## References

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9. Pryor, T., *Wind Measurement Systems*. 2014: Murdoch University.
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11. Whale, J. *Wind Energy- Wind Measurement Systems*. 2014 [cited 2015 26/5/2015]; Lecture Slide].

## Appendix A

### IEC 61400.2 Standards – Grid Connection of Wind Turbine

#### 10.7.3 Electrical power network (grid connected systems)

##### 10.7.3.1 General

A SWT, intended to be connected to the electrical power network, shall comply with the requirements in 10.7.3.2 through 10.7.3.3 and relevant interconnect standards.

##### 10.7.3.2 Self-excitation – loss of grid connection

Any electrical system that by itself can self-excite the SWT shall be automatically disconnected from the network and remain safely disconnected in the event of loss of network power.

If a capacitor bank is connected in parallel with a network-connected SWT (i.e. for power factor correction), a suitable switch is required to disconnect the capacitor bank whenever there is a loss of network power, to avoid self-excitation of the SWT electric generator. Alternatively, if capacitors are fitted, it shall be sufficient to show that the capacitors cannot cause self-excitation. Provisions shall be made in order to bleed the capacitors in the event that the capacitor bank cannot be disconnected.

##### 10.7.3.3 Harmonics and power conditioning equipment

Power conditioning components, such as inverters, power electronic controllers, and static VAR compensators, shall be designed such that harmonic line currents and voltage waveform distortion do not interfere with electrical network protective relaying. Specifically, for network-connected SWT, the current harmonics generated by the SWT shall be such that the overall voltage waveform distortion at the network connecting point will not exceed the acceptable upper limit for the electrical network.

## Appendix B

### Maintenance / checklist

In principle, FORTIS wind turbines do not require any maintenance at all. On the other hand, it would be unwise not to check the wind turbine occasionally. FORTIS advises that you should check the wind turbine at least twice a year. The following points should be checked:

1. Check noises; the noise level should not have increased and should sound normal
2. Check nuts and bolts; they might have worked themselves loose
- 3. Check the bearings and labyrinth seal; there should be no play in the bearings

4. Check the yaw bearing and the bearings of the tail blade, they must be able to move smoothly; if they do not, apply some grease to the bearings
- 5. Check the electrical wires that are hanging through the inside of the mast; the tension must not be too high; this can occur if the wires have been wound too far.
- 6. Check the leading edge of the blades, small damages can be caused by small objects carried by the wind; such damages will speed up the process of wear and tear and should be repaired
- 7. Apply grease to the two grease nipples on the generator support chassis with a grease-gun at least twice a year.

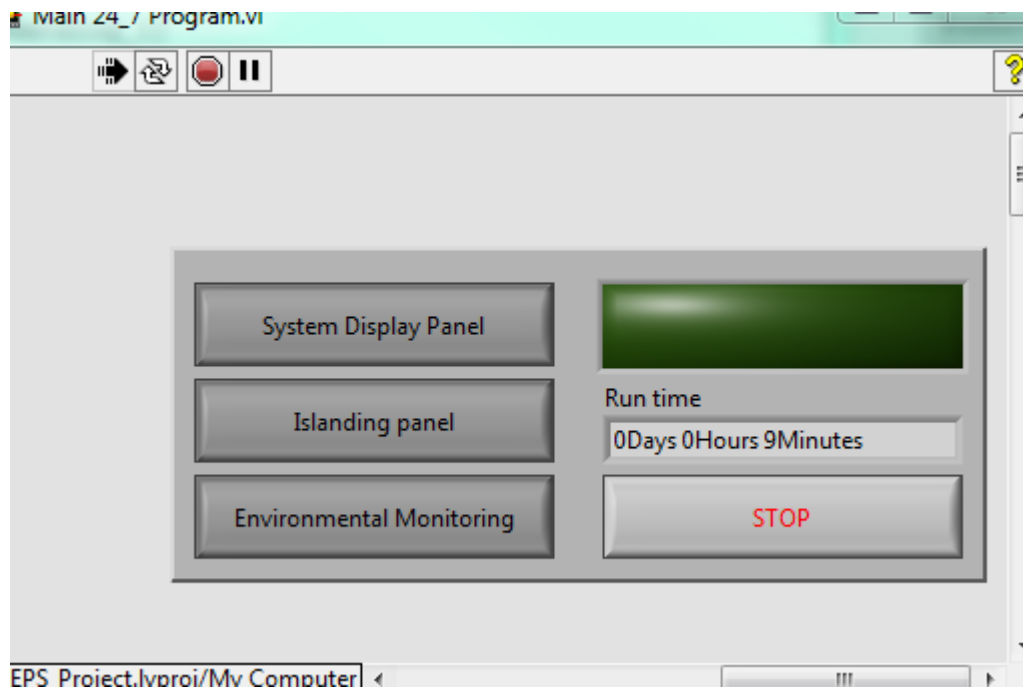
## Appendix C

### **Logging In**

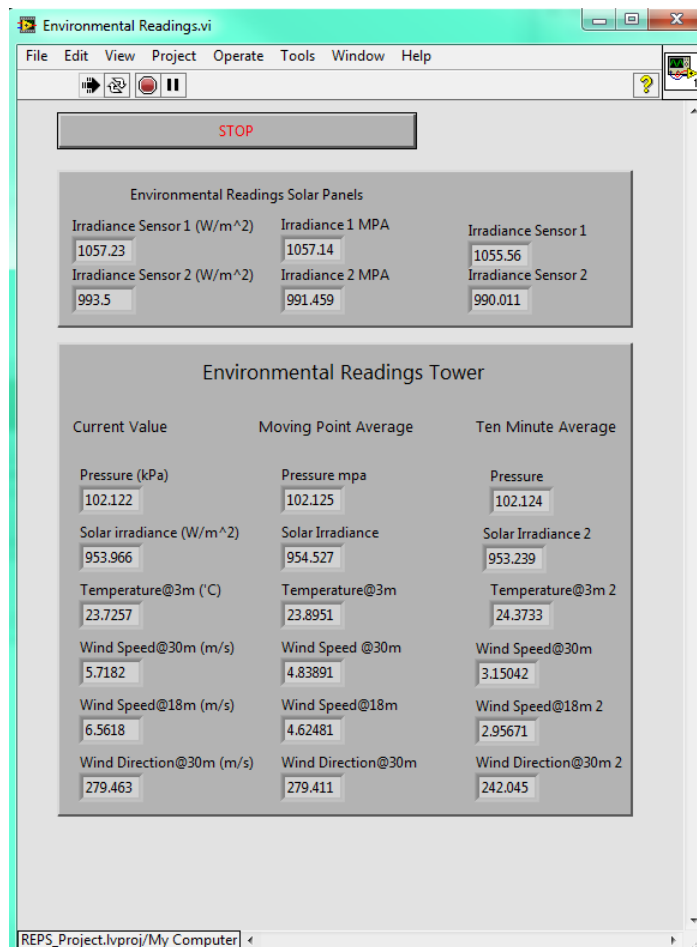
Due to security issues in order to log into the server an authorised persons credentials must be used in the REPS facility.



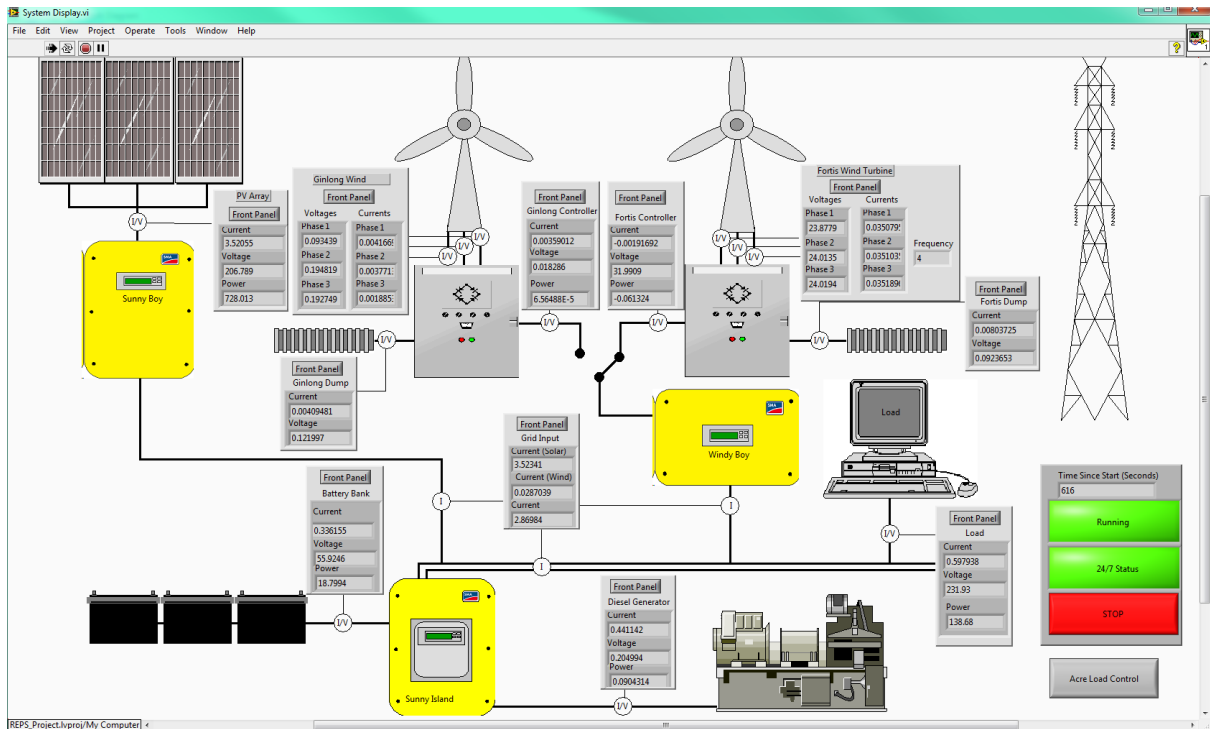
1. SQL server management was accessed using the connection using the combined user name password- eng-icl1,51055
2. Access the C drive then ENG 454 REPS then current LabVIEW code v4. This will bring up the current LabVIEW programs.
3. Now we run the REPS project and inside this program we need to run the 24\_7 program. You will get this display shown below



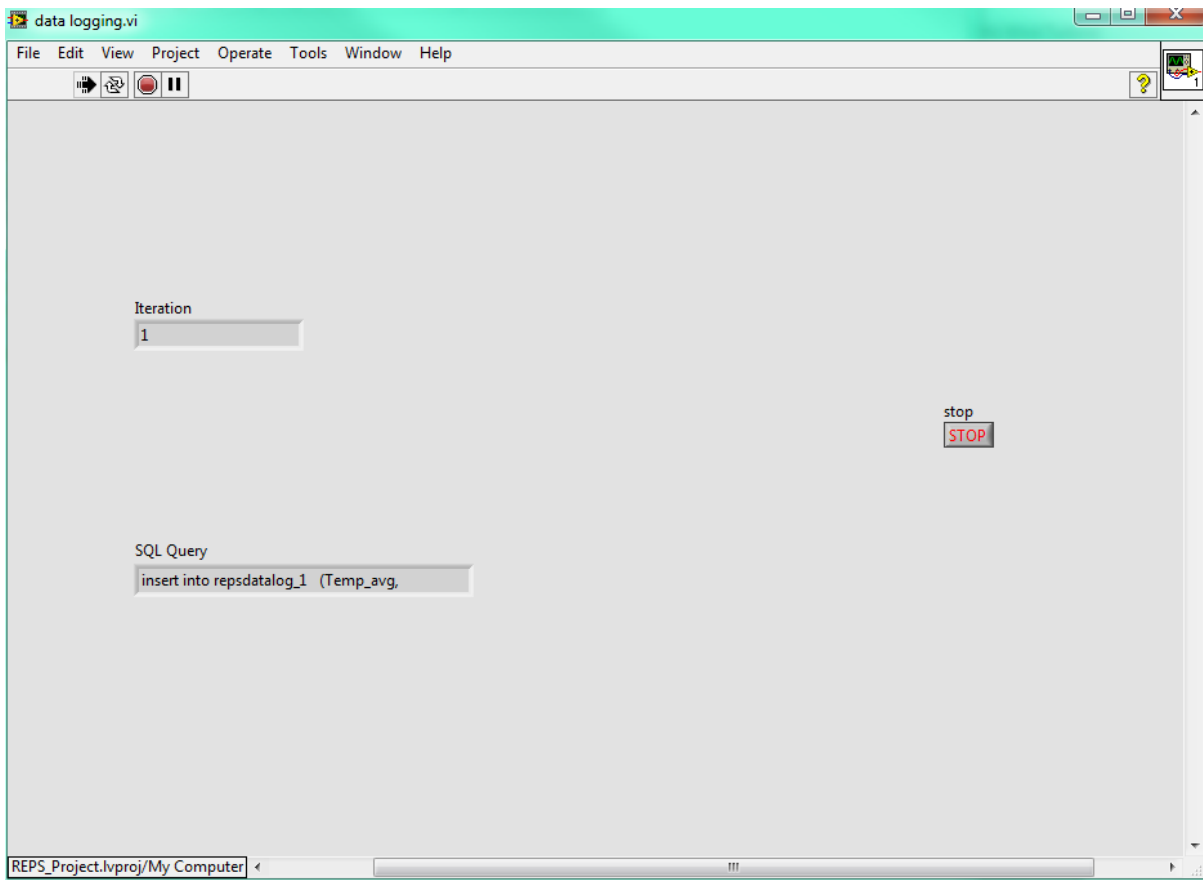
- Run the environmental monitoring and system display panel shown in the figure below



- Run the system display VI shown in figure below



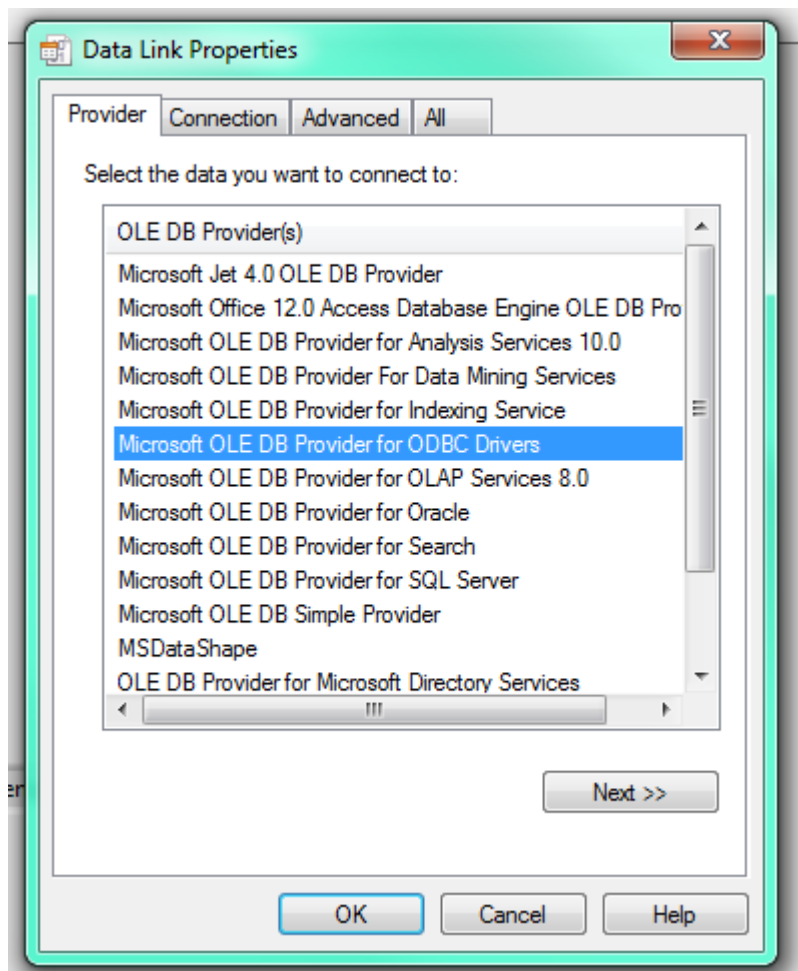
6. Access the data logging while the other programs are still running.



7. When all programs are running access the SQL server and type in username and password shown.

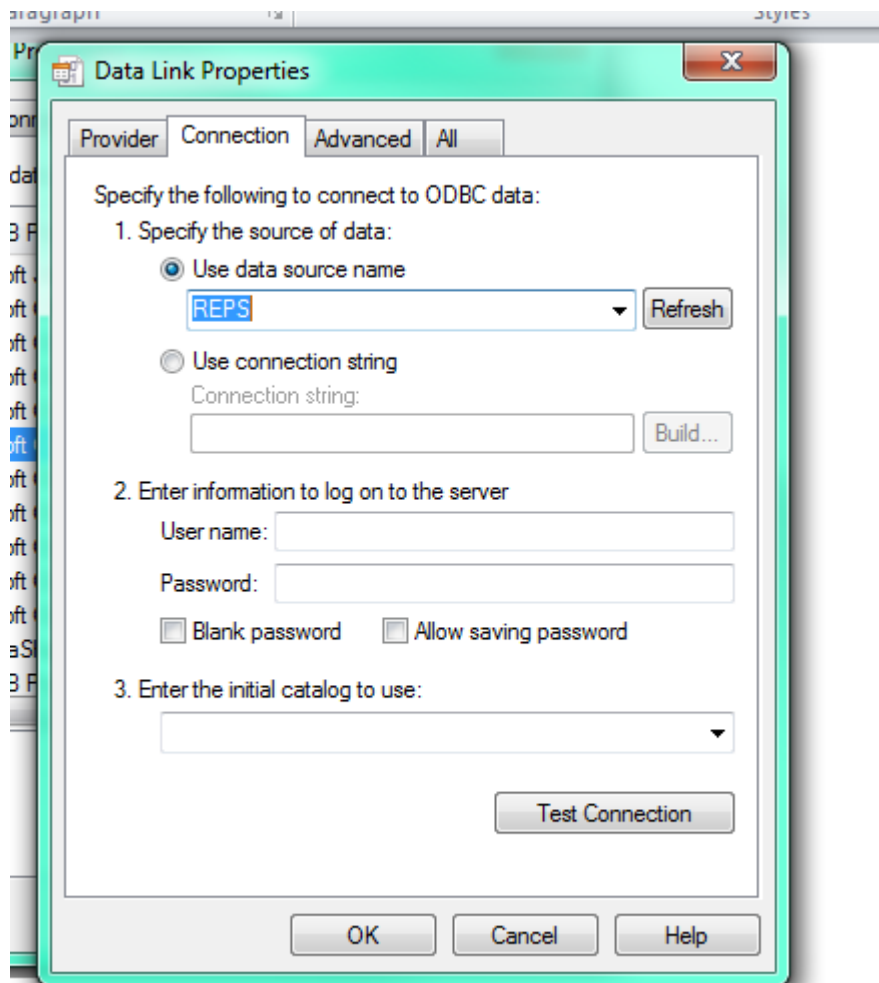


8. Choose the provider highlighted

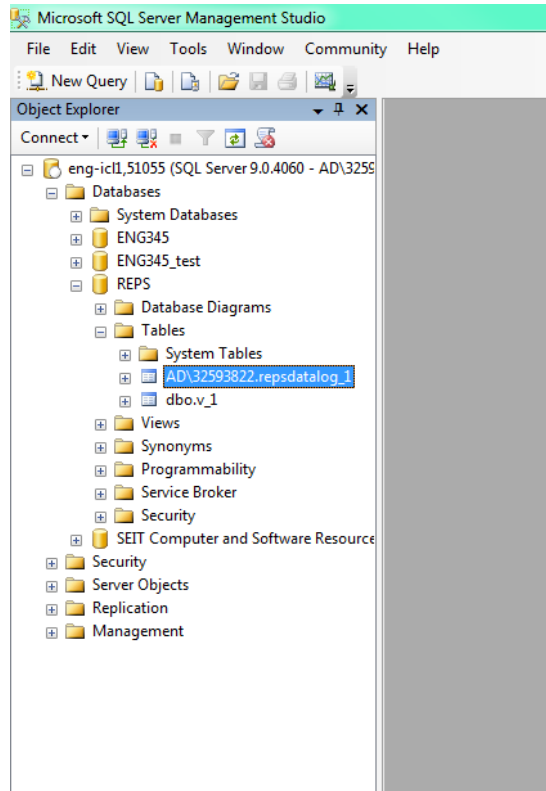


9.

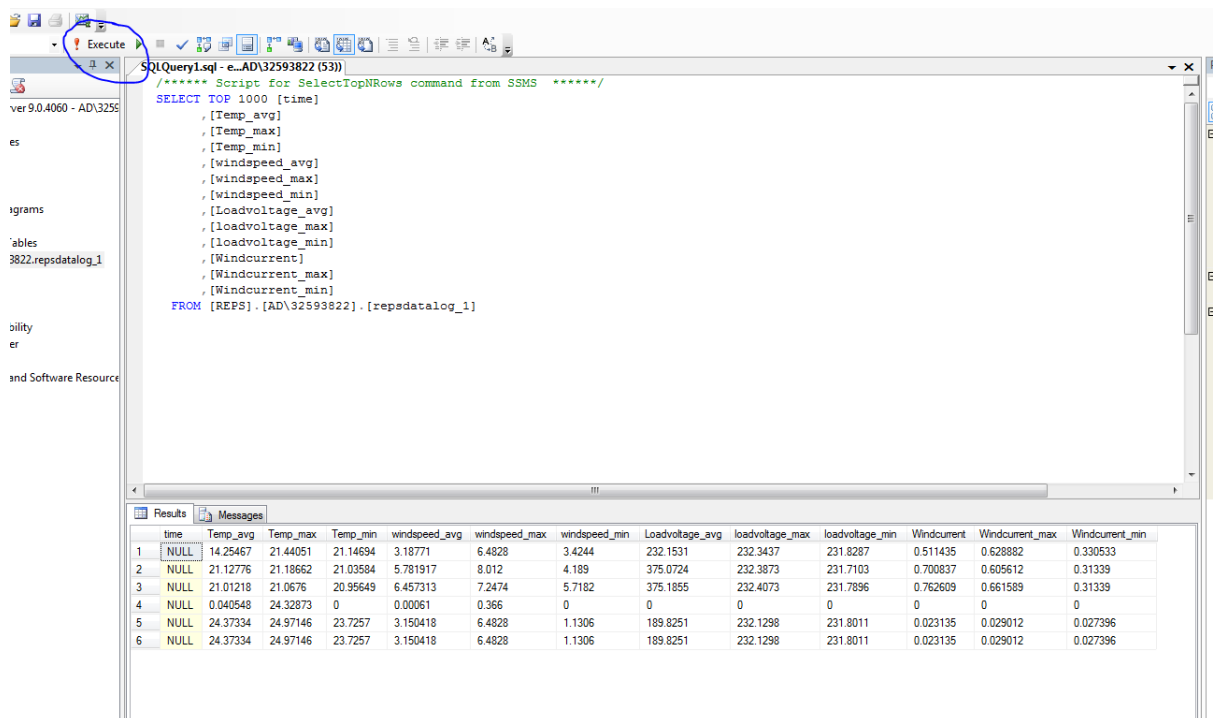
10. Choose REPS connection



From the selection need to right click and select **top 1000 rows**



Then the table for ten minute values will appear. Please note that the execute button must be pressed to refresh the table so roughly every ten minutes.



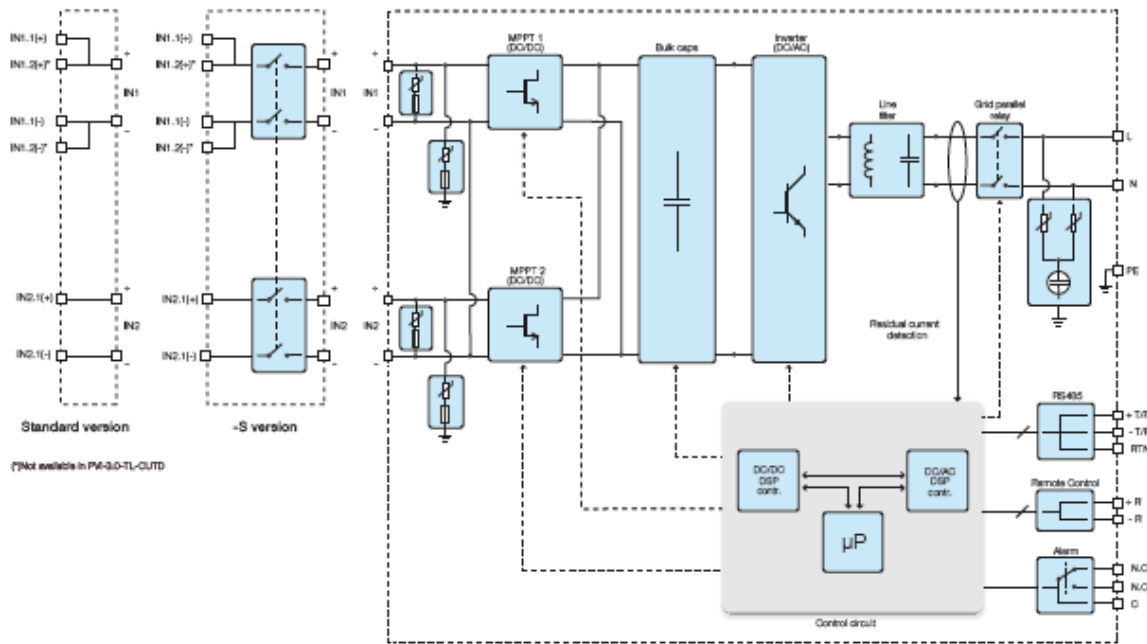


## Appendix D

### Technical data and types

Type code	PVI-3.0-TL-OUTD	PVI-3.6-TL-OUTD	PVI-4.2-TL-OUTD
<b>Input side</b>			
Absolute maximum DC input voltage ( $V_{max,dc}$ )	600 V		
Start-up DC input voltage ( $V_{start}$ )	200 V (adj. 120...350 V)		
Operating DC input voltage range ( $V_{oper,dc}...V_{dc,max}$ )	$0.7 \times V_{start}...580$ V		
Rated DC input voltage ( $V_{dc,r}$ )	360 V		
Rated DC input power ( $P_{dc,r}$ )	3120 W	3750 W	4375 W
Number of independent MPPT	2		
Maximum DC input power for each MPPT ( $P_{MPPT,max}$ )	2000 W	3000 W	3000 W
DC input voltage range with parallel configuration of MPPT at $P_{dc,r}$	160...530 V	120...530 V	140...530 V
DC power limitation with parallel configuration of MPPT	Linear derating from max to null ( $530V \leq V_{MPPT} \leq 580V$ )		
DC power limitation for each MPPT with independent configuration of MPPT at $P_{dc,r}$ , max unbalance example	2000 W ( $200V \leq V_{MPPT} \leq 530V$ ) the other channel: $P_{dc,r} = 2000W$ ( $112V \leq V_{MPPT} \leq 530V$ )	3000 W ( $190V \leq V_{MPPT} \leq 530V$ ) the other channel: $P_{dc,r} = 3000W$ ( $90V \leq V_{MPPT} \leq 530V$ )	
Maximum DC input current ( $I_{dc,max}$ ) <sup>7</sup> for each MPPT ( $I_{MPPT,max}$ )	20.0 A / 10.0 A	32.0 A / 16.0 A	
Maximum input short circuit current for each MPPT	12.5 A	20.0 A	
Number of DC inputs pairs for each MPPT	1	1	2 for MPPT1 and 1 for MPPT2
DC connection type	Tool Free PV connector WM / MC4		
<b>Input protection</b>			
Reverse polarity protection	Yes, from limited current source		
Input over voltage protection for each MPPT - varistor	2		
Photovoltaic array isolation control	According to local standard		
DC switch rating for each MPPT (version with DC switch)	25 A / 600 V		
<b>Output side</b>			
AC grid connection type	Single phase		
Rated AC power ( $P_{ac,r}$ @ $\cos\phi=1$ )	3000 W	3600 W	4200 W
Maximum AC output power ( $P_{ac,max}$ @ $\cos\phi=1$ )	3300 W <sup>8)</sup>	4000 W <sup>8)</sup>	4600 W <sup>8)</sup>
Maximum apparent power ( $S_{max}$ )	3330 VA	4000 VA	4670 VA
Rated AC grid voltage ( $V_{ac,r}$ )	230 V		
AC voltage range	180...264 V <sup>9)</sup>		
Maximum AC output current ( $I_{ac,max}$ )	14.5 A	17.2 A <sup>8)</sup>	20.0 A
Contributory fault current	16.0 A	19.0 A	22.0 A
Rated output frequency ( $f_r$ )	50 Hz / 60 Hz		
Output frequency range ( $f_{min}...f_{max}$ )	47...53 Hz / 57...63 Hz <sup>8)</sup>		
Nominal power factor and adjustable range	> 0.995, adj. $\pm 0.9$ with $P_{ac,r} = 3.0$ kW	> 0.995, adj. $\pm 0.9$ with $P_{ac,r} = 3.6$ kW	> 0.995, adj. $\pm 0.9$ with $P_{ac,r} = 4.2$ kW
Total current harmonic distortion	< 3.5 %		
AC connection type	Screw terminal block, cable gland M25		
<b>Output protection</b>			
Anti-islanding protection	According to local standard		
Maximum AC overcurrent protection	16.0 A	19.0 A	22.0 A
Output overvoltage protection - varistor	2 (L - N / L - PE)		

## Block diagram of PVI-3.0/3.6/4.2-TL-OUTD



## Technical data and types

Type code	PVI-3.0-TL-OUTD	PVI-3.6-TL-OUTD	PVI-4.2-TL-OUTD
<b>Operating performance</b>			
Maximum efficiency ( $\eta_{max}$ )		96.8%	
Weighted efficiency (EURO/CEC)		96.0% / -	
Feed in power threshold		10.0 W	
Stand-by consumption		< 8.0 W	
<b>Communication</b>			
Wired local monitoring		PVI-USB-RS232_485 (opt.)	
Remote monitoring		VSN300 Wifi Logger Card <sup>®</sup> (opt.), PVI-AEC-EVO (opt.), VSN700 Data Logger (opt.)	
Wireless local monitoring		VSN300 Wifi Logger Card <sup>®</sup> (opt.)	
User interface		16 characters x 2 lines LCD display	
<b>Environmental</b>			
Ambient temperature range	-25...+60°C / -13...140°F with derating above 50°C/122°F	-25...+60°C / -13...140°F with derating above 55°C/131°F	-25...+60°C / -13...140°F with derating above 50°C/122°F
Relative humidity		0...100 % condensing	
Noise emission		< 50 dB(A) @ 1 m	
Maximum operating altitude without derating		2000 m / 6560 ft	
<b>Physical</b>			
Environmental protection rating		IP 65	
Cooling		Natural	
Dimension (H x W x D)		618mm x 325mm x 222mm / 24.3" x 12.8" x 8.7"	
Weight		17.5 kg / 38.5 lb	
Mounting system		Wall bracket	
<b>Safety</b>			
Isolation level		Transformerless	
Marking		CE (50 Hz only)	
Safety and EMC standard	EN62109-1, EN62109-2, AS/NZS3100, AS/NZS 60950, EN61000-6-1, EN61000-6-3, EN61000-3-2, EN61000-3-3	EN62109-1, EN62109-2, AS/NZS3100, AS/NZS 60950, EN61000-6-1, EN61000-6-3, EN61000-3-11, EN61000-3-12	EN62109-1, EN62109-2, AS/NZS3100, AS/NZS 60950, EN61000-6-1, EN61000-6-3, EN61000-3-11, EN61000-3-12
Grid standard (check your sales channel for availability)	CEI 0-21, VDE 0126-1-1, VDE-AR-N 4105, G83/2, EN 50438 (not for all national appendices), RD1699, AS 4777, C10/11, IEC 61727, ABNT NBR 16149, CLC/FprTS 50549	CEI 0-21, VDE 0126-1-1, VDE-AR-N 4105, G83/2, G59/3, EN 50438 (not for all national appendices), RD1699, AS 4777, C10/11, IEC 61727, ABNT NBR 16149, CLC/FprTS 50549, PEA, MEA	CEI 0-21, VDE 0126-1-1, VDE-AR-N 4105, G59/3, EN 50438 (not for all national appendices), RD1699, AS 4777, C10/11, IEC 61727, ABNT NBR 16149, CLC/FprTS 50549
<b>Available products variants</b>			
Standard	PVI-3.0-TL-OUTD	PVI-3.6-TL-OUTD	PVI-4.2-TL-OUTD
With DC switch	PVI-3.0-TL-OUTD-S	PVI-3.6-TL-OUTD-S	PVI-4.2-TL-OUTD-S

- The AC voltage range may vary depending on specific country grid standard
- For UK G83/2 setting, maximum output current limited to 16A up to a maximum output power of 3.68kW
- The Frequency range may vary depending on specific country grid standard
- Limited to 3000 W for Germany

Remark: Features not specifically listed in the present data sheet are not included in the product

- Limited to 3600 W for Germany
- Limited to 4200 W for Germany
- Check availability before to order

