Educational Simulation Platform for Micro-grid

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***Abstract*—Recently, the micro-grid concept has been widely discussed and it is anticipated to be a key player for future power grid. Nevertheless, students often find micro-grid knowledge too complicated to comprehend with due to lack of real-life working examples. In this paper, we propose a new educational simulation platform to teach micro-grid technology with the help of the latest Electrical Transient and Analysis Program (ETAP). This fully integrated software has capabilities in planning and operating the electric grid with power monitoring and system optimization tools available for all project scales with high flexibility. A benchmark 0.4 kV low-voltage micro-grid including photovoltaic arrays and wind turbines generators is used both in grid-connected mode and island mode in this paper. Students can input different system parameters on static and dynamic components; the software can then conduct various simulations for further analysis. This paper will illustrate the use of power flow analysis and transient stability analysis. Students would learn more about the system outcome with result analyzer and alert view function on the result display interface. In short, this simulation platform is a valuable learning resource for students and it has a significant implication to the industry as well.**

***Index Terms* — Micro-grid, Power Flow Analysis, Transient Stability Analysis, Educational Simulation Tool, ETAP**

I. Introduction

THE idea of micro-grid has raised substantial interest from the academics over past few decades and recently has also drawn up attention from the general public as micro-grid technology is expected to be a key driver of power grid in the future [1]. Micro-grid is suggested to be modern distribution network architecture in order to take full advantage of integrating all range of distributed generations into low-voltage power network on top of current smart grid technology [2]. Micro-grid is defined as “a group of interconnected loads and distributed energy resources within clearly defined electrical boundary that acts as a single controllable entity with respect to the grid. A micro-grid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode,” according to the U.S. Department of Energy [3]. Micro-gird has three distinct advantages; first, it helps to maximize the operational efficiency and thus lowering the total system cost. Second, it can fulfil resiliency requirements and maintain service quality during contingency events. Third, it practically reduces environmental impact with reduction of greenhouse gases emission [4]. The rise of micro-gird has a revolutionary impact on teaching and learning in power systems.

Although micro-grid has increasingly been incorporated in many power system subjects in both undergraduate and postgraduate levels, students often found concepts such as bi-directional power flows, dynamic behaviors and stability theories of micro-grid in medium or low voltage network too complex to manage. Besides, micro-grid is a multi-disciplinary and highly complicated topic comprising of numerous new power system devices and it also applies communications, sensors, automation and computers to improve the flexibility, reliability, and efficiency of the system. Therefore, it is necessary to develop an educational simulation platform which can provide a user-friendly interface to manage power system components, analytical tools and database for students to reinforce their understanding in micro-grid from the fundamentals to the practical principles in layman’s term.

PowerWorld is one of the most comprehensive power flow packages and most widely-used for educational purpose [5]. Some MATLAB-based simulation tools for stability analysis are introduced in [6]-[12], and the comparison of their features is presented in [6]. Recently, some universities have started to adopt ETAP software as computer simulation tool in teaching power system [13]-[16], for example, students can understand the design of industrial power distribution systems by applying short circuit study and flow analysis with the help of ETAP [15]. Furthermore, ETAP is used to demonstrate topics like utility economics, protective device coordination and voltage management to students [16]. However, to the best of our knowledge, most of them only involve conventional power systems; micro-grid topics are predominantly focused in research aspect whereas coursework students are rarely exposed to this topic in the laboratory component of power system subjects due to lack of suitable learning package.

ETAP is the most comprehensive and robust analyzing software for power system design, simulation, monitoring, operation, control, optimization and automation. Unique functions of ETAP include real time simulator, dynamic load shedding, optimal load flow and cost optimization. In addition, ETAP can automatically generate a brief report for presentation together with alert message to highlight the presence of mistake for alarm and warning [17]. Furthermore, ETAP is a fully integrated software which supports project of all scales and allows modification from a collection of templates. Users can choose either start on the fly or from the scratch with high level of flexibility. It also comprises of a detailed database with typical information for all equipment. Therefore, ETAP is

This work was supported by the Teaching Development Grants (LTG12-15/SS/EE) and Department of Electrical Engineering of The Hong Kong Polytechnic University.

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advantageous in solving critical electrical system problem in real life scenario [18].

In this paper, a simulation platform for micro-grid teaching is developed based on ETAP software, and there will be a series of models of advanced power system components in micro-grid such as battery energy storage systems, renewable energy generations and electric vehicle charging stations. Furthermore, planning and operation tools including intelligent power monitoring, energy management, system optimization, advanced automation and even real-time prediction can also be integrated into the platform to support simulation analysis, control and operation of the micro-grid. Besides, several well-prepared simulation cases will be offered to guide students to start their analyses. It is anticipated that this platform will help students understand the operating principle of micro-grid, encourage active learning mode, incorporate the latest research into the education and refine the undergraduate curriculums by adding new knowledge of future power system operation.

The rest of this paper is organized as follows. Section II justifies the choice of ETAP software for the developed educational platform. In section III, a micro-grid simulation example is introduced to demonstrate load flow analysis and transient stability analysis as well as the interfaces for data input and results display. Section IV concludes the paper with its future implication.

II. Proposed Micro-Grid Simulation Platform

In this session, as shown in Fig. 1, a benchmark 0.4 kV low-voltage micro-grid is modified from [19] and is used as a demonstration of power flow analysis and transient stability analysis to students. It also shows the usefulness of ETAP as a simulation platform for teaching.

As shown in Fig. 1, the micro-grid network consists of one gas turbo generator (Gen2), two photovoltaic arrays (PVA1 and PVA2) and two wind turbines (WTG1 and WTG2) with five loads (Lump 1-5), and is connected to the medium voltage network of power grid via a 20kV/0.4kV transformer.

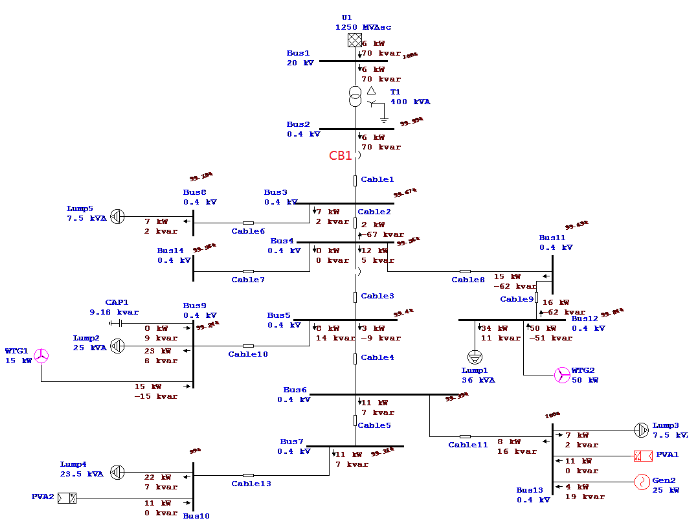

Fig. 1. Benchmark low-voltage micro-grid network in grid-connected mode

A. Data Input

The core tools in ETAP enable power engineering students to easily and quickly build three-phase and single-phase AC and DC network one-line diagrams (e.g. Fig. 1) with buses and elements including detailed instrumentation and grounding components. Students need to input various system parameters such as static data and dynamic data for simulation.

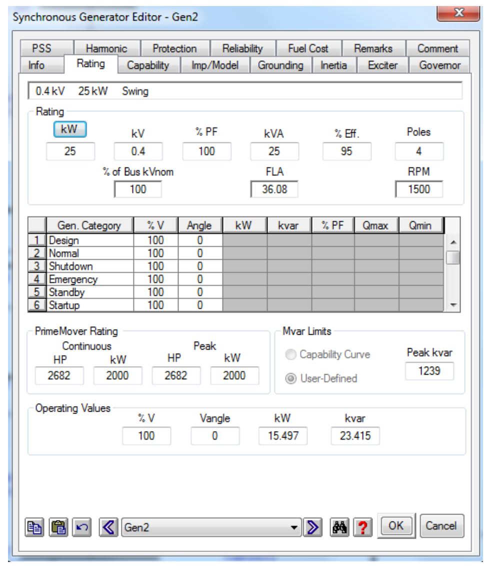

Fig. 2. Static data input – generator rating

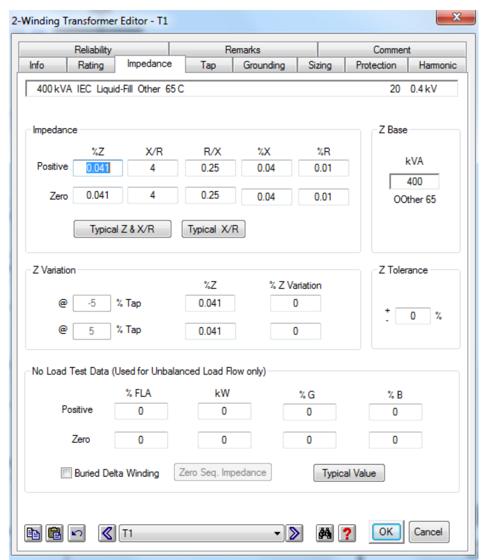

Fig. 3. Static data input – transformer impedance

Load flow analysis requires the input of static data, which includes the rating and impedance of generators, transmission lines, transformers etc. The input interfaces of static data for generator and transformer are shown in Fig. 2 and Fig. 3, similarly for the other elements.

Usually, students only understand the literal meaning of each parameter, without knowing the reasonable range of values to be applied in different equipment in a real system. The ETAP libraries (database) provide a complete pool of verified and validated data based on equipment manufacturers' published

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information. So students can simply select the equipment and use typical (sample) values of that particular equipment for analysis without the need to collect additional data, this makes the whole simulation process more efficient and convenient.

Apart from static data, dynamic data is also essential to conduct stability analysis. For example, Fig. 4 and Fig. 5 display the input interface of dynamic sub-transient model and governor of generator, respectively. At the top of these interfaces, one can see that there are more dynamic data needed to be input for stability, such as the inertia and the exciter of generator. Similar input interfaces are available to the rest of elements in the system, which are not shown here.

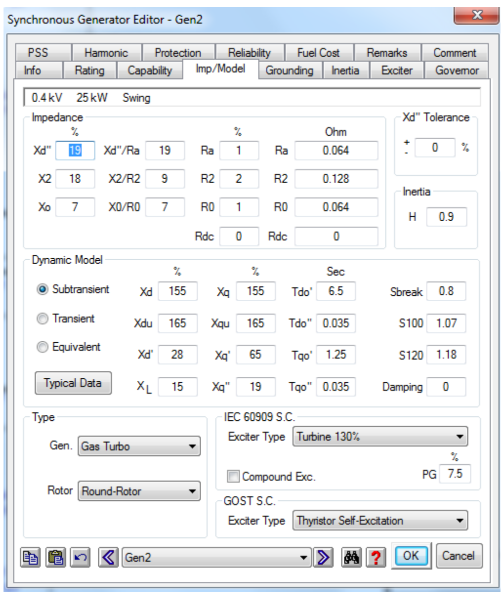

Fig. 4. Dynamic data input – dynamic model of generator (sub-transient)

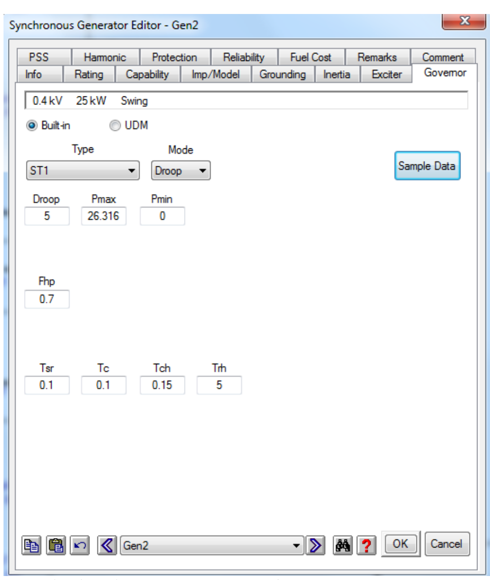

Fig. 5. Dynamic data input – governor of generator

As known, micro-grid includes numerous distributed renewable energy sources such as photovoltaic arrays and wind turbines. One of the advantages of ETAP for micro-grid analysis is the provided renewable source models. Wind turbine generator models (input interface shown in Fig. 6) in ETAP were developed by the WECC Modeling & Validation Working Group for analyzing the stability impact of large arrays of wind turbines with a single point of network interconnection. ETAP photovoltaic array (input interface shown in Fig. 7) can be used to represent individual panels connected in series or parallel combinations with a grid tied inverter in order to simulate and analyze the performance of solar farms.

These renewable source models are fully integrated with ETAP calculation modules such as Load Flow Analysis, Short Circuit Analysis, Transient Stability Analysis, Harmonic Analysis and Protective Device Coordination.

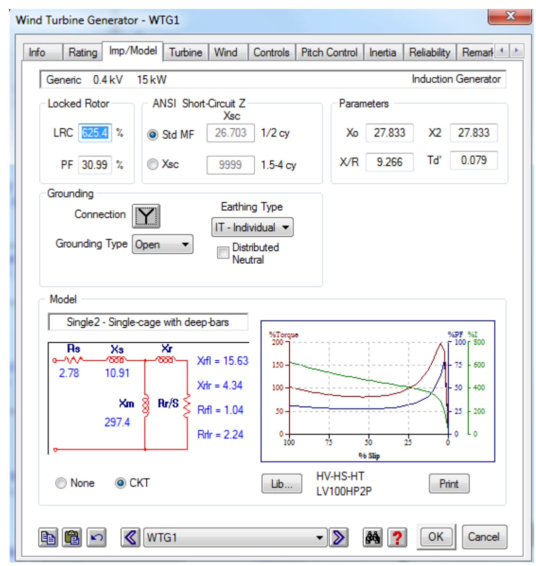

Fig. 6. Input interface of wind turbine generator

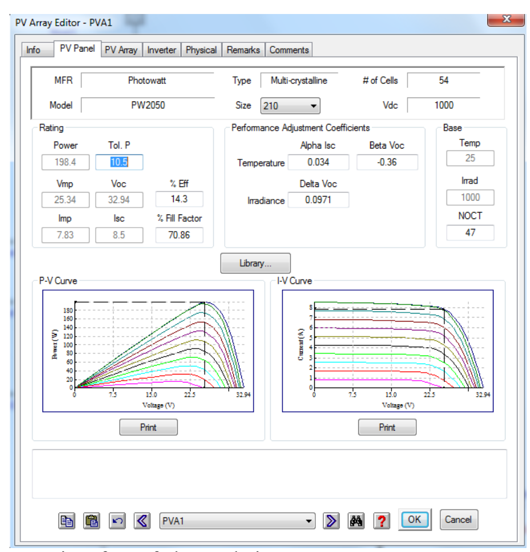

Fig. 7. Input interface of photovoltaic array

B. *Calculation Modules*

After the construction of network model, students can create a study case for the calculation module. Using load flow study as an example, several analysis methods including adaptive Newton-Raphson, Newton-Raphson, Fast-Decoupled and

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Accelerated Gauss-Seidel are available for students to choose. Next, students can further elaborate the load flow study cases by altering the loading conditions and generation categories to represent different situations as shown in Fig. 8.

Static voltage analysis such as voltage sensitivity test can be applied to load buses of both active and reactive power. Students can indicate the location of particularly weak buses or areas within the entire power network. Furthermore, students can define alert settings for both critical and marginal situations (Fig. 9) where it will be shown on the result display.

Transient stability analysis would assist students in identifying system disturbances and contingencies. Using the Action Editor in Fig. 10, students can study the impact of three-phase faults in buses and cables. Additionally, students can also simulate various operational events such as load shedding, critical clearing time and generation re-dispatch as shown in Table I. They can also define parameters such as total simulation time, simulation time step and plot time steps.

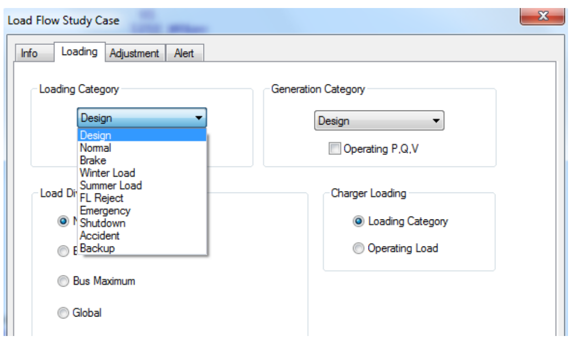

Fig. 8. Load flow analysis case edition interface

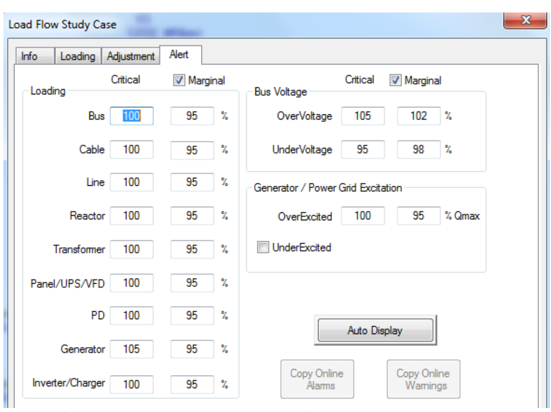

Fig. 9. Interface of alert setting for load flow analysis

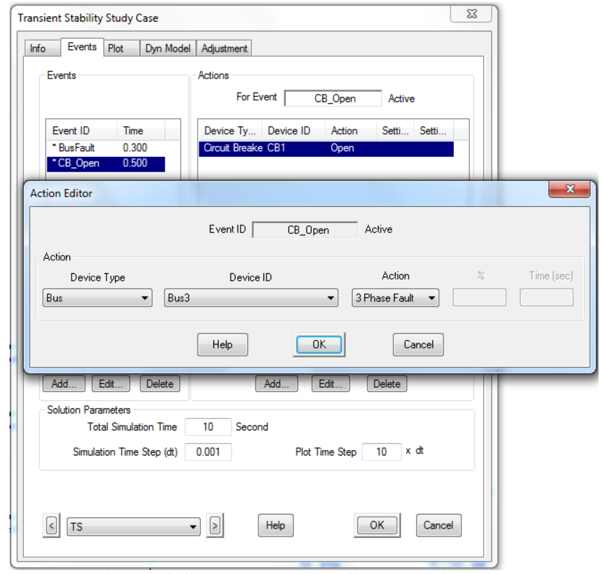

Fig. 10. Transient stability analysis case edition interface

TABLE I
DIFFERENT ACTIONS FOR DIFFERENT DEVICES

Device Type	Actions
Bus	Three-phase fault, LG fault, clear fault
Circuit Breaker	Closed, Open
Generator	Droop, loss saturation, generation ramp, voltage ramp
Load	Load ramp, load shedding
Wind turbine	Loss of generation

C. Results display

The power flow of all branches and the bus voltages are visually shown on the one-line system diagram with directions as shown in Fig. 1. In Fig. 11, power flow with reverse direction in some branches and the decrease of bus voltages can be observed when the micro-grid system is disconnected from the power grid by opening the circuit breaker (CB1).

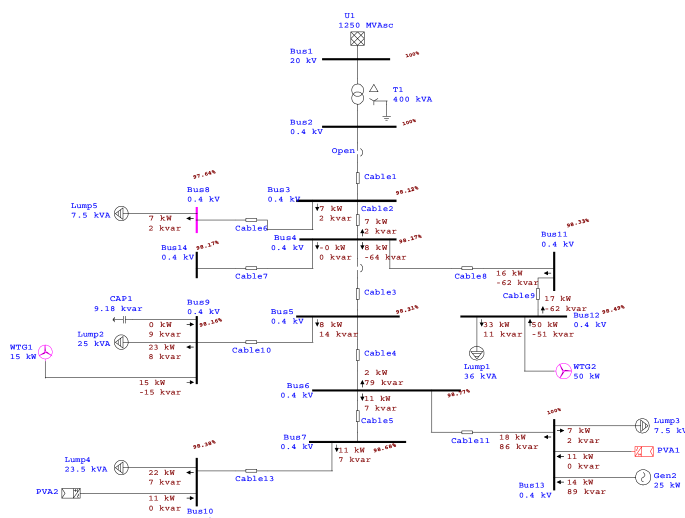
Fig. 11. Results of load flow analysis in island mode (CB1 is open)

Students will be warned with red and pink color to indicate elements that are out of critical and marginal range, respectively. The thresholds were set when creating the study case. Besides, as presented in Fig. 12, students can use Alert View function to obtain a brief error report with condition of the device and its operating level listed. The complete results of load flow analysis can be retrieved from the Load Flow Result Analyzer. As indicated in Fig. 13 and Fig. 14, the simulation result at every single node within the system can be viewed by checking appropriate options.

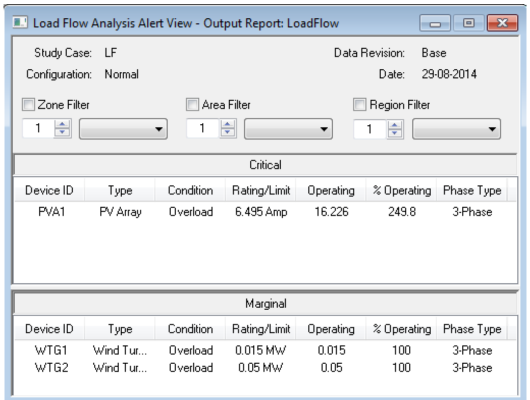

Fig. 12. Alert View of load flow analysis

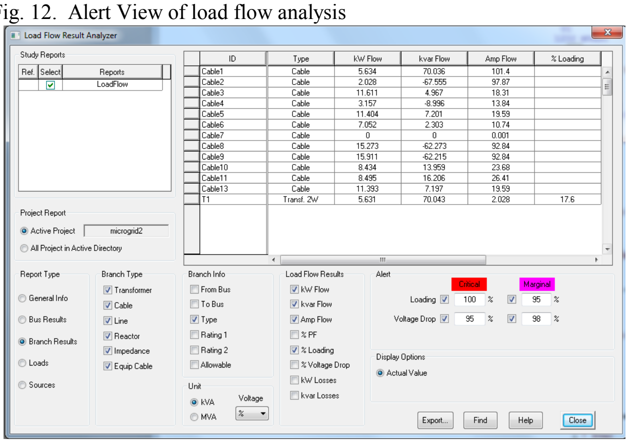

Fig. 13. Branch results viewed from Load Flow Result Analyzer

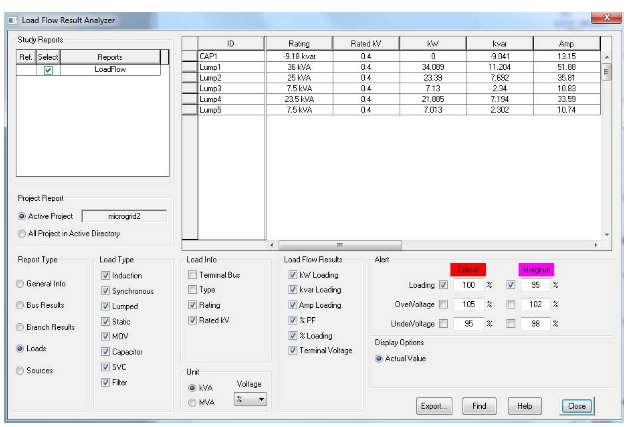

Fig. 14. Load conditions viewed from Load Flow Result Analyzer

In transient stability analysis, the time response of various system variables, such as bus voltages, frequencies, power transfers of the transmission line, rotor angles, speed of generators and more, can be obtained by Transient Stability Plot Selection function in ETAP as shown in Fig. 15. The generated swing curve provides information on the system performance after a disturbance or contingency event. Students can validate and compare the simulation results on different stability problems.

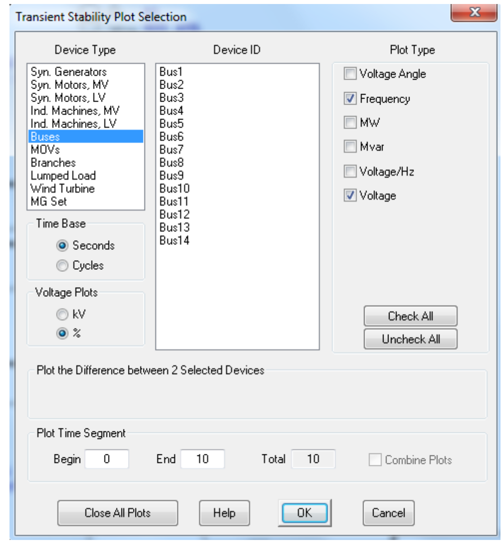

Fig. 15. Plots generation of transient stability analysis results

For example, a three-phase fault is simulated to occur at Bus 1 at t = 0.1s, then circuit breaker (CB1) is open at t = 0.15s and the micro-grid is switched into island mode. The analysis results are generated as a detailed report in MS Excel format for plotting purpose and further analysis. For a simulation time of 5s, the voltage and frequency curves of Bus 3 are presented in Fig. 16; active power of gas turbo generator is shown in Fig. 17; the active and reactive power of lumped load 2 and lumped load 5 are depicted in Fig. 18 and Fig. 19, respectively. The transient process can be observed in Fig. 16 – Fig. 19.

The voltage stability is mainly maintained by the medium-voltage network when the micro-grid is in grid-connected. Due to the relatively simple structure of micro-grid and the short distance between the micro-grid and the fault location, the bus voltages in micro-grid network drop significantly when the fault occurs. After the circuit breaker is open, the voltage levels can be restored by the exciter of generator, but cannot be increased to the same level as in grid-connected mode. During the fault occurs, the generator output is increased and short-circuit current is injected into the fault location by the distributed generators (DG). The load demand decreases as the voltages drop due to the fault. When the circuit breaker is open (switch to island mode), the system frequency will increase since the output of DG is higher than the demand. Afterwards, the system frequency is stabilized by the generator governor.

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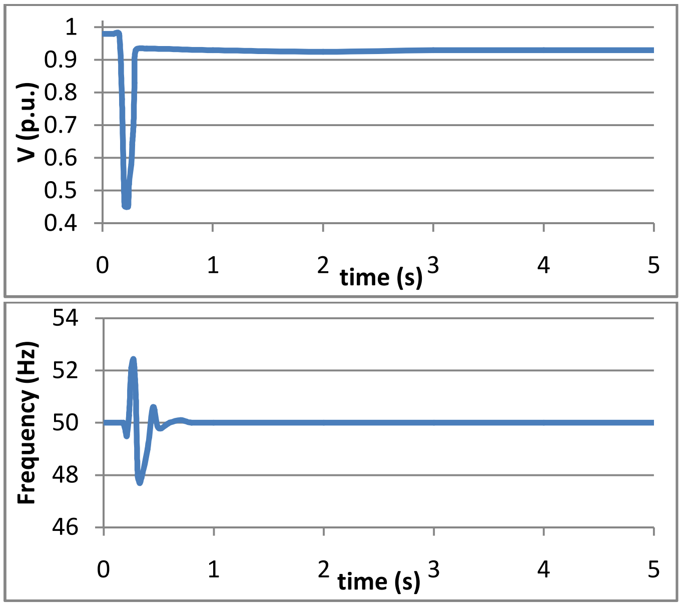

Fig. 16. Voltage and frequency curves of Bus 3

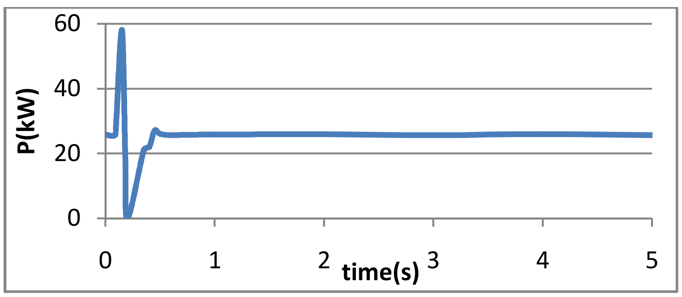

Fig. 17. Active power output of gas turbo generator (Gen2)

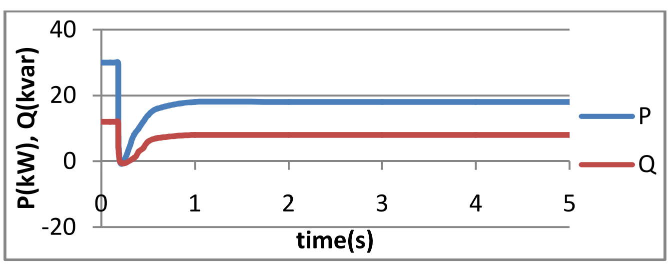

Fig. 18. Active and reactive power of lumped load 2

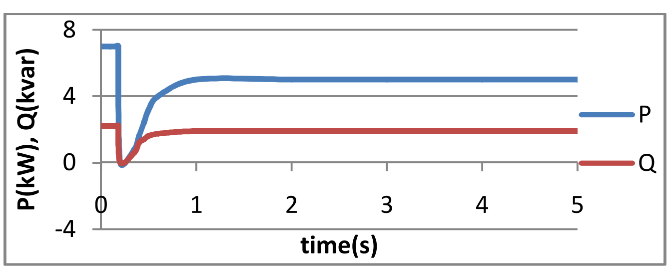

Fig. 19. Active and reactive power of lumped load 5

III. Conclusion

This micro-grid learning platform is an invaluable and useful resource for all students. This simulation software provides high level of flexibility for students to vary the input variables, so students can understand the interplay and effect of each element within the model. Also, plenty of analytical tools would help student to establish better understanding with the micro-grid system and cultivate an ability to detect and solve potential fault earlier. Students can resemble numerous micro-grid examples to abound their learning experience.

The development of this educational platform has an important implication to engineering students and the industry. By teaching micro-grid knowledge, undergraduate students would stand a better chance to pursue advanced study and commence their professional career earlier with a specialization in micro-grid section. For post-graduate students, this platform would help them augment their mindset and integrate with their strengths to cope with more complicated problems in reality.

Furthermore, it can support training and retooling the current workforce. This platform would add value to industry insiders by connecting the latest power grid technology with their previous technical backgrounds. In addition, it can facilitate the exchange and innovation of ideas with the industry including new product design and technology application. This revolutionary educational platform would complement current staff training programs in various ways and thus assist fostering the entire organizational growth in both technical and knowledge development.

References

[1] L. Hernandez, C. Baladron, J. Aguiar, B. Carro, A. Sanchez-Esguevillas, J. Lloret and J. Massana, "A Survey on Electric Power Demand Forecasting: Future Trends in Smart Grids, Microgrids and Smart Buildings," *Communications Surveys & Tutorials, IEEE,* vol. PP, Issue 99, pp. 1 - 36, 2014. doi: 10.1109/SURV.2014.032014.00094

[2] Lawrence Berkeley National Lab. *About Microgrid*, 2004, [Online] Available: http://building-microgrid.lbl.gov/about-microgrids-0 [Accessed: Aug. 12, 2014]

[3] Lawrence Berkeley National Lab, *Microgrid Definition*, 2004 [Online] Available: http://building-microgrid.lbl.gov/microgrid-definitions [Accessed: Aug. 10, 2014]

[4] T. Roughan. *Workshop on Microgrid Technologies and Applications*, 2014, Presented at National Grid RPI Centre for Future Energy Systems, [Online]. Available: http://www.rpi.edu/cfes/Workshop%20on%20Microgrid/C3%20Roughan%20NGrid.pdf [Accessed Aug. 20, 2014]

[5] S. Bhattarai, PowerWorld Simulator Tutorial, [Online], Available: http://learn.sdstate.edu/shietpas/classes/sprg07/ee434L/TutorialSantosh.pdf [Accessed Aug. 18, 2014]

[6] F. Milano, "An Open Source Power System Analysis Toolbox," *IEEE Trans. on Power Syst*., vol 20, no. 3, pp. 1199-1206, Aug. 2005.

[7] K. Schoder, A. Hasanović, A. Feliachi, and A. Hasanović, "PAT: A Power Analysis Toolbox for MATLAB/Simulink," *IEEE Trans. on Power Syst*., vol. 18, no. 1, pp. 42-47, Feb. 2003.

[8] J. H. Chow and K. W. Cheung, "A toolbox for power system dynamics and control engineering education and research," *IEEE Trans. Power Syst.*, vol. 7, no. 4, pp. 1559–1564, Nov. 1992.

[9] R. D. Zimmerman, C. E. Murrillo-Sánchez, and D. Gan. (2005) Matpower, Version 3.0.0, User's Manual. Power System Engineering Research Center, Cornell Univ., Ithaca, NY. [Online] Available: http://www.pserc.cornell.edu/matpower/matpower.html

[10] A. H. L. Chen, C. O. Nwankpa, H. G. Kwatny, and X. Yu, "Voltage stability toolbox: an introduction and implementation," in *Proc. 28th North American Power Symp*., Nov. 1996.

[11] C. D. Vournas, E. G. Potamianakis, C. Moors, and T. Van Cutsem, "An educational simulation tool for power system control and stability," *IEEE Trans. Power Syst.*, vol. 19, no. 1, pp. 48–55, Feb. 2004.

[12] J. Mahseredjian and F. Alvarado, "Creating an electromagnetic transient program in MATLAB: MatEMTP," *IEEE Trans. Power Delivery*, vol. 12, no. 1, pp. 380–388, Jan. 1997.

[13] Lamar University, *ELEN 3441 Lab 16: Introduction to ETAP*, 2012 [Online]. Available: http://www.ee.lamar.edu/gleb/power/ELEN%203441%20SYL%20Spring%202009.pdf [Accessed Aug. 15, 2014]

[14] Ryerson University, *2012-2013 Undergraduate Calendar, Electrical engineering (EES, ELE).*, 2012 [Online]. Available: http://www.ryerson.ca/calendar/2012-2013/pg3180.html [Accessed Aug. 12, 2014]

[15] West Virginia University, Institute of Technology, *2013-2014 College Catalog*, pp. 213, 2013 [Online]. Available: http://techregistrar.wvutech.edu/r/download/179715 [Accessed Aug. 16, 2014]

[16] P. Idowu, Penn State University – Harrisburg, *Power Systems Protection Laboratory through University –Industry Partnership*, pp. 6, 2012 [Online]. Available:http://www.ece.umn.edu/groups/power/faculty_workshops/Feb12_napa/Posters/Power_Systems_Protection_Laboratory_through_University_Industry_Partnership.pdf [Accessed Aug. 18, 2014]

[17] P. Selvan and R. Anita., "Revelation For New User To Select Power System Simulation Software." *Journal of Asian scientific Research*, vol. 1(7), pp. 366-375, Nov. 2011 [Online] Available: http://www.aessweb.com/pdf-files/jasr-1(7)-pp-366-375.pdf

[18] S. Li, "A Comparative Study of Power System Simulation Based on MATLAB and ETAP", *Journal of Nanjing Institute of Technology :Natural Science Edition*, Vol.4(2), pp.50-55 , Jun. 2006

[19] K. Rudion, Z.A. Styczynski, N. Hatziargyriou, and S. Papathanassiou, "Development of benchmarks for low and medium voltage distribution networks with high penetration of dispersed generation," *Proceedings of 3rd International Symposium on Modern Electric Power Systems*, Sep. 6-8 2006, Wroclaw, Poland.