Full Paper

Introduction

Despite the technological revolution arisen due to the spread of affordable personal computers, laptops and their networks, most laboratories for engineering education continue to use stand-alone hardware systems, panel-mounted or hand-held meters whose readings are recorded on paper by students. The laboratory reports are usually submitted and assessed in paper form. However by transforming the laboratory classes to incorporate more digital means of conducting and assessing laboratory classes, many benefits can be reaped both by the students as well as staff. Inevitably such major transformation of an engineering laboratory is a very expensive exercise. However opportunities do arise especially when new laboratories are built.

In 2013, a state of the art custom-designed laboratory in renewable energy was commissioned at the Bentley campus of Curtin University in Western Australia. Since the new facilities were far more advanced and comprehensive than the existing traditional laboratory classes, a need and an opportunity arose not only to produce a new set of laboratory experiments but also to redesign the entire process of conducting and assessing laboratory classes. The new laboratory classes were offered to undergraduate and postgraduate students in two teaching units and the perception of students on the new processes and the laboratory were collected in 2013 and 2014. This paper presents the resources developed and the procedures followed in the new facility and a critical analysis of their effectiveness.

Background

The adverse climate changes and environmental pollution due to the burning of fossil fuels such as coal, oil and natural gas for electric power generation has driven the entire world community towards power generation using renewable energy sources such as solar, wind and hydro sources. As a consequence, an increased number of engineering graduates find employment in this field. In order to equip the engineering graduate with the necessary theoretical and practical knowledge, building new laboratories for teaching and research has become a necessity in many parts of the world.

However, due to the high cost of building a laboratory in renewable energy, the recent trend has been to use remote online laboratories using a small-scale hardware test setup. Al-Zoubi, Hammad et.al, (2014) demonstrated how a Lego Mindstorms based solar lab was built to share resources among Jordanian universities. A very similar approach is described by Tobarra, L., Ros, S., et.al, (2014) in building a mini-solar and mini-wind laboratories as remote laboratories. A mobile virtual laboratory for renewable energy was built in Romania by Cotfas, Cotfas and Samoila (2013) using National Instruments myDAQ device as the controller. The power level that can be handled by such mini-scale laboratories is limited to a few tens of watts which is far below real-scale renewable energy systems. While such mini-scale labs definitely help understanding the fundamental concepts, they do not resemble the practical systems and therefore immune to some of the practical challenges faced by engineers in the real world applications.

Real-Scale Hardware Laboratory

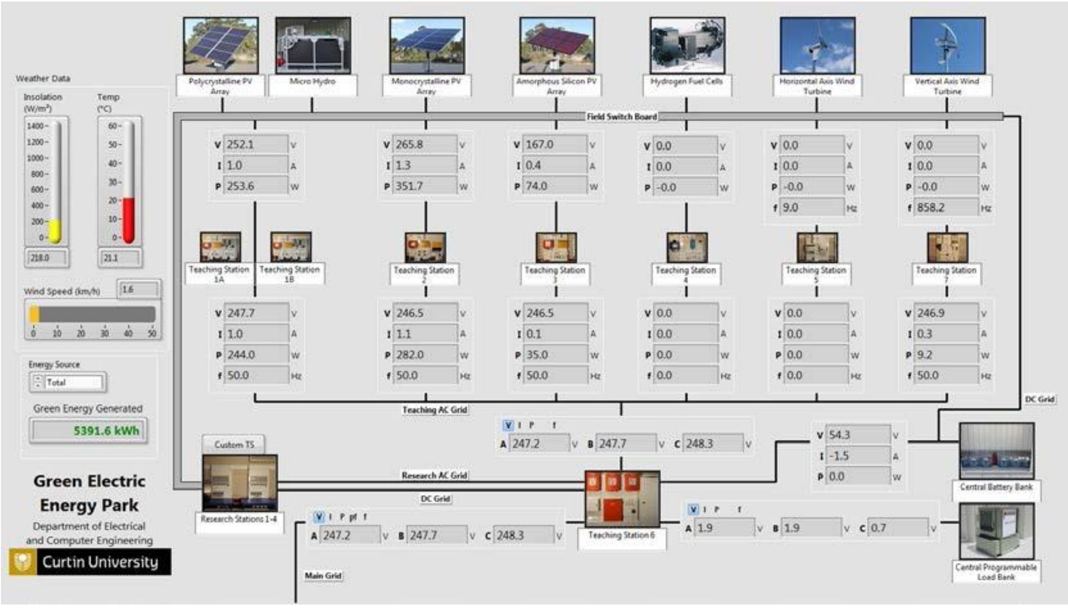

Figure 1: Software home screen of Green Electric Energy Park

Considering the importance of exposing students to real-scale renewable energy systems, a unique laboratory named ‘Green Electric Energy Park (GEEP)’ comprising of all major renewable energy sources was custom-designed and built at a cost of about $1.2 million from 2009 to 2013 at the Bentley campus of Curtin university. Rajakaruna and Islam (2011) detailed the objectives, facilities and the challenges faced during the design and construction phases of this project. As illustrated in Figure 1, the outdoor facilities at the laboratory features 3 solar PV arrays, 2 wind turbines, a micro hydro turbine-generator system, a proton exchange membrane fuel cell stack with necessary hydrogen generation and storage, a large battery energy storage and a comprehensive weather monitoring station. The internal arrangement of the laboratory is such that there is a dedicated teaching station for each external energy source and the power can also be diverted to research projects at one of the four research stations. At teaching stations, 3 to 4 students conduct an experiment using the teaching station switch panel where power from external source is diverted to different types.

Custom Designed Software

All the electrical variables such as voltage, current and power at different branches of the circuits are measured using either by dedicated transducers or by reading off the power converters. Using National Instruments devices all the measured signals are converted to digital form and the server computer is updated with the latest readings. The readings from transducers are updated 1000 samples per second whereas the readings from the converters are updated only at one sample per second, thereby creating two sets of variables as ‘fast’ and ‘slow’. Furthermore, a comprehensive array of weather data such as solar radiation, temperature measured by the on-site weather station is also read by the server computer at a rate of 1 sample per second. As depicted in Figure 1, overall status of power and weather information of the entire laboratory is displayed and updated every one second on the home screen of the custom designed LabVIEW based GEEP software.

Each teaching station and research station is equipped with a desktop computer working as one of the client computers of the dedicated local area network of the laboratory. These teaching station computers can display the data at any of the teaching stations at any time. The server computer is also accessible through internet via the university's wide area network. Therefore the laboratory can be remotely monitored from lecture theatres and offices of the campus as well as from anywhere on the globe.

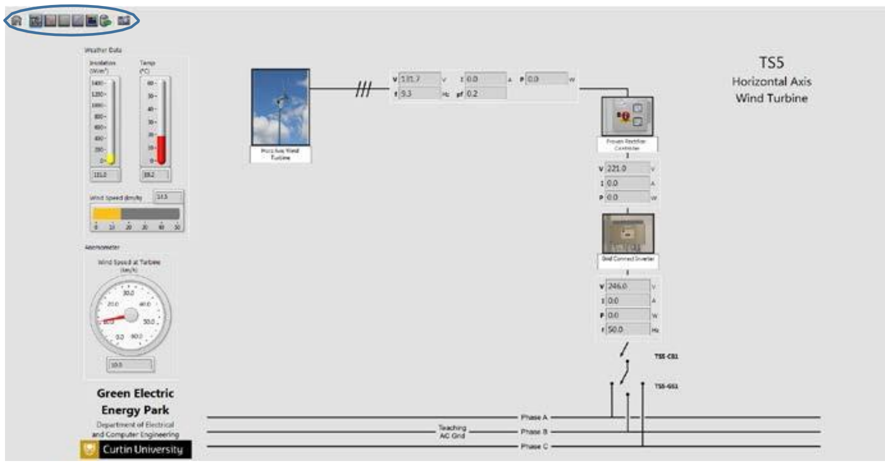

Figure 2: Process view of a teaching station

Detailed Teaching Station Views

Detailed circuit diagram of a teaching station can be displayed with some of the key electrical and weather data at that station getting lively updated by clicking the photograph of the teaching station at the middle of the home screen. For example, when the photograph above 'Teaching Station 5' in the middle of the home screen for the horizontal axis wind turbine is clicked, the software opens the 'Process View' screen shown in Figure 2. While this screen is useful to understand the circuit connections and recording some key data, four other data displays are available by clicking the left hand top corner buttons to view and record data during experiments. In any of the four views, by right clicking of the mouse on the display area, all numerical data of selected variables can be saved in clipboard or as an Excel file or the waveforms can be saved as pictures. Students can save the Excel file or any other form of a file to the desktop computer or to their memory sticks directly.

1. Waveform View: Displays selected 'fast' signals from transducers (1000 samples per second) up to a time duration of 1 second. As evident from Figure 3, the waveform view works like an oscilloscope. It can be zoomed in 20 times in time scale, reducing the time duration to 0.05 seconds. This waveform view is very useful in capturing fast transients happening below 1 second.

2. Fast Fourier Transform (FFT) View: This is similar to the waveform view but the information is displayed in frequency domain instead of time domain.

3. Trend View: The trend view is displaying both 'fast' and 'slow' variables within time duration of 60 seconds. This view is suitable to capture slow variations of data and steady- state values. It is one of the most commonly used views as it can show any of the data related to the teaching station.

4. Historical View: This view is capable of displaying any number of selected slow or fast data of a teaching station up to 24 hours duration on any day and time period in the past since the commissioning of the system. This view is extremely useful in capturing all what happened during a given period during the lab class or during the entire lab session.

However, it is maximum sampling is at 1 sample per second. If necessary, sampling interval can be increased to reduce the size of the data file.

In addition to these four views of capturing data over a period of time, a snapshot of data at a given time can also be recorded as one line in an excel file by clicking the ‘Snapshot’ camera button near the historical view button. This replaces the traditional practice of noting down of data by pen and paper.

Thus the GEEP custom-designed software is capable of capturing both steady and transient data during an experiment in digital form and saving them in Excel files, in picture forms etc. in the memory sticks of students. The files after necessary commenting are ready to be uploaded to the Blackboard and shared among students and the supervisor.

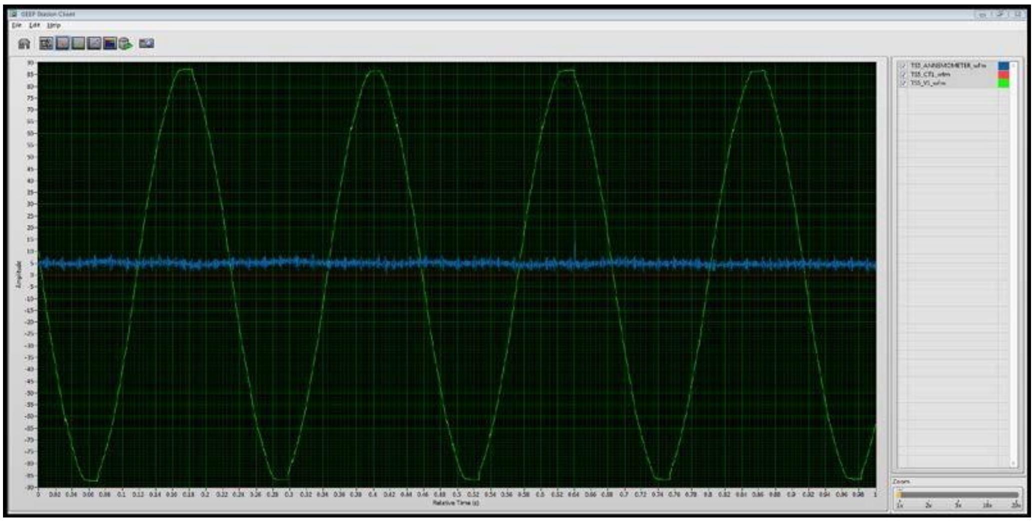

Figure 3: Waveform view of a teaching station

Approach

Pre-Laboratory Preparation

In order to assist students preparing prior to arriving in the laboratory class, following documents were prepared for each of the laboratory experiment.

1. Laboratory Manual: Giving the electrical circuit diagrams of the teaching station/s used, physical views of components and the procedure to be followed in each part.

2. Brief Theory Document: The fundamental knowledge required to perform the experiment and to prepare necessary reports was provided through a brief theory document.

3. Safety Documents: As safety of students and staff is paramount, safety guidelines were provided for GEEP in general and for the specific teaching station in use.

4. Pre-Laboratory Report Guidelines: Students were required to submit a brief pre-laboratory report prior to arriving in the class. This report answered few questions asked within the laboratory manual. These simple questions could be answered if students read the provided preparatory materials.

Performing the Experiments

Students follow the guidelines given in the laboratory manual. The data is recorded in their memory sticks using one of the five views of the teaching station or the snapshot button.

In-Class Submission

After recording all data, students prepare a Word file relating the names and contents of different Excel data files to the parts of the lab manual. Any missing information or problems encountered can also be noted in this word file. Then, as a means of reporting data to the supervisor and also a means of sharing the collected data among all students in the group, students upload the prepared Word file and the Excel files to a 'Group Journal'. Group Journal is a Blackboard tool that can be selected when creating a 'Group' in Blackboard. As per the Blackboard Help: Journals (2015), "*When used in the group area, members of a group can view and comment on each other's entries for the group journal. The group, as a whole, can communicate with you and all members benefit from the comments*." The Journal allows students to upload files, share files and make comments. Therefore it can be used as a means to promote collaboration in preparing final lab reports. Uploading of data during the lab class prevents the regular plagiarism of students in copying the final lab reports from previous year reports. Also group collaboration in preparing the final lab report can be promoted by awarding a percentage of marks to the comments made in the Group Journal.

Data Analysis and Final Report

Students prepare an individual final lab report answering the questions given at the end of the lab manual. It usually is a comprehensive report with calculations, plotting graphs, data analysis, predictions and discussion.

Online Submission of Reports

Deviating from the conventional way of submitting paper based reports through a central assignment office of the faculty, online submission of reports was made possible by creating Blackboard Assignments under the Assessments folder. As outlined by Blackboard Help (2015), a course group must exist prior to creating group assignments for it. Prior to creating any group assessments in Blackboard, it is therefore important to create the Blackboard 'Groups' enrolling the correct students belonging to a lab group. Once a report is submitted to a group assessment, the same mark awarded by the assessor is automatically awarded to each student. Online submission of reports avoided the need for students to rush to the assignment office at a particular due time. Furthermore it helps in making the laboratory class procedure a paper-free one.

Online Assessments and Feedback

A report submitted to the Blackboard Assignments link appears as an attachment under a student's name in the 'Grade centre' column corresponding to the assessment. To make the assessment and feedback process digital, consistent among different assessors and easy to use, online marking rubrics were created for each assessment. As defined in Klimovski (2013) and Rubrics (2012), a rubric is a clear and unambiguous indication of what is expected of students in order to achieve the various grade levels for a piece of assessment. An online marking rubric was therefore developed for the pre-laboratory report, the in-class submission and the final lab report of each experiment. The online rubrics can be viewed by students prior to preparing the reports to understand the requirements. They can be opened within the Grade centre by the assessors and can be used to grade the answers and to provide comments in each part. The rubrics make assessment process much more consistent among assessors at the same campus or at different campuses including overseas campuses. Once the marking period is over, the students are allowed to see the marks with the comments through My Grades section of the Blackboard.

Satisfaction of Students

The developed processes at GEEP were launched in semester 1 of 2013 in the unit of Renewable Energy Principles and in semester 2 of 2013 in the unit of Renewable Energy Systems. The effectiveness of the developed resources and processes were surveyed through a Qualtrics online survey during these two semesters. Although the response rate was low at about 23%, valuable feedback was received. After making necessary changes to the procedures, a paper based survey was conducted in Renewable Energy Principles unit at the end of semester 1 2014. A total of 84 responses were received with a very encouraging response percentage of 79%. The class comprised of 77% undergraduates and 23% postgraduates. An 88% of the class studied Electrical Power Engineering course while the remainder followed Mechatronic Engineering. A vast majority of students, 76%, did not have any prior study or work experience in renewable energy. Below is a summary of findings of the paper based survey.

Lab Manuals and Other Documents

On the questions of the adequacy of the laboratory documents developed, the satisfaction of the students is clearly established through the high percentages of 84% for lab manuals, 82% for in-class submission guidelines, 90% on final lab report guidelines and 91% for safety guidelines. The response for lab manuals and final lab report are shown in Figure 4.

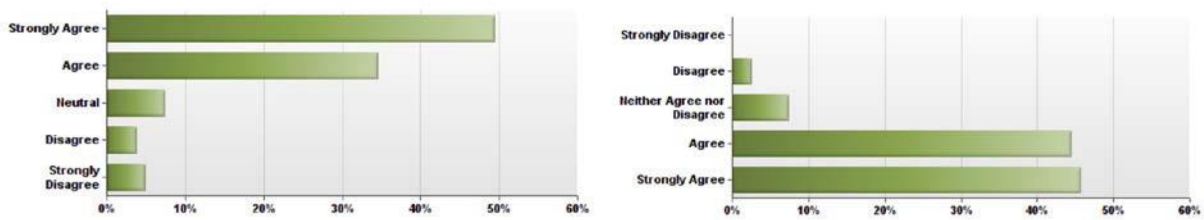

Figure 4: Students agreement on the adequacy of documents developed (a) Lab manuals (b) Final lab report guidelines

Online Submissions and Assessments

According to the feedback received, an overwhelming 95% students preferred online submissions over hard copy submissions and also 95% agreed that GEEP design with automatic data logging and digital storing is helpful in preparing lab reports for online submissions. One student commented as "*Online submission is very helpful. It saves time and also we can make the report better. I wish every lab is like this.*" The online rubrics made available on Blackboard were considered as helpful by 85% of students in deciding how to answer questions in lab reports. The satisfaction on the amount of guidance given by rubrics was 81%. Some students commented as "*Rubrics are excellent*" and "*Rubrics are amazing*". On the question of "*I received sufficient feedback through marking rubrics and feedback comments*", the student agreement was an acceptable 74% whereas the agreement with the statement "*I recommend using online submission and assessment for the future lab assessments*." was a resounding 96%.

Group Journal

There was a very high agreement of 88% and 89% on the Journal as an effective way of replacing the logbook that is normally used in other laboratory classes and it is an effective way of reporting the work done during the class to the supervisor, respectively. Furthermore students strongly agreed that Journal is making it easy to retrieve and share the measurements among group members and that it prevents loss of data after a lab class with the agreement percentages of 86% and 90% respectively. However, on the statements that "*Journal helps us to work as a group*" was agreed by only 75% and "*Journal is an easy to use Blackboard tool" was agreed by 80%.* The comments such as *"I found our group talked extensively over Facebook, with very little discussions occurring over the Journal*.", "*Our group mostly used Facebook to communicate*." and "*We use E-mail more often*." clearly indicated Journal is not a good way to communicate with lab group partners in preparing the lab reports.

Workload

As a result of the reductions made to the workload by making some lab reports group submissions, a strong satisfaction could be seen with the questions related to the workload. An 85% agreement was received for the statement "*The workload of laboratory classes in this unit is similar to that of other laboratory classes.*" The increased marks of 30% awarded the laboratory component was strongly approved by students with a 93% agreement with the statement "*Percentage of unit marks awarded to the laboratory classes was reasonable.*"

Overall Experience

Finally, over 97% agreement was reported for the statement "I am happy with the way GEEP software, data acquisition and storage system has been designed." and over 97% agreement was also reported for the statement "I am happy with the use of e-learning technologies in GEEP laboratory classes making it closer to a paperless laboratory." On the final statement "Overall, it was a great learning experience." the agreement was an overwhelming 97% as well. The students highly praised the lab experience in their final comments as "I simply love to come to this lab. It's interesting to learn practically about renewable energy systems", "Very well designed unit, unfortunately the other do not follow this." and "It was a great experience overall".

Lessons Learnt and Conclusions

Based on the student feedback through online surveys, paper surveys and the formal teaching and unit surveys by the university, it clearly showed students were highly appreciative of the new learning environment created at GEEP by integrating e-learning technologies with the lab facilities. While most of the developed procedures remain the same, the workload was reduced by revising the lab report guidelines and making some submissions group instead of individual. In addition, considering the significant amount of marking hours required, the submission of pre-lab report was abandoned. Furthermore, the marks percentage for the lab component was increased to 30% from 15% to take into account the increased workload compared to other lab classes. The online submissions, online rubrics for assessment and feedback are making it easy for the students to submit reports and get feedback in quicker time with consistency among assessors. The Journal was appreciated as a tool for reporting data but not as a means of collaboration for final report preparation. Therefore, the marks awarded to Journal comments were withdrawn allowing them to use other media such as Facebook, emails and Skype for collaboration. The unit satisfaction of Renewable Energy Systems unit through the formal student feedback of units by the university increased to 100% for the first time in Semester 2 of 2014 after making the necessary changes. It was satisfying to see 100% satisfaction in the areas of learning experience, assessment tasks and feedback. Unit satisfaction in the Renewable Energy Principles unit in semester 1, 2015 was at a very satisfactory 96%.

The lab supervisors also appreciated the efficiency of new working environment with no papers to handle. The ab assessors can work from anywhere as long as internet is available. Due to the lab facilities and the procedures developed to utilize them, GEEP was made a paperless laboratory achieving the objective of this project. It is now ready to be further expanded to offer remote laboratory classes and offer online units as well.

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