

Laboratory demonstration system for the VPS2 project

Technical Report for the Virtual Power Station 2 Milestone
Report 3.1b to ARENA

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Energy Flagship

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Executive summary

The Virtual Power Station 2 Project requires a laboratory demonstration system in place with capabilities to conduct experimental tests and further development of real and reactive power control of loads, photovoltaic generation and energy storage systems. This brief report describes such laboratory demonstration system, which is set up at CSIRO's Renewable Energy Integration Facility (REIF). A sample test data capture has been conducted to demonstrate that all laboratory systems are ready to conduct the experiments required by VPS2 Work Stream 2: Control System Design on the coordinated management and control of loads, active and reactive power and energy storage systems at a single site.

Contents

1	Laboratory demonstration system at the REIF	5
1.1	General description	5
1.2	Power grid simulator	6
2	A sample experiment and data collection test	7
3	Conclusions	9

Figures

Figure 1 – REIF equipment single-line diagram 5

Figure 2 – Power Grid Simulator electrical design and configuration 6

Figure 3 – Chart of results for PV + Generator + Load experiment 7

1 Laboratory demonstration system at the REIF

1.1 General description

CSIRO's Renewable Energy Integration Facility (REIF) is a microgrid laboratory and system test facility, located in Newcastle, NSW. The facility has been designed to allow sophisticated experimentation of power generation, load and storage systems ranging from residential to commercial-scale applications. This is backed by an ultra-high-speed, high fidelity data acquisition system monitoring all voltages and currents within the facility, which allows detailed analysis of power flows and full transients and harmonics from all equipment.

The REIF experimental facility incorporates the following equipment:

- 30kW/40kVA gas microturbine with grid-connect and off-grid operating modes
- 100kVA resistive/inductive/capacitive programmable load bank
- 70kW of solar PV, including 39kW of programmable PV emulators
- 30kW/150kW of lead-acid and UltraBattery energy storage
- 100kVA two-branch Power Grid Simulator (details below)
- 5kHz DC-coupled data acquisition system for full waveform capture
- 50kHz AC-coupled data acquisition system for detailed harmonic analysis

A single line diagram for the facility is shown in Figure 1.

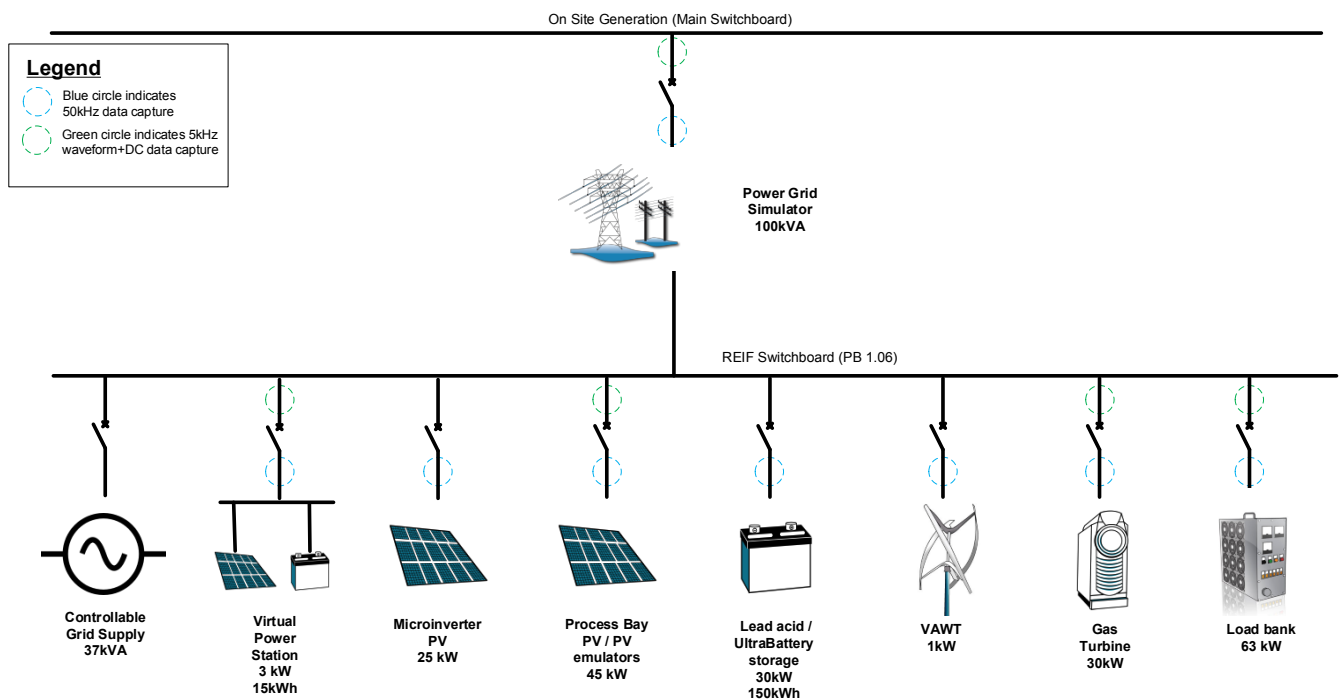


Figure 1 – REIF equipment single-line diagram

1.2 Power grid simulator

A key piece of equipment available at the REIF for VPS2 experiments is the Power Grid Simulator (PGS). The PGS provides the ability to emulate up to two segments of 415V network, which allows the investigation of impacts of a number of combinations of variable generation and load on network voltages and power quality, as well as the impacts of these on electrical equipment. Each network branch in the PGS is designed to emulate up to 1000m of hard-drawn bare copper (HDBC) or Cross Linked Polyethylene (XLPE) cable, and is characterised and implemented using a PI-model impedance network.

The system setup is designed such that each piece of REIF equipment may be connected at one of three points on a low-voltage network, as shown in Figure 2. This three-bus network configuration is sufficient to test and analyse conditions at any point in a network. Bus 1 can be used to emulate grid-side, upstream conditions Bus 2 represents the connection point under test, and Bus 3 emulates the downstream loads/generation/network conditions.

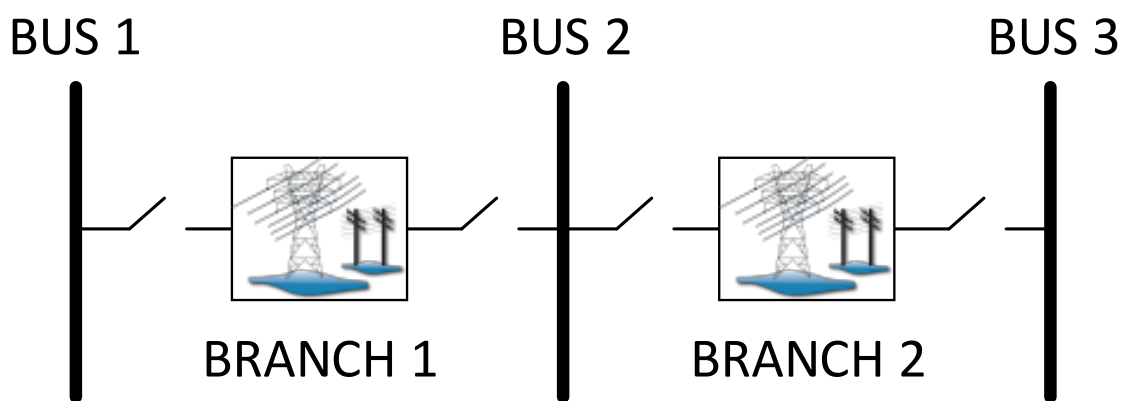


Figure 2 – Power Grid Simulator electrical design and configuration

2 A sample experiment and data collection test

To demonstrate the capabilities of the REIF equipment, below is a brief summary and results from an example set of experiments conducted recently in the REIF. The system was configured with a stable 240V grid connection at Bus 1, followed by an 800m Hard Drawn Bare Copper (HDBC) run to Bus 2, and then 100m of XLPE cable to Bus 3. The load bank, 7kW of PV through five inverters, and the gas microturbine were all connected at Bus 3 to emulate a small commercial system consisting of a mixture of solar and conventional generation (e.g. a diesel gen-set) co-located with site loads. The generator and load were then put through a pre-defined profile to see how the solar systems would react to a varying voltage due to the power flows in the system. A chart of the results is shown in Figure 3.

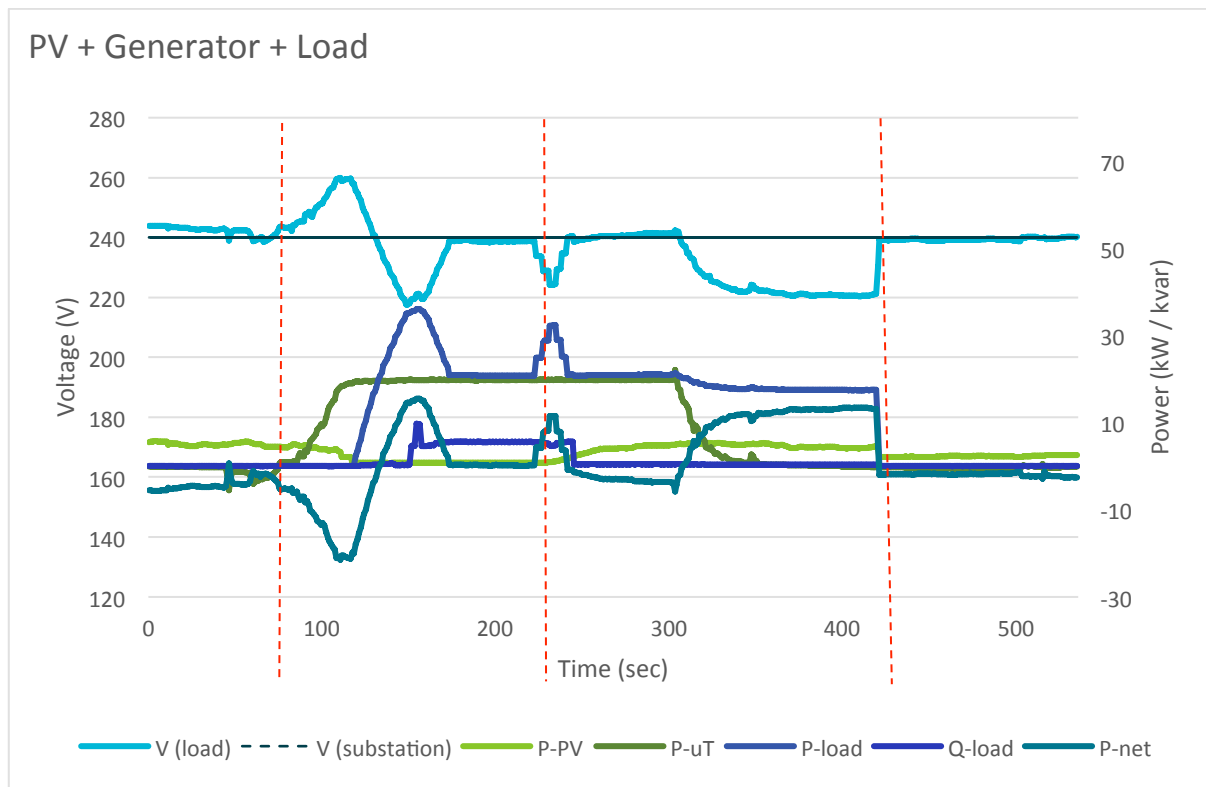


Figure 3 – Chart of results for PV + Generator + Load experiment

For the purposes of this summary, P_{net} is equal to $P_{\text{load}} - (P_{\text{PV}} + P_{\text{uT}})$.

At time $t=0$ the system is in steady-state, with no load applied and a moderate amount of power from the PV system (P_{PV}) providing a small voltage rise across the HDBC and XLPE networks. At $t=80$ s the gas microturbine (P_{uT}) begins to ramp up, resulting in a commensurate rise in the Bus 3 voltage. After a short period of time the turbine has ramped up to 20kW, and the voltage has risen sufficiently (up to 260V phase-neutral) to force four of the five PV inverters to detect an over-voltage situation and disconnect, while one continues to export despite this situation. While the reason for this requires further investigation, it may be supposed that degradation in the inverters' grid-protection device may be the cause. This is the type of behaviour that the REIF and the VPS2 project is intended to address.

At this point the loads begin to ramp up steadily, to a maximum load of 40kW. This reverses the direction of voltage excursion, which drops as low as 220V phase-neutral. For the next 300s the net load (P_{net}) oscillates between 0 and 20kW, including a small reactive power (Q_{load}) spike of 10kvar (which had a small but significant impact on the bus voltage). At time $t=225$ s the offline PV inverters have detected a relatively stable voltage for sufficient time that their grid-protection devices allow them to reconnect, and the system ramps up to its previous steady-state output of approximately 5kW.

As may be seen in Figure 3, at time $t=300s$ the turbine begins to ramp down and then shutdown (even drawing a small amount of power for the remainder of the experiment while it runs through its cool-down procedure), however this did not cause any conditions that impact upon the operation of the PV system. What does impact the PV system is the loss of the 20kW of load at time $t=410s$ – while the voltage simply returns to 240V, the rate of change in voltage was high enough that three of the five PV inverters had their grid protection devices trigger another disconnection, and remained offline for the remainder of the experiment. The ability to perform full-scale testing of hardware within this controlled environment prior to deployment allows the investigation of potential deployment issues (such as the interactions seen in this experiment) to be thoroughly tested without impacting customers within the actual deployment sites.

3 Conclusions

As described in the present report, the REIF has at this stage all the experimental equipment and data acquisition systems in place to conduct a wide range of tests and further developments on the control of loads, generated active and reactive power, and energy storage, as required by VPS2 Work Stream 2. Key REIF capabilities include a high sampling rate of the data acquisition system, which allows for full transient and harmonic analysis of the equipment connected, and a power grid emulator, which has the flexibility to emulate conditions at any point in real networks. A sample data capture experiment has been conducted and is reported to demonstrate some of the key laboratory components in action.



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