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Design and Practical Experience in Power Electronics Project Based Learning Approach at UKM

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Teaching and learning of power electronics courses typically involves various activities such as circuit design, circuit development and circuit testing for predetermined application. To comply with the course outcome assessment, a project based learning (PBL) methodology has been introduced in the course. This PBL requires the design, development and testing of a Buck converter circuit to be carried out by a group of students. The PBL project initiates with a design of Buck converter circuit model based on MATLAB Simulink tool. Next, a construction of Buck converter circuit prototype is carried out and followed by a demonstration of prototype performance to validate it. Additionally, this includes an oral presentation and a report submission. In order to motivate the students, a design competition is organized. The practical experience gained from the proposed PBL has increased student comprehension of and interest in power electronics application and studies. As a result, the students showed improvement in their practical skills e.g. assembling, constructing and tuning the Buck converter circuit. With practical experience in hand, students have better self-confidence and competencies which lead to significant improvement in practical engineering skills.

Key words: Power electronics, project-based learning, Buck converter, design competition, demonstration.

Introduction

Previously, a guided based laboratory was implemented in the power electronics course offered to final semester students of electrical and electronics program by the Department of Electrical, Electronics and System Engineering, (JKEES) Faculty of Engineering and Built Environment, (FKAB), National University of Malaysia (UKM) (FKAB, 2011). However, recently the guided based laboratory has been replaced by a problem-based learning (PBL) project that is embedded in the power electronics course (Yusof, Zaim & Arsad, 2016). The main motivation for the replacement is because some students were found to duplicate past year's reports. This behaviour should not be tolerated since it can be categorized under the plagiarism act, which must be strictly avoided. Moreover, the guided based laboratory was relatively easy, where the students were only required to follow the instructions of the laboratory manual in order to do experiment (Yusof, et. al., 2014).

Further, due to practising continuous quality improvement (CQI) the past guided laboratory manual needed to improve its content regularly in order to deter some student's uncharacteristic behaviour such as copying past reports. In addition, it was observed that some students were not actively participating in experiments and there was lack of cooperation among group members and lack of motivation and concentration in grasping the experiment objectives. As a result, a number of students became bystanders in the group. This issue further escalated when it resulted in lack of attention and interest in learning power electronics subject as a whole. Therefore, the aforementioned problems related to guided based laboratory implementation had to be reviewed and reformed so that student interest in the power electronics course is always kept at a high level. Hopefully, this will result in better understanding and a good student achievement result for this course.

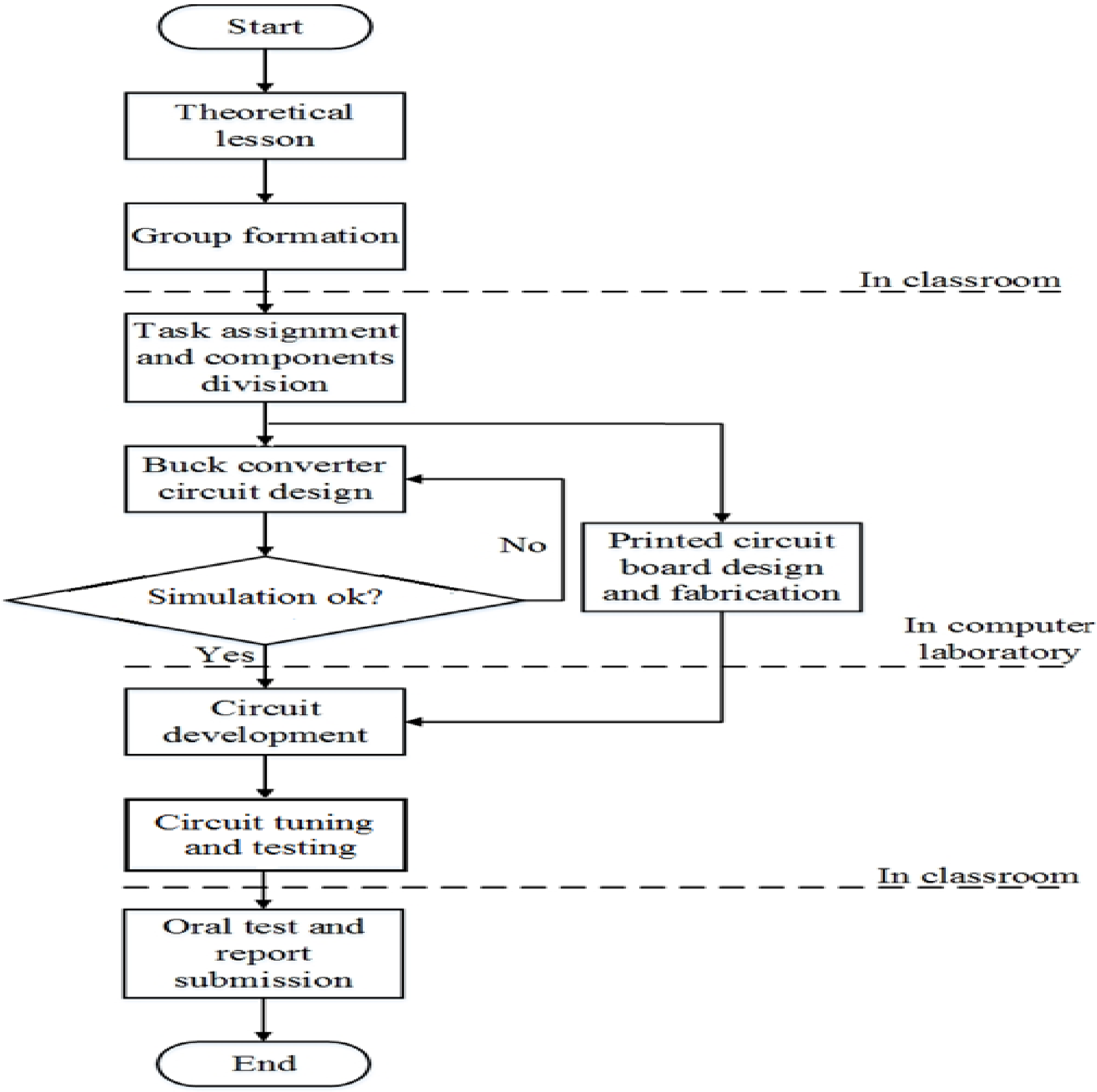
With these motivations in mind, a new pedagogy intended to replace the guided based laboratory has been successfully introduced and implemented on 2014/2015 and 2015/2016 academic years. The replacement was implemented in the form of PBL method. Instead of depending on the lecturer instruction, a student-centred learning approach was adopted. This requires a flipped role where the students play the main role in handling the design project by themselves (Yusof, et. al., 2014). Hence, they have an opportunity to experience real-life engineering exposure and undergo the whole process of designing a practical application through development of power electronics circuit.

PBL is defined as a learning method that makes used of suitable problems to increase the level of knowledge and comprehension through application (Ariff, et. al., 2014). In other words, PBL can also be represented as learning through experience (Wood, 2003; Mills & Treagust, 2003). This learning method is considered suitable to be implemented in engineering education since it stimulates the student motivation towards experimental work as well as fostering responsibility and teamwork collaboration among them. Moreover, sufficient engineering and technical knowledge can be gained from the experience through active involvement in the project experimental work (Dym, et. al., 2005; Wu, Hsieh & Pan 2017).

The power electronics learning problems have been identified in the literature (Zhang, Hansen & Andersen, 2016). Usually, according to the textbook or course syllabus, the topics of power electronics course comprise of power converters ranging from (alternative current-direct current) AC-DC, DC-DC, DC-AC and AC-AC circuits. Often, many students have difficulty in understanding the power converter, especially in switched-mode operation (Lamar, et.al, 2012; Lee, et. al., 2010). Based on the past experience and observation, due to the difficulty to comprehend the course contents, it resulted in lack of attention and focus during the lecture sessions. Consequently, the students would distract themselves with other matters and tend to feel uninspired and mundane which led to tangential disruption in the class. Normally, tutorials or quizzes would be given to the students in such a way that deeper understanding and analysis are expected from them in order to engage with relatively higher cognitive level rather than just merely listening to the lecture. These quizzes were designed to test their preparation and understanding towards each lesson in the course. From the results analysis the averaged marks are found to be quite well. However, the questions which related to circuit operation could not be explained by the students satisfactorily.

Basically, a mathematical formulation used to relate an input and an output of DC-DC converter such as Buck converter is simple and easy to be memorised. However, the operation becomes more challenging when it involves explanation of current flow within circuit, energy storage elements operation, and circuit control system. The foregoing teaching and learning of power electronics practice was typically conducted by presenting the theoretical knowledge and assuming idealized circuit's parameters and equations memorisation. These methods cannot directly assist student's learning and understanding of complex practical engineering skills comprehensively. Alternatively, deeper understanding can be achieved through comprehensive experiment work that involves the students in designing, building, developing and testing the circuit prototype (Tatje & Vos, 1995). To implement the aforementioned experimental work, a design and experiment-based project was introduced. Figure 1 below shows a flow chart which has been used as the guideline for the proposed practical project of power electronics course, implemented in the FKAB, UKM.

Figure 1. a flow chart of the proposed power electronics project



Methodology

Recently, the PBL method has become a standard pedagogy or teaching method in engineering studies as it has been reported in the literature in this field. It is quite attractive and able to improve engineering education significantly (Zhang, Hansen & Andersen, 2016). A type of PBL called project-based learning, which has identical abbreviation, has been proposed in (Zhang, Hansen & Andersen, 2016; Lamar, et.al., 2012; Lee, et. al., 2010; Chu, Lu, & Sathiakumar, 2008). It focuses on designing, developing, constructing and testing a hardware of typical power converter circuit. The PBL is carried out in groups and fully conducted by students themselves. The lecturer only acts as a facilitator or adviser. Both theoretical knowhow and construction practice are extensively involved. From a direct perspective, the students gain valuable hands-on experience when performing the circuit development.

From indirect perspective, the students are able to improve their skills in self-directed learning, teamwork and project management attributes. In achieving these targets, several objectives have been established. The first objective of the project is to motivate the students to have interest and to inspire the students to critically dedicate their efforts in learning power electronics course. The second objective is to encourage the students to learn the techniques and skills to develop hardware prototype of a real electrical and electronics engineering application. In general, the PBL is considered as a dynamic approach in which students encounter and explore real world problem and challenges (Tatje & Vos, 1995). Therefore, the embedded PBL integrates or combines various disciplines in electrical and electronics engineering into one discipline in order to accomplish the course outcomes and program outcomes respectively.

Among the principal engineering disciplines associated with the power electronics are Circuit Theory, Analog Electronics, Digital Electronics, Control System, Power Engineering, Signal Processing, Data Communication and Computer System etc. Even though power electronics course is inherently electrical engineering subject but to make used of its full potential, it requires substantial knowledge of electronics engineering as well as control engineering. This is because a control circuit is made of electronics components. That is the reason why the power electronics cannot be independent course, since it depends on many engineering disciplines in order to be applied. Moreover, as usual practice, most power electronics design or application is strongly suggested to be verified experimentally via validation of power converter hardware application (Chu, Lu, & Sathiakumar, 2008). This requires a lot of effort such as designing a power converter, identifying components, developing and experimenting with the circuit prototype, and analysing of results obtained from the experiment. Therefore, by active involvement through the whole design process and fulfilment of assigned tasks in the proposed embedded PBL, the expectation to see the students doing well in learning power electronics course can be achieved.

Project Management

To simplify the implementation of PBL carried out by the students, they were divided in several groups consisting of three students each. A time period of four weeks was given to the students to complete their projects. Consumables components such as low power resistors, capacitors, inductors, operational amplifiers (op-amp) and integrated circuits (ICs) were provided to the students. Attendance in the laboratory was recorded. Instead of having a lecture in classroom, the time allocated for the lecture was replaced by the laboratory experiment. The lecturer or instructor was also available in order to assist and monitor the students' activities. After group formation, each group was assigned to a similar project title. This was to avoid any confusion or unfairness of difficulty level and to encourage academic collaboration among groups.

The project title was determined by the lecturer. Hence, a Buck circuit, a type of DC-DC power converter which reduced and regulated the input voltage was selected as the project objective. Nevertheless, each group task was discriminated by different circuit parameters and outputs as indicated in Table 1 below. After completing the circuit construction and testing, all circuits were evaluated. Each group was required to demonstrate their circuit performance according to prespecified parameter. This including question and answer (Q&A) session. Lastly, they were required to submit a report. As addressed in (Yusof, Zaim & Arsad, 2016), the power electronics subject undergoes three stages of learning process. It started with theoretical lesson, subsequently, simulation design using computer tool and finally, validation process via laboratory experimentation.

Table 1: Buck circuit design specification

Parameters	**Specification**
Input DC voltage: V_i	22–30 V
Output DC voltage: V_o	Vary
Output ripple voltage:	<1% of V_o
Maximum output current:	Vary
Inductor current ripple:	< I_{max}
Switching frequency: f_s	20-100 kHz

Theoretical Lesson

With regards to the theoretical lesson, students were introduced to Buck converter in classroom. In this topic, the students were taught about the configuration of Buck converter, principle of operation, current flow, switching technique and the method to design the circuit as depicted in Figure 2 below. Next, the first step to evaluate their comprehension on this topic is by introducing a quiz. From the marks, many students managed to obtain a good mark in the quiz. Thus, the results of quiz are an early indication of students' comprehension, albeit this assessment only covers the theory and exercise to measure their understanding. Apart from quiz, an assignment was carried out also. In general, the student comprehension level is moderate, since they have not yet explored the visual and real circuit application.

Basically, the Buck converter is a regulated and not isolated DC-DC power converter which its output is less than the input (Mohan, Underland & Robbins, 2003; Ejury, 2013). It sees many applications in photovoltaic (PV) installation, regulated DC power supply, adaptor etc. The typical Buck converter circuit topology consists of an inductor, a capacitor, a diode and a switching device such as Metal Oxide Semiconductor Field Effect Transistor (MOSFET) or Insulated Gate Bipolar Transistor (IGBT) etc. The Buck converter can be controlled via a duty cycle, D. The duty cycle is determined based on a ratio of switch-on time and switching period. Usually, the D is selected between 0-1. The switching device is operated based on a very high frequency pulse width modulation (PWM) signals. The common switching frequency chosen for a typical Buck converter is between 20-100 kHz. Based on Figure 2 below, the circuit model looks easy to construct but the real circuit as depicted in Figure 3 below, it is totally a different story. It is not easy to construct the circuit prototype, since the design and development process involves many aspects that is not learned in theoretical class (Yusof, Zaim & Arsad, 2016). Therefore, a basic equation which relates the input and the output of Buck converter is given as follows:

$$V_o = DV_i \qquad (1)$$

Figure 2. A basic circuit model of Buck converter

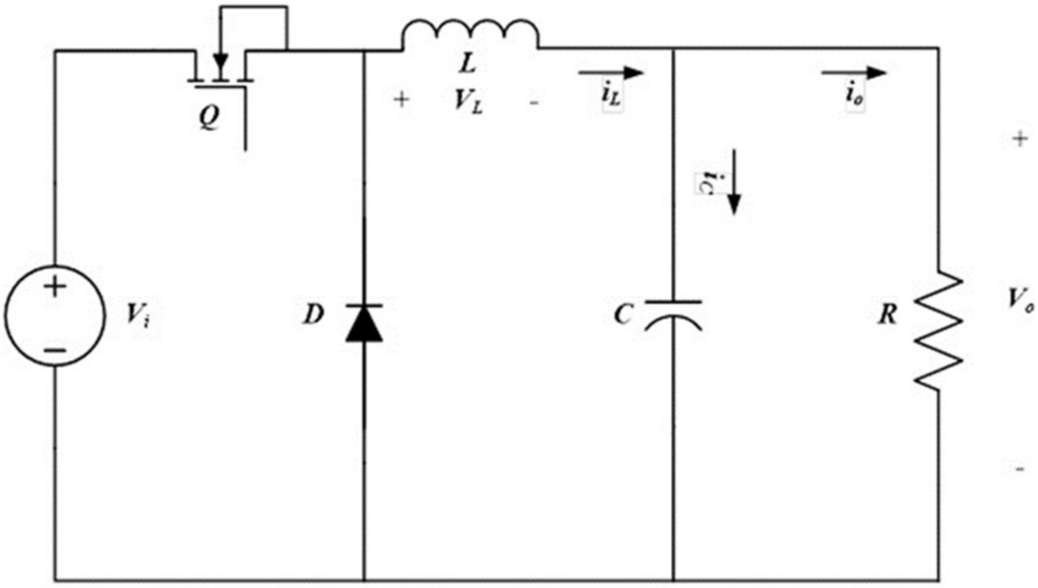
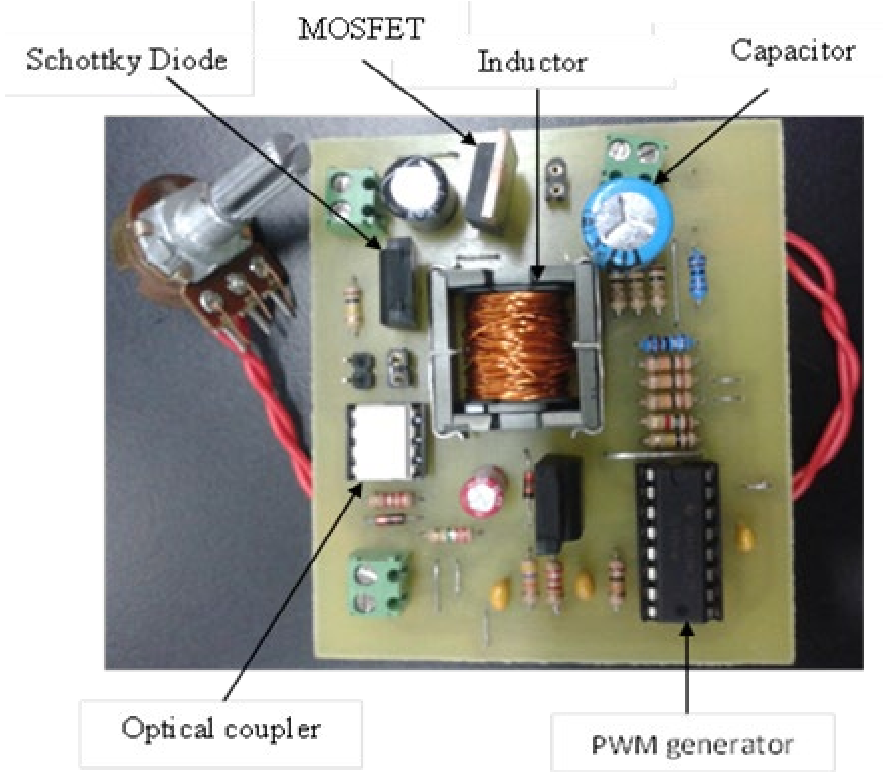


Figure 3. A prototype of Buck converter circuit



Modelling and Simulation

At the start of the design process, each group was required to submit their Buck converter circuit model to be evaluated by the lecturer. At this stage, the schematic circuit was sketched on a paper prior to modelling and simulation using MATLAB Simulink software. The MATLAB Simulink is intuitive and interactive for the user to perform self-learning exercises and more importantly, it can be easily integrated with MATLAB programming language and toolboxes [2]. The students have been exposed to MATLAB Simulink since year one. Hence, there was not much problems in implementing the circuit design using the software. Moreover, the MATLAB Simulink had been established as the main computation tool used in electrical engineering teaching and learning in UKM (Yusof, Sanusi & Mat, 2012; Yusof & Rahim, 2010).

Next, any groups that succeeded to perform the modelling and simulation stage, the group is qualified to design a printed circuit board (PCB) for the Buck converter. On the other hand, the unsuccessful group, they were required to redesign their model before they were given permission to design the PCB. Usually after resubmission was done, all groups were allowed to do the PCB design. Again, a computer simulation tool based on Eagle software was chosen for PCB design. The limited version of Eagle software can be downloaded from the internet for free. However, it is limited to student version where there are not many features available as compared to the full version. Every completed PCB design is required to be sent to the lecturer for evaluation purpose. Normally, at this stage all groups should be able to pass at first submission since this stage is the easiest stage as compared to the rest. Mistakes that were usually detected are unsuitable selection of track size and unconnected line track. After they have been given an approval of PCB design by the lecturer, they need to send their PCB design to the PCB laboratory to fabricate the real PCB circuit. At this point, the students need to wait for at least two days in order to obtain the readily real PCB circuit. In average, the whole design stage takes about one week to complete which involves computer modelling tools and PCB fabrication process.

Student Activities in Laboratory

Following the predetermined schedule, all groups should be completed their respective PCB circuits within two weeks. Advises and supervisions on the Buck converter design was given by the lecturer during laboratory visit. Furthermore, some tips on circuit assembling and construction were also given as well as an open discussion especially about any related problems. Since the project practices two-way communication between the students and the lecturer, students are encouraged to ask any questions and discussed the solution as well. Even though the proposed laboratory project is handled by a small group of three students each, frequently they were advised to work hand in hand and sharing and exchanging ideas between the rest of the groups at large. Moreover, all members in a group are responsible to do their designated tasks, where a ‘sleeping partner’ is not permitted. Thus, in order to prevent this issue, a group leader is appointed in order to assist the lecturer in term of monitoring the group progress as well as managing his/her group members’ activities. A good cooperation among group members and between the rests of the groups at large definitely has lightened the heavy load assignment. Figure 4 below shows students were working together during experimental work in the laboratory.

Figure 4. Students at work

The laboratory opens daily during office hours. Students were prohibited to come to the laboratory if they have other academic commitments. So, the laboratory schedule was determined by the group themselves according to the specified time table, with a condition that it would not clash with other classes. Students were not allowed to skip other class solely to do their project. Therefore, to avoid time table clash among groups and preventing any students from skipping other class, they were required to book a laboratory schedule. The laboratory experiment runs during afternoon, between 2-5 pm. The attendance is made compulsory, in order to avoid absentees as well as to ensure the project completed on time. Students were encouraged to do revision and preparation before coming to the laboratory (Yusof, Sanusi & Mat, 2012). Adequate preparation ensures smooth experimental flow and adherence to design milestone. Other than laboratory safety measure and regulation, a great emphasise on general good engineering practices have been highlighted. These include cleaning up the workbench after used, and returning back the equipment and tools to their original place before leaving the laboratory. It is hoped that this effort will establish a good engineering attitude to the students. In order to assist students, apart from the lecturer, a lab assistant also presented during the experiment.

Construction of References

As expected, the output of PBL is a real Buck circuit as depicted in Fig. 3. Therefore, to evaluate their project, each group is required to demonstrate their circuit performance according to the specification given in Table 1. Marks allocation for the project-based learning is set at 30% of the overall marks. Project assessment was done continuously. Since the project is an affirmative evaluation from Taxonomy Bloom level, hence, the assessment makes used of rubric form. There are five segments that have been identified to be evaluated. Categorized by a circuit and PCB design, an attendance, a prototype development and demonstration, an individual performance, and finally a project report.

Each segment carries different full marks in between 5 to 35%. For example, in evaluating circuit development and testing, based on rubric form, three main performance determinants were used which are complete, half-complete and incomplete. For each performance determinant, a range of score between 0-5 are given for evaluation. The segment is further divided into smaller partitions. A respective marks distribution is provided in Table 2 below. The segment of demonstration carries the highest mark of 55% from overall project marks. On the other hand, the lowest percentage of mark is 10% and is obtained from the attendance. In order to evaluate an individual performance, an oral test was carried out. The lecture asked questions related to the Buck converter's circuit theory and development methods to the group and to the individual member. A high mark was given to the student who answered correctly and confidently. Hence, the individual performance substantially depends on his/her oral test. Lastly, the project written report evaluation depends on contents. The report contributes 35% of the total marks.

Table 2: Marks distribution

Itemized assessment	**Marks**
Demonstration: a. Circuits design b. Inductor design c. Produced PWM control signals d. Produced an operational MOSFET gate drive circuit e. Produced an operational buck converter circuit f. Fulfilling all the specifications in Table 1 g. Individual Q&A session	 10% 5% 5% 5% 5% 15% 10%
Weekly laboratory individual attendance:	10%
Report:	35%
Total:	100%

Furthermore, a competition was held as a way to celebrate student effort and to motivate the students (Regueras, et. al., 2008). With this regard, some prizes were offered to the best group and individual categories. Figure 5 below depicts the prize presentation to the winner in individual category. Moreover, a certificate of participation to all students was also presented to appreciate their tireless effort and commitment towards the completion of project.

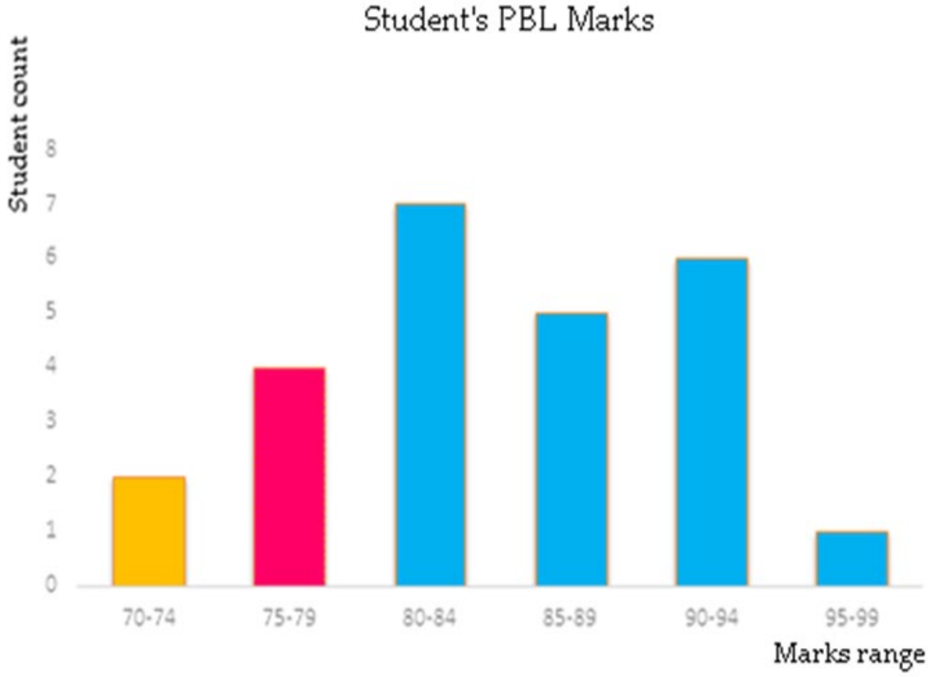
Figure 5. Prize presentation to the winner

Results and Discussion

The overall results of project-based learning are satisfactory, where average students' marks of 84% was obtained. Out of 25 students, the highest mark was 97% while the lowest was 74% as indicated in Figure 6 below. The result shows all students successfully obtained considerable marks. This certainly influenced their final marks since the PBL covers 30% of it. Most groups were able to demonstrate their Buck circuit performances well, except two groups. In other words, they have shown their potential and skills in circuit development and testing. Other than assessment test listed in Table 2 above, tests and measurements were also conducted on inductor current saturation and automatic circuit switching. Bonus marks were given for group that managed to perform measurements on inductor's saturation current.

From the demonstration, student teamwork and individual skills were carefully observed and evaluated. Most of them were able to complete their respective task smoothly and effectively, while some of them had some difficulties in doing practical work and were also unable to answer the question satisfactorily. Despite the project runs in group, typical marks obtained among group members are different. The difference originates from individual competency, knowledge, attitude and soft skill that was presented during demonstration and oral test sessions. All groups managed to build their own Buck circuit prototype on time. However, only two groups out of eight could not produce an expected output due to unidentified error. Most probably the error originates from the control section of the circuit. Therefore, the assessment on this part is rather straight forward, whether the prototype is fully working, partly working or not working at all. There was a case where a group claimed that their circuit's actually working, but during the demonstration day it was not working.

Figure 6. Student's PBL marks



Various moments happened to the students while performing the project assignment. A total of 8 groups were formed and each had 3 group members. Unfortunately, 2 groups were unsuccessful to show their circuit prototypes functioned as expected during demonstration session. These malfunction circuit prototypes when being asked to the group members about the reason behind the failure, they could not give the suitable answer. Actually, the shortcoming of malfunction prototype is that the design did not follow the predetermined specification. Moreover, student attitude could be another factor of the failure, maybe they started their project late. A busy schedule should not to be blamed. Certainly, this issue could be avoided if a proper plan and good time management was exercised by the students. Indeed, the PBL implemented at the Department of Electrical, Electronics & System Engineering, Faculty of Engineering & Built Environment, UKM has been successful method in fostering experience and useful skill to the students who took the power electronics course.

Valuable skills such as construction of circuit hardware, circuit assembly and experimentation could not be easily obtained through the theoretical lesson. The chance to learn these practical skills is quite limited since many courses in electrical and electronics programme have not embedded hardware development or circuit testing. Even though the teaching laboratory courses have been offered since year one to year three, it was found that these laboratory courses could not offer the same effects as the PBL. This is because the implementation is based on instructional laboratory manual which utilises ready-to-use equipment and tools. Therefore, the student's effort is lesser and it is at lower level of competency. On the other hand, the project-based learning was implemented starting from the fundamental of circuit design. The initial design was sketched on paper prior to become the functioning prototype of Buck converter circuit. The PBL is a platform for student-centred learning approach where the lecturer intervention is minimized, thus, students are able to understand the subject better since they had involved in practical experience themselves.

Conclusion

The objectives of the introduction of PBL in power electronics course at UKM have been achieved. The student passion and perseverance in carrying out the practical project shows their potential in technical skill. Moreover, their sense of responsibility and teamwork management has increased significantly. All students deserved to be given some opportunities to study in their preferred way, such as a hands-on project. More importantly, the students must have interest, perseverance, competencies and a teamwork spirit in order to succeed. After implementing the project, their comprehension and understanding towards the DC-DC converter topic have been elevated as mirrored by the successful of Buck converter circuit development and demonstration. Obviously, the theory they learned in the classroom is not adequate in mastering the aforementioned topic, so the students would still be required to give extra effort to achieve their goals. Instead of using computer assisted simulation tools to fulfil the learning objective, a constructive hands-on design project such as the proposed PBL approach has proven to be a better solution in delivering the related knowledge. Furthermore, the students also gained valuable practical experience and skills similar to that of industry practice. Hopefully in the future, the proposed laboratory project implemented in the power electronics course could be continued and its quality improved.

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