Role of Step-by-step Laboratory Experiments in the Education of Sustainable Energy Technologies

Huiqing Wen

Department of Electrical and Electronic Engineering, Xi'an Jiaotong-Liverpool University (XJTLU), Suzhou 215123, China (Email: Huiqing.Wen@xjtlu.edu.cn).

Abstract

This paper presents an attempt to improve the education quality of power electronics and sustainable energy by building an experimental environment for both undergraduate and graduate students. A real renewable energy system including PV modules, vertical-axis wind turbine and batteries is adopted. Industry-standard tools including Matlab, PSPICE, DSP, and dSPACE are used to design, test, and evaluate the performance of sustainable energy systems. Unique experiments are designed in order to meet various levels of teaching requirements. Results from the students' performance in laboratory experiments are presented to verify the effectiveness of the proposed method.

***Index Terms*—University Teaching; Power Electronics; MPPT; Full-Bridge Converter**

INTRODUCTION

Due to the concerns of energy crisis and environment pollution, sustainable energy including Solar, Wind Turbine, and Electric Vehicle is experiencing a rapid development. As the efficient energy transformation and control technology, power electronics become more and more important, which also brings some concerns about the education quality in power electronics and sustainable energy sector (Drofenik & Kolar, 2002; Jennings & Lund, 2001; Rojko & Spaner, 2013). A research conducted by European vocational training society shows that a lack of competent workforce can slow down the development of sustainable energy in European (Strietska-Ilina et al, 2011). In China, there is a rapidly growing need for students with power electronics and sustainable energy knowledge due to the quick growth of economy (Shijie, 2009; Yao et al, 2005; Cherni & Kentish, 2007; Geng et al, 2010). Thus, teaching materials and methods are required to update accordingly to adapt the quick development of technologies and meet various training requirements. Multimedia, interactive method using virtual experiments and e-learning material is proposed for lifelong education and self-education (Rojko et al, 2014). A step-by-step project based education method in electric vehicle lectures is discussed by Takahashi & Uda (2013). For graduate-level education, problem-based learning method is proposed in wind energy courses (Santos-Martin et al, 2012).

Although remote courses by using virtual laboratories can reach a wider audience in engineering education, a real laboratory environment is still irreplaceable in universities considering the truly hands-on experiences required in solving realistic sustainable energy design problems. The problem-solving skills or experiences in the field of power electronics and sustainable energy are emphasized by companies, which push universities to increase the investment in the infrastructure and equipment of laboratories.

This paper presents an attempt to improve the education quality of power electronics and sustainable energy by building an experimental environment. The laboratory experiments are well-designed considering the different teaching requirements for both undergraduate and graduate students. Both advanced experimental equipments including PV simulator, Wind Turbine testbench, and Power Analyzer along with industry-stand tools such as Matlab, PSPICE, and dSPACE are provided for students to design, test, and evaluate the performance of sustainable energy systems.

1. LABORATORY EQUIPMENT AND FACILITIES

There are three key laboratory platforms involved in this teaching innovations: universal power electronics lab platform; sustainable energy generator platform including 600W wind turbine, two 270W solar modules, batteries, inverter with sinusoidal output and main controller; and digital control platform including dSPACE, DSP and FPFA.

As shown in Fig. 1(a), the universal power electronics lab platform is of modular structure and consists of a basic unit, optional experimental units and a metal framework desk. It can test the switching characteristics of different power electronics devices including thyristor, MOSFET, IGBT and their drive protection circuits. Typical power electronics circuits like AC-DC converter, DC-DC converter, DC-AC inverter with various PWM strategies can be tested and evaluated.

The sustainable energy generator platform is shown in Fig. 1(b). Vertical Wind turbine with Carbon Fiber blade and Permanent Magnet generator are used and located on the rooftop of our department building. To ensure the safety of the equipment, various protection strategies including over-charge protection, short-circuit protection, pole-confusion protection and automatic diversion load function are adopted.

(a)

(b)

Fig. 1 Key laboratory platforms. (a) Universal power electronics lab platform; (b) Sustainable energy generator platform.

The purpose of digital control platform is to implement and evaluation different control strategies. The dSPACE DS1104 is used for data collection and control implementation via its interface with Simulink in order to simplify the programming process and enable students speed up learning progress. Furthermore, students can gain field project experiences thanks to the widely usage of these tools in industry.

2. Laboratory Exercises

TABLE I shows a list of laboratory exercises including three simulation works, two basic tests, and one final project. Students can choose one topic from two options. This series laboratory exercises are expected to achieve two intended outcomes: be knowledgeable in the fields of power electronics and sustainable energy; grasp the ability to design power converter and tackle some problems in real energy converters.

TABLE I LABORATORY EXERCISES

Number	Type	Exercise Title	Tools or Equipments	Purpose
1	Simulation	Basic Modules of Simulink, Pspice, Psim, and dSPACE	Simulink, Pspice, Psim, dSPACE	Familiar with software, DLL programming, Control Implementation

2	Simulation	Battery Management in PV Power System	Simulink, Pspice, Psim, dSPACE	PV modeling, MPPT control, Buck converter, PWM control, Battery Charging Control
3	Simulation	DFIG Wind Turbine System	Simulink, Pspice, Psim, dSPACE	Active and reactive po wer control, Maximum Wind Energy Capture, Fault Ride Through
4	Basic Test	Characteristics of SCR, GTO, MOSFET, GTR, and IGBT	Power Electronics Lab	Operating Characteristi cs of various power devices, Drive and Protection Circuit
5	Basic Test	Phase-shift ZVS PWM Soft Switching Technique	Power Electronics Lab	PS-ZVS-PWM topology and control strategy
6	Final Option 1	Soft-switching Current-fed Half-bridge Converter	DSP, High Power Voltage Sour ce	DSP Programming, PWM, Control, Oscilloscope
	Final Option 2	MPPT control strategies in PV system	dSPACE, Auxiliary Power Supply, PV simulator	MPPT control, PV Array Properties, Boost Converter Design

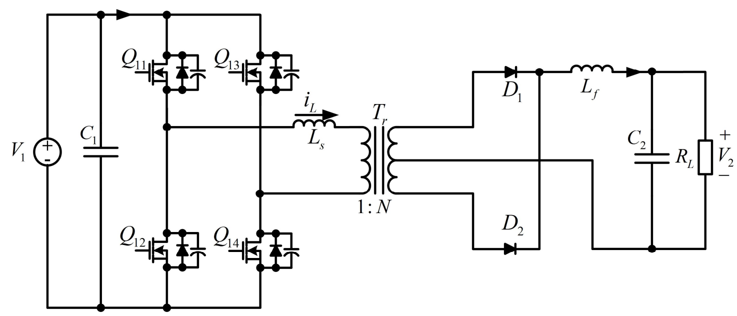
Take the basic test of "Phase-shift ZVS PWM Soft Switching Technique" as example to show the implementation process:

1) Several questions asked about the basic concept: three questions are raised here: what's the ZVS soft-switching? What are the typical operating modes in a switching period? How to implement the phase-shift

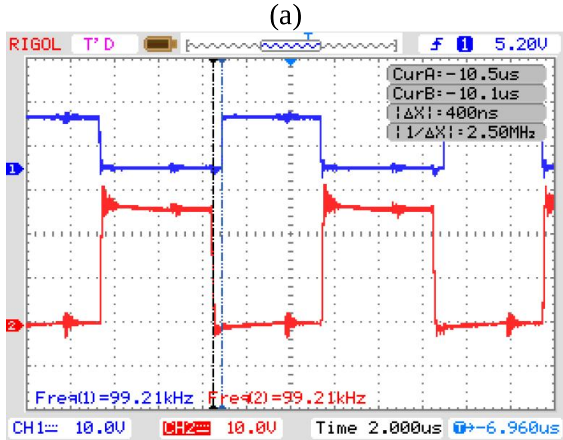
in UC3895?

2) Simulation results preview: students are asked to set up the simulation model and get the simulation results before the test.

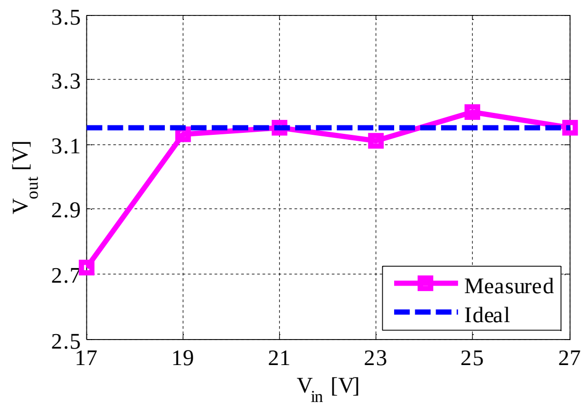
3) Experimental results analysis: students are asked to show their experimental results and give detailed analysis. Fig. 2 shows the main circuit and experimental results from this test. Fig. 2(b) shows the experimental result about ZVS soft-switching. Students should know how to illustrate the realization of ZVS soft-switching. Furthermore, compared with simulation results, the experimental results are always non-ideal, as shown in Fig. 2(c), including the switching spike and ringing, output voltage and current ripple compared with simulation results. These phenomena will inspire students to consider the effects of deadtime and the parasitic parameters.



(a)



(b)



(c)

Fig. 2 Basic Test of PS-ZVS DC/DC converter. (a) Circuit; (b) Experimental ZVS soft-switching waveform; (c) Measured relationship of V_{in} vs V_{out}.

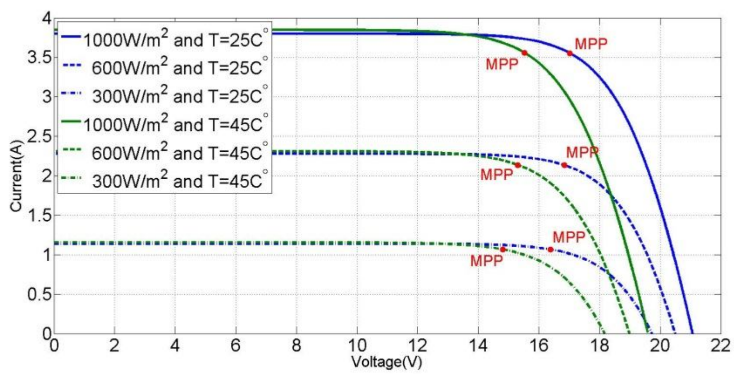
3. CASE STUDY FOR FINAL PROJECT

The students can choose one project from two options: Soft-switching Current-fed Half-bridge Converter and MPPT control strategies in PV system. Before the test, students are required to give a brief summary of the problem statement and design requirements. Take the second final project option as example, students should know the effects of irradiation and temperature on PV characteristics through simulation exercises. The electrical power output from a PV module depends on the atmospheric conditions such as irradiance and cell temperature. However, PV manufacturing datasheets only provide certain electrical parameters, such as the open-circuit voltage V_{oc}, the short-circuit current I_{sc}, the voltage at the MPP V_{mpp}, the current at the MPP I_{mpp}, the temperature coefficients of open-circuit voltage K_v and short-circuit current K_i. Furthermore, these parameters are only available at standard test condition(STC), namely 1000W/m^2 for irradiance and 25° for cell temperature. Therefore, accurate and easy-to-implement modeling of the PV source is essential for the prediction of energy production from a photovoltaic panel under all conditions, as well as for the design of the MPPT methods. In this report, the Solarex MSX-60W was modeled as the PV source. The electrical characteristic specifications under the STC from the manufacturer datasheet are shown in TABLE. II.

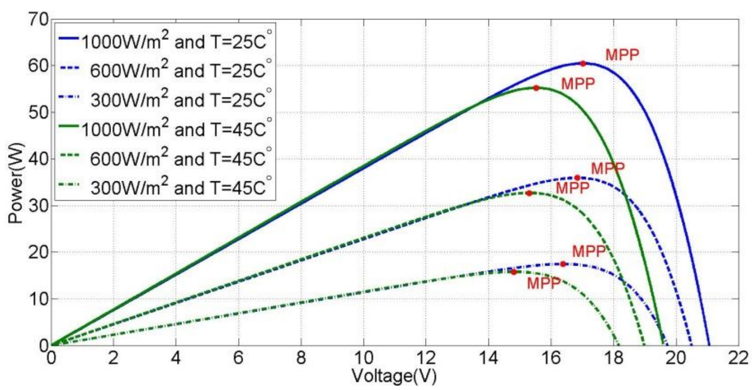
TABLE II: THE ELECTRICAL CHARACTERISTICS OF THE MSX-60W

Parameter	Variable	Value
Maximum power	P_{mpp}	60W
Voltage at maximum power	V_{mpp}	17.1V
Current at maximum power	I_{mpp}	3.5A
Open-circuit voltage	V_{oc}	21.1V
Short-circuit current	I_{sc}	3.8A
Temperature coefficient of V_{oc}	K_v	−80mV/°C
Temperature coefficient of I_{sc}	K_i	0.065%/°C

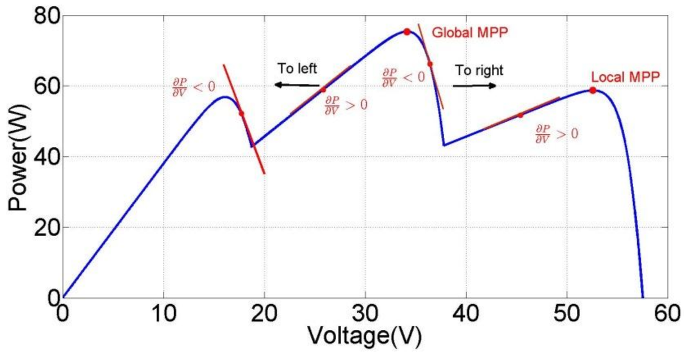
Students should know the difference of local MPP and global MPP due to shadow effect, as shown in Fig. 3(c). Various MPPT strategies should be compared in terms of dynamic response and steady-state errors.



(a)



(b)



(c)

Fig. 3 Characteristics of PV modules. (a) I-V curve; (b) P-V curve; (c) Local and global MPP.

After students finish the basic test of "Phase-shift ZVS PWM Soft Switching Technique", they have the ability to design a dc/dc converter to regulate the output power of PV module. Students can select a MPPT algorithm by themselves such as "Hill Climbing" method, "Perturb and Observer" method, or other advanced methods. The MPPT methods will firstly be simulated in Simulink and the dSPACE will be adopted to implement control strategy and collect data.

In order to compare the performance between the basic MPPT methods and the conventional Beta method, a diagram of the complete MPPT system in Matlab/Simulink is shown in Fig. 4, which includes the PV module, the Boost circuit and the MPPT controller.

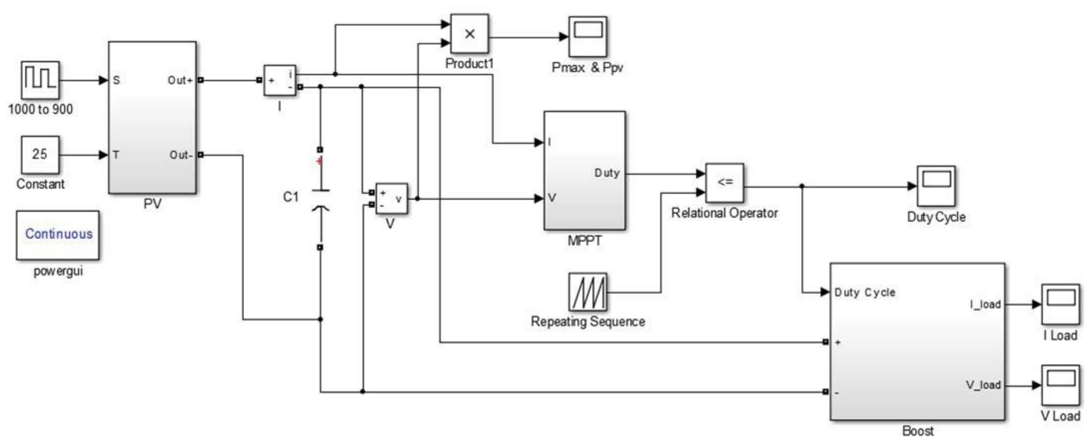


Fig. 4 The diagram of the complete MPPT system in MatLab/Simulink

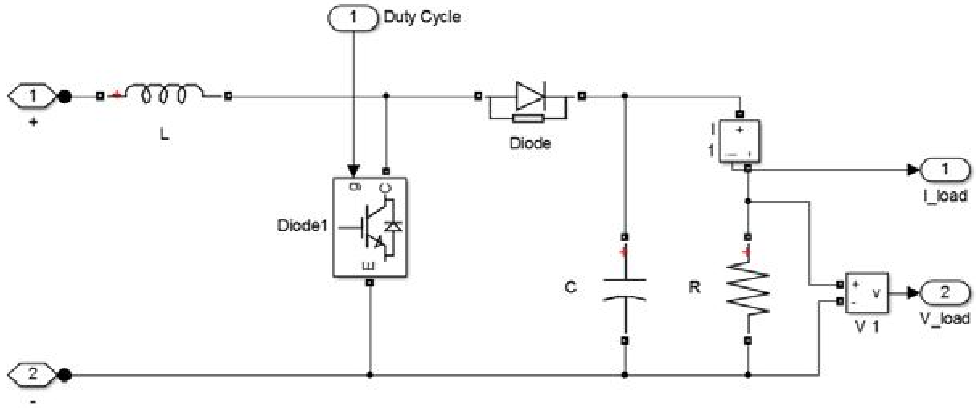


Fig. 5 The diagram of the boost circuit

The diagram of the boost circuit is shown in Fig. 5 and the simulation specification is as follows:

- Capacitor C1 (PV side) = 470uF

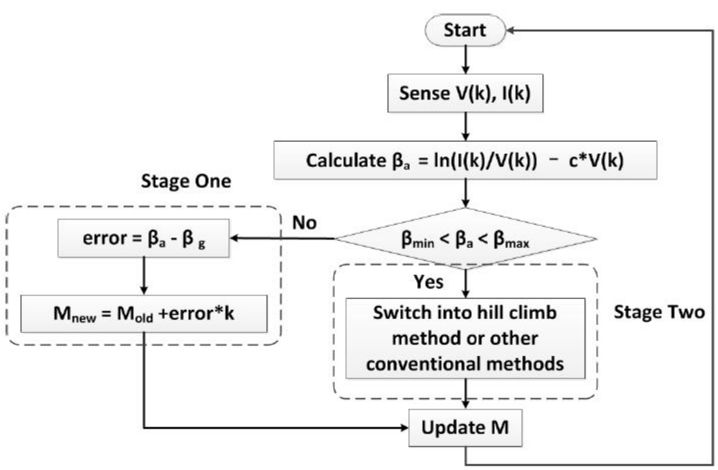
- Inductor L = 0.1mL

- Capacitor C (Boost circuit) = 47uF

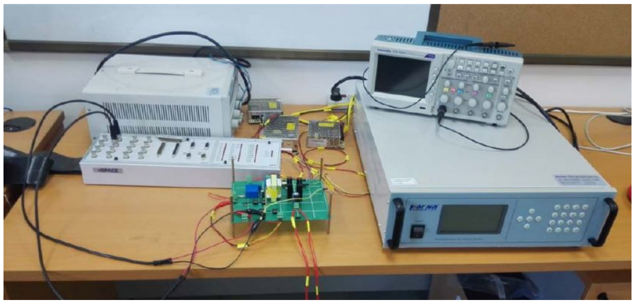
- Resistance load R (Boost circuit) = 87Ω

- switching frequency (IGBT) = 10 kHz

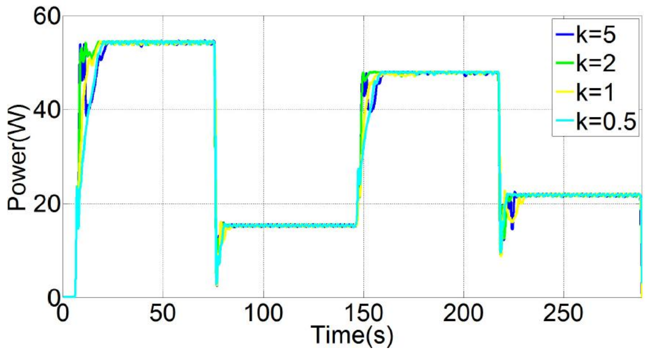
Through these laboratory exercises, students can finish the programming independently. Fig. 6 (a) shows the control flow chart of a beta-parameter-based MPPT method which is adopted by one master student. Fig. 6(b) shows the experimental setup and main experimental results are illustrated in Fig. 6(c), which shows the effect of one parameter, *k*.



(a)



(b)



(c)

Fig. 6 MPPT using dSPACE. (a) Control flow chart; (b) Experimental setup; (c) Main experimental results with different parameter *k*.

4. Discussion and Conclusion

Two aspects are discussed for the effects of the proposed method. TABLE III shows the comparison of key knowledge required in the module of "photovoltaic energy technology". TABLE III shows that through experiments-based teaching method, students show fully understand the operating features of solar cells and a complicated solar power system. Furthermore, students master the skills required to Tackle some problems of energy conversion using batteries and solar cells, design a complicated photovoltaic system, which are important for them in future job careers. Fig. 7 illustrates the improvement from the students' feedback.

TABLE III
Comparison of knowledge required in the module of "photovoltaic energy technology"

Knowledge Points	Conventional Methods	Proposed Method
Be knowledgeable about solar cell s	Only basic description	Fully understand the features through simulation
Analyze solar radiation in energy terms.	Basic Level	Fully understand the features through simulation
Design and operation of a photovo ltaic system	Knowledge level	Design level through simulati on and experiments
Identify and size a photovoltaic sy stem for a given application	Knowledge level	Design level
Tackle some problems of energy c onversion using batteries and sola r cells.	Knowledge level	Design level with lots of field experience
Describe the fundamentals of phot ovoltaic energy conversion	Basic Level	Advanced level, clearly know a complicated system

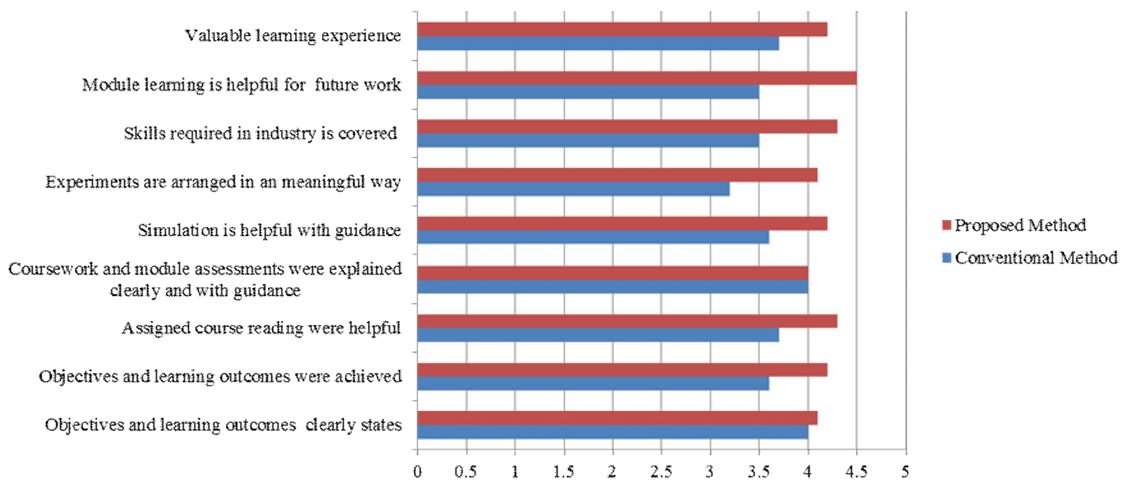


Fig. 7 Students' Perception on the learning outcome of the module

This paper has presented a successful laboratory course on power electronics and renewable energy. The laboratory experiments are well-designed considering the different teaching requirements for both undergraduate and graduate students. This teaching method will provide students opportunities to use real renewable energy generation systems. Both advanced experimental equipments including PV simulator, Wind Turbine testbench, and Power Analyzer along with industry-stand tools such as Matlab, PSPICE, and dSPACE are provided for students to design, test, and evaluate the performance of sustainable energy systems.

REFERENCES

Drofenik, U., & Kolar, J. W. (2002). Survey of modern approaches of education in power electronics. In Applied Power Electronics Conference and Exposition, 2002. APEC 2002. Seventeenth Annual IEEE (Vol. 2, pp. 749-755). IEEE.

Jennings, P., & Lund, C. (2001). Renewable energy education for sustainable development. Renewable Energy, 22(1), 113-118.

Rojko, A., & Spaner, M. (2013, November). Education in sustainable energy for professionals from industry and teachers. In e-Learning in Industrial Electronics (ICELIE), 2013 7th IEEE International Conference on (pp. 108-113). IEEE.

Strietska-Ilina, O., Hofmann, C., Haro, M. D., & Jeon, S. (2011). Skills for green jobs: a global view: synthesis report based on 21 country studies.

Shijie, X. I. A. O. (2009). Consideration of technology for constructing Chinese smart grid [J]. Automation of Electric Power Systems, 9(33), 1-4.

Yao, R., Li, B., & Steemers, K. (2005). Energy policy and standard for built environment in China. Renewable Energy, 30(13), 1973-1988.

Cherni, J. A., & Kentish, J. (2007). Renewable energy policy and electricity market reforms in China. Energy Policy, 35(7), 3616-3629.

Geng, Y., Lipei, H., Dehong, X., & Honglin, Z. (2010, June). States on education of power electronics and electrical drive in China's university. In Power Electronics Conference (IPEC), 2010 International (pp. 1101-1104). IEEE.

Rojko, A., Spaner, M., & Hercog, D. (2014, February). Sustainable energy education: Hybrid electric vehicles.

In Remote Engineering and Virtual Instrumentation (REV), 2014 11th International Conference on (pp. 332-338). IEEE.

Takahashi, Y., & Uda, K. (2013, October). Project based learning using natural energy powered small electric vehicle for sustainable technology education. In Control, Automation and Systems (ICCAS), 2013 13th International Conference on (pp. 788-793). IEEE.

Santos-Martin, D., Alonso-Martinez, J., Eloy-Garcia Carrasco, J., & Arnaltes, S. (2012). Problem-based learning in wind energy using virtual and real setups. Education, IEEE Transactions on, 55(1), 126-134.