

Circuit Analysis for Undergraduates

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ABSTRACT—

This paper presents the outcome-based education about solar cells in the course of EECC0292 Engineering Laboratory using basic electric circuit analysis. It focuses on deploying problem-based learning and active learning. This is a result-oriented learning scheme that centers on the engineering undergraduates and instructors will be responsible for organizing learning process through activities concerned about solar cell based on active learning. The objective of this approach is to understand and develop the knowledge skills of students in the hard and soft skills.

Keywords—Outcome-based learning, Problem-based learning, Solar cells, Basic electric circuit analysis

1. INTRODUCTION

In recent year, education in this recent has been shifted to a new model in higher education from focusing on teaching to learning. Universities in many countries pay attention to improving their tertiary education in order to produce graduates who are knowledgeable, creative and innovative. Outcome-based education (OBE) approach has gained more attention over the years to improve the quality graduate engineers as presented in [1] - [4].

In [1], the OBE approach has been proposed for civil engineering students after the learning process in the level of awareness and understanding the OBE implementation, which shows that students have opportunity to develop both the technical skills (or hard-skills) and non-technical skills (or soft-skills such as communication and lifelong learning skills) through the

active learning activities.

According to the OBE emphasis on student involvement, students are expected to actively participate in the learning activities instead of traditional education methods like passively memorizing knowledge. The impact of OBE method has been investigated in software technology and application program, which can improve the learning effectiveness of students in problem solving capability in software design and implementation [2].

The outcome-based education using KAPIS evaluation in Thailand was applied in the Electric Circuit Analysis course [3] for engineering undergraduates. KAPIS evaluation consists of knowledge, analytical thinking, practical, innovation and soft skills. In [4], an outcome-based education in the biomedical electronics course using problem-based and project-based learning was proposed. Thailand Qualification Framework (TQF) [5] is to evaluate the outcome of these activities.

Solar energy resources on Earth are prodigious and nonpolluting. Magnitude of solar radiation as an energy source depends on the geographical location. In only one hour, the amount of solar energy that shines on the Earth equator to the amount used by the world's population in an entire year [6]. In [7], solar energy utilization used a locally designed solar concentrator for project-based learning among Nigerian science students in Anambra State, Nigeria, West Africa. This study showed an experiment were in which participants asked to design a solar concentrator using locally available materials to generate high temperatures at the focal region of the concentrator where the absorber was positioned.

This paper introduces how OBE approach can be implemented to improve the study of understanding about solar cell using basic electric circuit analysis in the

compulsory course of EECC0292 Engineering Laboratory for engineering undergraduates.

2. OUTCOME-BASED EDUCATION

Technology-enabled OBE model is a teaching-centric and goal-oriented approach which is intended to help lecturers creating outcome-based curriculum to facilitate learning pathway and to design courses.

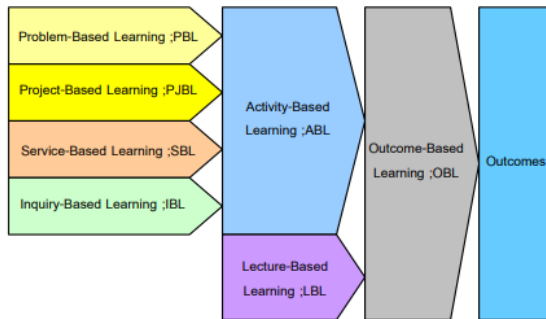


Fig. 1 Relation of outcome-based education and other learning [3]

When instructors create assessments that are standards based and outcome-based learning activities mapped with the outcomes, they need to provide learning activities to promote critical thinking and innovation to achieve things they will be able to do at the end of the course as appropriate for the subject matter and the lecture will become an activity in a variety of activities. Relation of outcome-based education and other learning schemes is depicted in Fig. 1.

3. SOLAR PHOTOVOLTAIC SYSTEMS

Since they produce electricity from light, solar cells are also called photovoltaic (PV) cells (“photo” is Greek for light and “volt” is a unit of electricity). A photovoltaic cell works by capturing a photon from the Sun using semiconductors. When a photons hits a semiconductor, it creates electron-hole pair producing electricity. A semiconductor to build solar cells, we can generate electricity from sunlight [8], [9].

Discrete packets of light energy known as photons, strike the PV cell, knocking the electrons in the silicon material out of their normal energy state, putting them in a position to be conducted as electricity. This phenomenon is exploited in the individual solar cell on wafers of silicon.

A solar cell is an electronic device which can use photovoltaic (PV) effect to directly convert sunlight into electricity. Light shining on the solar cell produces both voltage and current to generate electric power. A typical

schematic diagram of the silicon solar cell [10] is shown in Fig. 2.

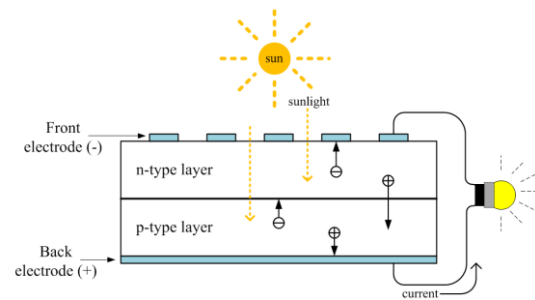


Fig. 2 Photovoltaic effect in a silicon solar cell.

A. Current-Voltage and Power-Voltage curves

Current-Voltage (I-V) and Power-Voltage (P-V) characteristic curves are used to show the electrical performance of a solar panel. This allows the end user to determine where the "maximum power point" (MPP) of the particular solar panel is. PV cells have a nonlinear voltage-current characteristic curve, where the I-V relationship spans the short-circuit current (I_{SC}) at zero volts, all the way to zero current at the open circuit voltage (V_{OC}) as shown in Fig. 3, where P_{max} is the maximum power point, while I_{mp} is the current and V_{mp} is the voltage at the maximum power point.

A current-voltage (I-V) curve shows the possible combinations of current and voltage output of a solar cell. A solar cell produces its maximum current when there is no resistance in the circuit, i.e., when there is a short circuit between its positive and negative terminals.

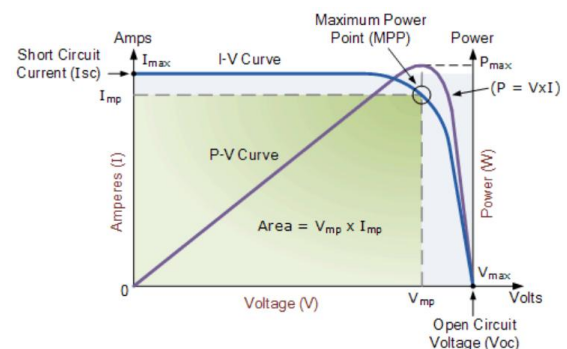


Fig. 3 Typical current-voltage (I-V) and power-voltage (P-V) characteristic curves between $V=0$ and $V=V_{oc}$.

Source from: <http://www.alternative-energy-tutorials.com/energy-articles/solar-cell-i-v-characteristic.html>

B. Series -Connected Solar Cells

In a standard PV panel, these solar cells are connected together in **series**, resulting in high voltage

but the same value of current flows through all the connected cells as shown in Fig. 4. As long as the sunlight hitting the surface of the PV panel is uniform, each photovoltaic cell within the same panel will produce the same amount of electrical voltage, approximately 0.5 volts. For instance, at full sun a 2 watt PV cell produces a constant current of about 4 amperes, ($0.5 \times 4 = 2$ watts).

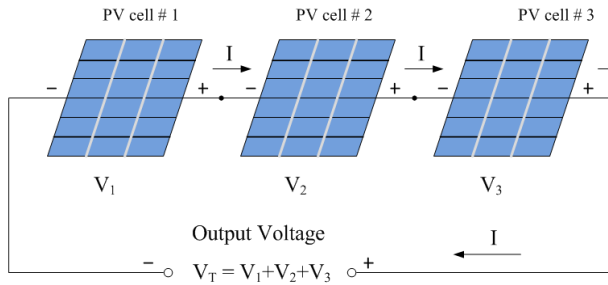


Fig. 4 Series-connected PV cells schematic and its I-V curve

In Fig. 4, the three PV cells are connected in series, hence the generated current (I) is the same (assuming the cells are evenly matched). The total voltage, V_T is the sum of individual cell voltage, ($V_1 + V_2 + V_3 = 0.5V + 0.5V + 0.5V = 1.5V$), thus the I-V characteristic curves of the three cells are simply added along the voltage (horizontal) axis as the current is common and constant. Using aforementioned 2-watt cell example, the maximum power point for this series string would be 6 watts ($1.5V \times 4A = 6W$).

C. Parallel- Connected Solar Cells

Connecting solar panels in parallel boosts the total system current and is the reverse of the series connection [10]. Parallel wiring means connecting all the positive terminals together (positive to positive) and all of the negative terminals together (negative to negative) until you are left with single positive and negative connection to attach to your regulator and batteries.

When the solar panels are connected in parallel, the total voltage output remains unchanged as it does for a single panel, but the output current becomes the sum of the outputs of each panel as shown in Fig. 5.

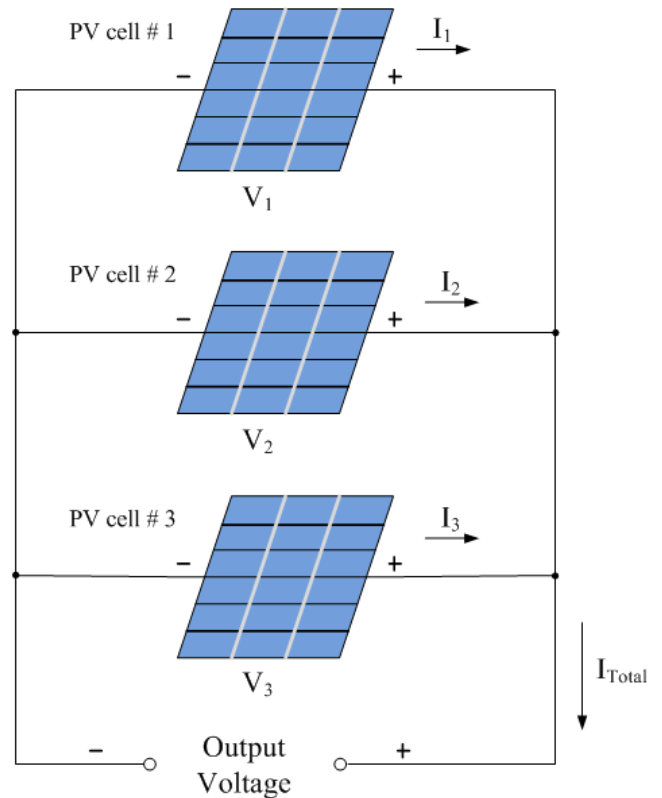


Fig. 5 Parallel-connected solar cell

Photovoltaic panels can be wired or connected in either series or parallel combinations to increase the voltage or current capacity of the solar array as shown in Fig. 6. If the array panels are connected in a series combination, the voltage increases. If they are connected in parallel, the current increases.

The electrical power generated by these different photovoltaic combinations is the product of the voltage times the current. However the solar panels are connected, the upper right hand corner will always be the maximum power point (MPP) of the array.

4. OHM'S LAW AND POWER

Ohm's law relates voltage, current, and resistance. Ohm's law states that when a voltage (V) is applied across a resistance (R), a current (I) shall flow across that resistance. This relationship is expressed as

$$V = I \times R, \quad I = \frac{V}{R} \quad (1)$$

where V is voltage in volt (V), R is resistance in ohm (Ω) and I is current in ampere (A).

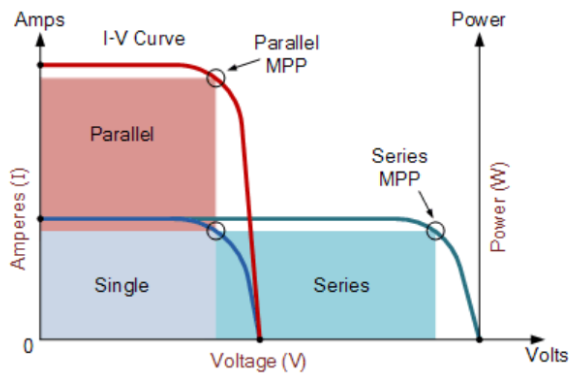


Fig. 6 Series and Parallel connected Solar cell I-V characteristic curves

Source from: <http://www.alternative-energy-tutorials.com/energy-articles/solar-cell-i-v-characteristic.html>

Power is energy per unit time and is defined as the voltage times the current, at as any given point in time, and can be written

$$P = I \times V \quad (2)$$

where P is power in watt (W).

5. METHODOLOGY FOR OBE APPROACH BASED ON PROBLEM-BASED LEARNING

In this section, an overview of OBE method using problem-based learning with the case study on engineering laboratory for undergraduate is proposed.

D. Overview of OBE method

The student-centered learning development of OBE method is consisting of two parts as

- 1) Students can measure voltage and current on solar panel through the basic concept of Ohm's law using the basic electronic workbench for improving their hard skills.
- 2) Students can collaborate with other member to improve communication and team work skills.

Based on the above OBE method, the learning outcomes have been identified as shown in Table I and evaluated this OBE in the course of EECC0292 Engineering Laboratory in 2018.

E. Case study on Engineering Laboratory

Experiments on solar cells consist of series and parallel connection. There are three outcome-based key-points for organizing the laboratory-based course of EECC0292 Engineering Laboratory of 2018 cooperated with activity-based and project-based learning as follows.

- 1) To separate into small groups with 2 or 3 members per group working with a team of lecturers whose role is to motivate and support these students.
- 2) To guide the students by using basic concept of ohm's law for understanding the solar I-V characteristic curves with series and parallel connection.
- 3) After end of laboratory, to answer questions concerning the trends of electricity use and energy.

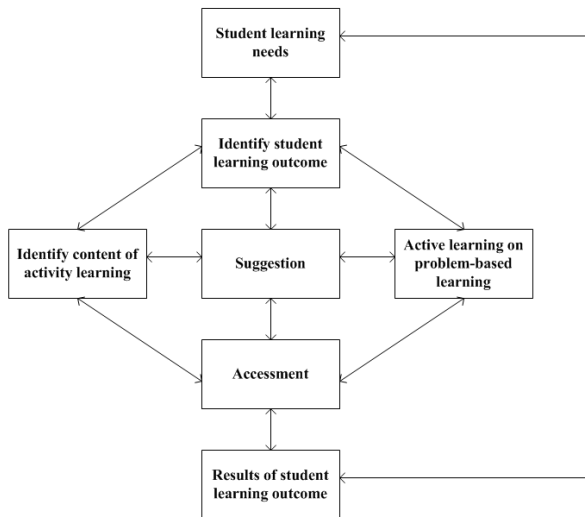
Details of experiment about solar cell implementing OBE method are described in Table II. The standard test condition (STC) is used to specify a cell temperature of 25°C and an irradiance of 1000 W/m² with an air mass of 1.5 (AM1.5) [11].

Table 1 student learning outcomes

No.	Outcome description
1	Apply fundamental knowledge of mathematics and basic electric circuit analysis.
2	Determine the requirements appropriate for the experiments.
3	Function effectively as a team member to accomplish a target.
4	Give effective with oral test.

Table 2 Details of experiment about solar cell

Topic	Activity
Characteristic of solar cell	To find I-V curve when loaded, short circuit and open circuit using the set of basic electronic workbench as Oscilloscope, Digital Multimeter and DC Power Supply.
Characteristic of solar cell connected in series	To find I-V curve when loaded, short circuit and open circuit.
Characteristic of solar cell connected in parallel	To find I-V curve when loaded, short circuit and open circuit.
Ohm's Law	To find the maximum power (P_{max}), short circuit current (I_{sc}) and open circuit voltage (V_{oc})

**Fig. 7** Flow chart of the proposed outcome-based education.

6. RESULTS AND EVALUATION

The flow chart of learning process based on the outcome-based education approach is shown in Fig. 7 as modified from [3]. Figs. 8-9 show the example of Labsheet for series and parallel connected solar panel. The evaluated test results of engineering problem-solving skill development for undergraduate students is shown in Table III. Mean scores is 91.25 of this course related to the performances of students.

In general, all students feel enjoy and interest in activities used in course as shown in Figs.10 - 13. To observe and answer the questions, the questionnaire following on the Thailand qualification framework (TQF) [5] is to meet the learning outcomes. Their outcomes are based on active-learning and problem-based learning in which they can enhance their students' skills.

Average value of this course from questionnaire in 2018 is 4.65 of 5.00 from 4 indicators of TQF as 1) Numerical Analysis, Communication and Information Technology Skills, 2) Knowledge, 3) Cognitive Skill and 4) Interpersonal Skills and Responsibility.

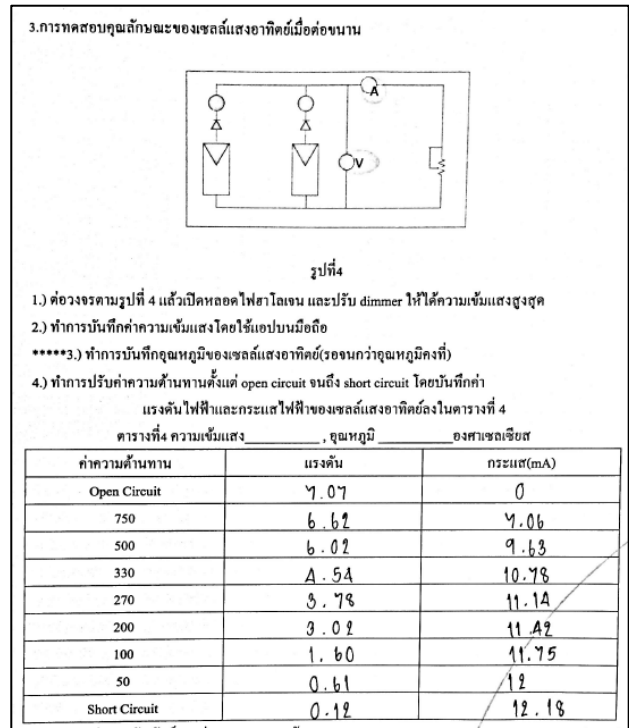
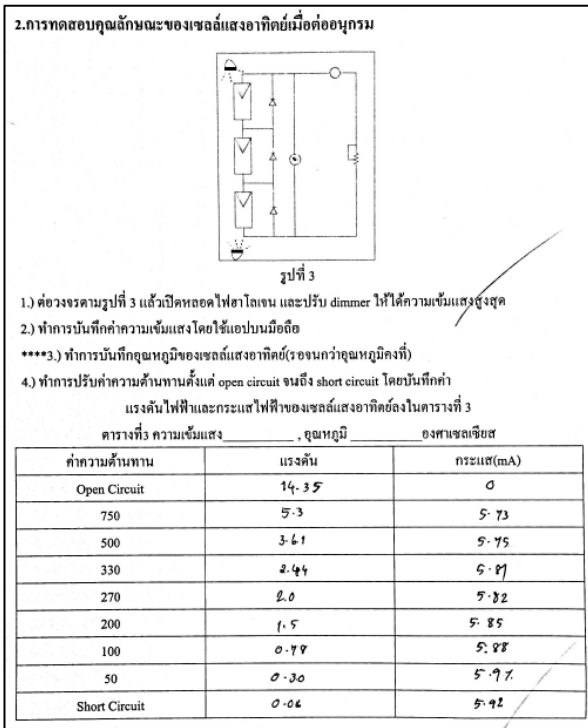
Table 3 Evaluated results from raw score of 96 students in the course of EECC0292 engineering laboratory in 2018.

Type of score	Score
Full score	100
Maximum score	97.20
Minimum score	39.77
Mean score	91.25
Standard deviation	7.81

7. CONCLUSION

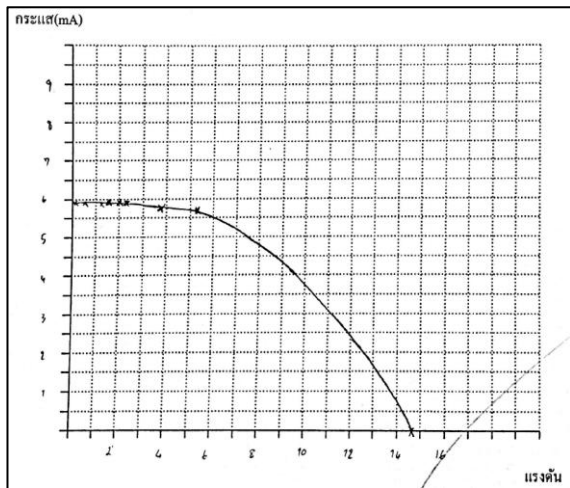
Outcome-based education approach is a tool of educators for enhancing the engineering problem-solving skills and soft-skills. The experiments explain how light can be converted into useful electrical energy. Techniques for measuring and understanding the availability of the solar resources are used with the basic concept of Ohm's law.

It can improve process of learning in the engineering with attention. This helps the students feel interested in study and work. Mean scores are used to determine the average performances of students. The concept of active learning and problem-based learning is continuously developed by OBE-assignment and activities in the engineering.

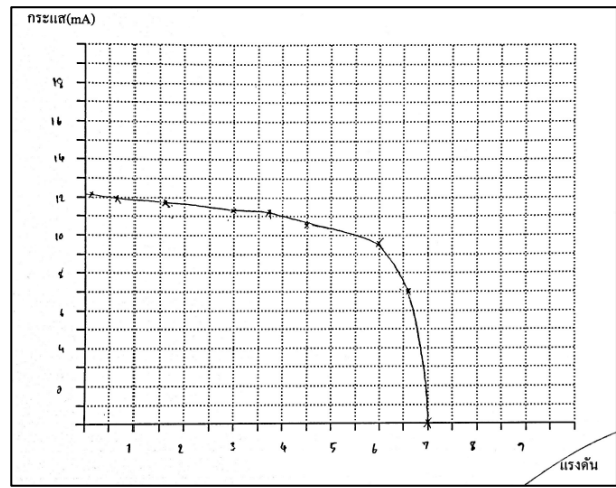


a) Labsheet for charateristic of **series** connected solar panel

a) Labsheet for charateristic of **parallel** connected solar panel



b) Graph of I-V characteristic curve



b) Graph of I-V characteristic curve

Fig. 8 Example of Labsheet for **series** connected solar panel

Fig. 9 Example of Labsheet for **parallel** connected solar panel

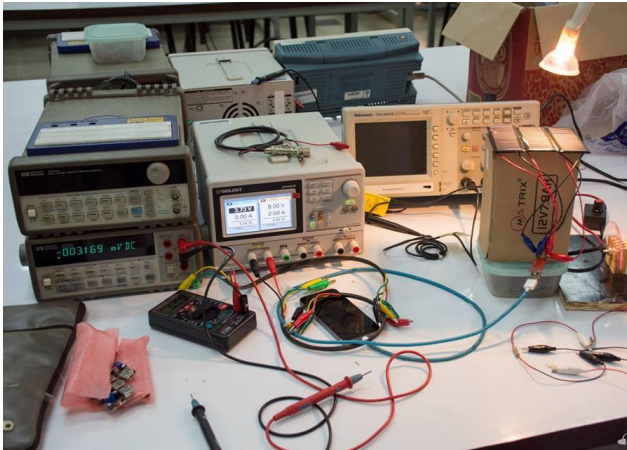


Fig. 10 Electronic workbench equipment used



Fig. 13 How to measure voltage and current



Fig. 11 How to test the solar panel



Fig. 12 How to test the solar I-V characteristic

8. ACKNOWLEDGMENT

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REFERENCES

- [1] C.M.M.Isa, W.Tahir, H.M.Saman, J.Jani, and M. Mukri, "Understanding of Outcome-Based Education (OBE) Implementation by Civil Engineering Students in Malaysia", in *Proc. IEEE International Conference on Engineering Education*, pp. 96-100, Nov. 2017.
- [2] Dai, W. Wei, H. Wang, and T. Wong, "Impact of Outcome-Based Education on Software Engineering Teaching: a Case Study", in *Proc. IEEE International Conference on Teaching, Assessment, and Learning for Engineering*, Hong Kong, pp. 261-264, Dec. 2017.
- [3] P.Duchsuwan, "Outcome-based Education using KAPIS Evaluation (in Thai)", *Engineering Transactions*, vol. 2, no. 1 (44), Jan-Jun 2018, pp. 99-109.
- [4] S.Witthayapradit, "Model based on Outcome-based Education for Biomedical Electronics of Mahanakorn University of Technology (in Thai)", *Engineering Transactions*, vol. 2, no. 1 (44), Jan-Jun 2018, pp. 90-98.
- [5] Office of Higher Education Commission, "National Qualifications Framework for Higher Education in Thailand", Implementation Handbook, November 2006. Available source at <http://www.mua.go.th/users/tqf-hed/news/FilesNews/FilesNews8/NQF-HED.pdf>, Access on March 30, 2019.
- [6] A.F.Zobaa, R.C.Bansal, "Handbook of Renewable Energy Technology", World Scientific, 2011.
- [7] O.M Felicia, E.C. Innocent, "Project-Based Learning And Solar Energy Utilization Using Locally Designed Solar Concentrator: Encouraging Sustainable Development Practices Among Nigerian Science Students", *PUPIL: International Journal of Teaching, Education and Learning*, vol. 1, issue. 1, pp. 28-50, 2017.
- [8] G.Boyle, "Renewable Energy: Power For A Sustainable Future", Oxford University Press, 2012.

- [7] A.V.da Rosa, "Fundamentals of Renewable Energy Processes", Academic Press, 2013.
- [8] Q.Su, G.Zhang, J.Lai, S.Feng and W.Shi, "Green Solar Electric Vehicle Changing the Future Lifestyle of Human", World Electric Vehicle Journal, vol. 4(1), pp. 128-132, Jan. 2011.
- [9] "Standard Test Conditions (STC): definition and problems", Nov. 4, 2011. Retrieved from <https://sinovoltaics.com/learning-center/quality/standard-test-conditions-stc-definition-and-problems/>