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Module-Based Laboratory Course for the Industry Sponsored "Research and Design Master Program" in *Power Electronics*

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ABSTRACT The main purpose of this paper is to present a developed modular laboratory course for the industry sponsored "Research and Design Master Program" in power electronics. The objective of this modular laboratory course is for students to (i) Appreciate the theory of power converter with the aid of the state-of-art simulation tools, (ii) Derive the converter model and design the controller, (iii) Understand the magnetic components, (iv) Comprehend the closed-loop control of power converter, and confirm the modeling and controller design, (v) Realize the power converters by PCB layout, magnetic components implementation and debug. Therefore, this modular laboratory course is expected to bring the industry sponsored "Research and Design Master Program" students both systematic learning and hands-on experience. This module-based laboratory course is designed mainly by considering the application of magnetic components to power converters. The designed course modules include (i) Forward converter module for inductor and transformer with center-tapped winding, (ii) Flyback converter module for transformer with air-gap acting as inductor and transformer, (iii) Push-pull converter module for transformer with center-tapped winding and (iv) Half or Full-bridge converter module for driver transformer. The controller design for each module with closed-loop control is included. The designed laboratory course has been given for years and some assessment results will be illustrated. The feedback from the students indicates that this designed modular course receives excellent acknowledgment for providing practical training and covering the wide range of magnetic components as well as controller design in power converter learning.

INDEX TERMS Modular laboratory course, modeling and controller design, power converter, R & D master program, state-of-art simulation tools.

I. INTRODUCTION

As well known, the power converter industry is quite strong and becomes one of the most promising industries. As shown in Table 1 [1], four out of the worldwide top five, including Delta Electronics Inc., Lite-On Technology Corporation, Chicony Power and Meanwell Co. Ltd, etc. are Taiwanese companies in the power supply industry, 2019. Therefore, demand of the research and design man power is heavy in demand. To meet the industry demand and speed up the training process of such Master-level engineers, the Research and Development Master program [2], [3], R & D Master program, hereafter, is developed and sponsored by the power supply industry. The obligation of the students is to serve in the sponsored company after graduation. Since the students has received job offer aiming at R & D of power converter industry as they join this program, both hands-on and elementary knowledge trainings are important.

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TABLE 1. Top-5 Merchant PS manufacturers CY 2019 worldwide sales [1], 4 Taiwanese companies out of 5.

No	PS Companies	Sales (US Dollars in Millions)
1	Delta Electronics	~$4388
2	Lite-On	~$1550-1600
3	Chicony Power	~$1133
4	MEAN WELL	~$1001
5	Flex™	~$850-875

The R & D Master program in power electronics in our university has been established since 2006. The modular-based course, "Practice of Power Electronics System", is designed and modified year by year to reflect the assessment results from the students and comments from the industry.

To reflect the key elements of the course and course contents of the presented module-based laboratory course, comparisons of various designed courses [4]–[12] for power converter related topics are shown in Table 2. The laboratory course for transformer and inductor design, and converter implementation is presented in [4]. However, controller design and implementation are not covered. In [5], a specific converter is implemented with the aid of MATLAB simulation tools, no introduction of magnetic components, modeling and closed-loop control are included. Although converter modeling is introduced in [6], magnetic components and control parts are missing. In [7], FPGA-based closed loop control is realized based upon the MATLAB/Simulink simulation tools, some practical parts for power converters are not shown, especially, the magnetic components and various types of converter topologies. Similarly, only inductor is covered in [8] and only a specific topology, boost converter or flyback converter, is introduced in [9] and [10], respectively. In [11] and [12], no magnetic components is included while covering a specific converter topology only.

For the concerns of simulation tools used for power electronics laboratory course, as demonstrated in [13], [14], both MATLAB and PSIM provide circuit-based/model-based simulation, and even C-code generation for further verification based upon specified FPGA and DSP. Due to these special features for power electronics simulation, control and implementation, to our best knowledge, they are categorized as state-of-the-art simulation tools.

The highlighted items include: the used state-of-art simulation tools, converter modeling & controller design, magnetic components design, closed-loop converter controller design & confirmation, realization of power converters, converter topologies and the pedagogical approaches. The presented designed course in this paper covers many aspects especially in converter modeling & controller design, magnetic components design, and converter topologies.

As shown in Table 2, for the courses [4]–[12], either simulation only, or no/mathematic modeling only, or limited/no magnetic components, or dedicated converter topology is covered. The power electronics course contents connect control theory, modeling using software, closed-loop controller design using software and confirmation by implementation, various magnetic components design and implementation, and hands-on works of almost all essential converters is not fully explored in previous references in listed in Table 2. In contrast, the contents of the presented modular laboratory course cover the above-mentioned contents for the power electronics training. More details of these contents will be introduced and confirmed by the response of the students.

For the teaching strategy, comparing to the previous self-learn, simulation-based and project-oriented learning courses, a modular laboratory course is presented in this paper. The proposed module-based laboratory course is designed mainly by considering the application of magnetic components to power converters. The designed course modules include (i) Forward converter module for inductor and transformer with center-tapped winding, (ii) Flyback converter module for transformer with air-gap acting as inductor and transformer, (iii) Push-pull converter module for transformer with center-tapped winding and (iv) Full-bridge converter module for driver transformer.

The controller design for each laboratory module with closed-loop control is designed and simulated based upon MATLAB [6]–[9] and PSIM [14]–[18] for the students to know why and know how, rather than trial-and-error. The designed and simulated course modules are then further confirmed by PCB layout, magnetic components implementation and debug. Therefore, the designed modular laboratory course brings the students of industry sponsored R & D master program a systematic learning as well as hands-on experience.

II. MODULE-BASED LABORATORY COURSE

The objective of this course is for students to:

1) Appreciate the theory of power converter with the aid of the state-of-art simulation tools,
2) Derive the converter model and design the controller,
3) Understand the magnetic components,
4) Fulfill the power converters by PCB layout, magnetic components implementation and debug.

The proposed module-based laboratory course is designed mainly by considering the application of magnetic components to power converters. The magnetic components for power conversion include: (i) inductor, (ii) driver and (iii) transformer, as shown in Fig. 1. For the transformer applications, one is uni-directional excitation and the other one is bi-directional excitation. For forward and flyback converters, uni-directional excitation transformer is used, in which magnetizing current is provided only in one direction. Noting that the transformer for flyback converter also acts as an inductor with air-gap to prevent from saturation. Its stored energy in the duty-on duration is released in the duty-off period. In contrast, the energy stored in the transformer of forward converter is pumped to the output side in the duty-on period. Under this circumstance the third winding is needed to release potential magnetizing energy.

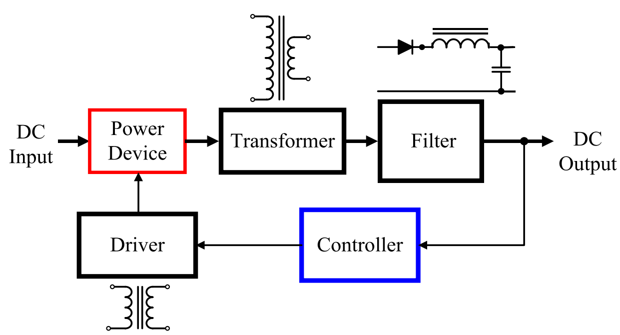


FIGURE 1. Magnetic components and control in DC/DC converters.

Moreover, for the bi-direction excitation transformer which are applied to push-pull, half-bridge and full-bridge

TABLE 2. Comparison of the various designed courses.

Ref.	The used state-of-art simulation tools	Converter modeling & controller design	Magnetic components design	Closed-loop converter controller design & confirmation	Realization of power converters	Converter topologies	Types of pedagogical approaches
[4]	None	None	Various magnetic components	Implementation for confirmation	PCB layout, magnetic components implementation and debug	Flyback, Forward, Push-pull, Half-bridge, Full-bridge	Project/Self-based learning
[5]	MATLAB	None	None	None	Thyristor rectifiers	Buck-boost	Problem/Self-based learning
[6]	MATLAB /Simulink	Mathematical model	None	None	Simulation	Multilevel grid-side converter and six-phase generator	Self-based learning
[7]	MATLAB /Simulink	None	None	FPGA-based closed-loop system	Unipolar SPWM-based single-phase inverter	Buck	Problem-based learning
[8]	MATLAB /Simulink	None	Inductor design	ATV312HU15M3 drive (Schneider Electric) with SoMove software	Buck converter and the PCB are provided by the teachers	Buck, boost, buck-boost, half-bridge, push–pull, and full-bridge	Project-based and jigsaw cooperative learning
[9]	MATLAB	None	Inductor and transformer design	Closed-loop converter controller confirmation	PCB provided by the teacher was assembled by the students, inductor design and test	Boost	Problem/ Project-based learning
[10]	None	None	Design magnetic components	Closed-loop controller design	PCB layout, magnetic components implementation	Flyback	Project-based learning, Oral exam.
[11]	MATLAB /Simulink and SimPower-System	None	None	TMS320F240 DSP	Photovoltaic system	Boost or SEPIC	Project-based learning
[12]	MATLAB /Simulink	None	None	FPGA-based dSPACE DS1104	None	Buck	Project-based, educational web-based learning
Presented in this paper	PSIM/MATLAB & Simulink	PSIM for modeling, MATLAB/SISO Tool for controller design	Various magnetic components, See Table III	Using SISO Tool & implementation for confirmation	PCB layout, magnetic components implementation and debug	Flyback, forward, push-pull, Half-bridge, full bridge	Project-based/Self-based learning

TABLE 3. Application of magnetic components to power converters, Tr. = transformer.

	Forward	Flyback	Push-pull	Half-bridge	Full-bridge
Transformer	√	√	√	√	√
Inductor	√		√	√	√
Driver transformer					√
Special Features of magnetic components	Uni-direction Tr. with 3rd winding for de-magnetizing	Uni-direction Tr. also acts as inductor	Bi-direction Tr. with center tapped windings	Bi-direction Tr. with center tapped winding on secondary	Bi-direction Tr. with center tapped winding on secondary
Control Mode	Peak current mode	Peak current mode	Voltage mode	Voltage mode	Voltage mode

converters, the magnetizing current is positive and then negative in one cycle.

Therefore, the magnetic components presented in this course applied to power conversion include: transformer/inductor with air gap for flyback converter, transformer with the third winding for forward converter, transformer with center-tapped windings for bi-directional converters, inductor and power device driver. The module-based laboratory course is therefore designed to cover these magnetic component applications to power converters as shown in Table 3.

Table 3 shows the special features of the designed module-based laboratory course related to the magnetic components for power conversion applications. As shown in the Table 3, the designed course modules include:

1) Forward converter module for inductor and transformer with center-tapped winding,
2) Flyback converter module for transformer with air-gap acting as inductor and transformer,
3) Push-pull converter module for transformer with center-tapped winding and
4) Full-bridge converter module for driver transformer.

TABLE 4. List of the designed module-based laboratory course.

Theory and Simulation		Experiments	
1. Introduction to PSIM Software Package	3 hours	5. Introduction to Basic Concept	3 hours
2. Open Loop Circuits	3 hours	5.1 Fundamental of Topologies	3 hours
2.1 Single-Phase and Three-Phase Rectifiers	3 hours	5.2 Control Mode	3 hours
2.2 Step-Down (Buck) and Step-Up (Boost) Converters	3 hours	5.3 Transformer Design	3 hours
2.3 Buck-Boost and Flyback Converters	3 hours	5.4 MOSFET Driver Circuits	3 hours
2.4 Forward Converter	3 hours	5.5 Sensing and Feedback Circuit	3 hours
2.5 Half-Bridge and Full-Bridge Converters (Open Loop)	3 hours	6. Introduction to Layout Software	3 hours
2.6 Push-Pull Converter	3 hours	7. Practice of Converters	
3. Closed-loop Circuits	3 hours	7.1 Flyback Converter	6 hours
3.1 Step-Down (Buck) Converter	3 hours	7.2 Forward Converter	6 hours
3.2 Step-Up (Boost) Converter	3 hours	7.3 Push-Pull Converter	6 hours
3.3 Flyback Converter	3 hours	7.4 Half-Bridge Converter	6 hours
3.4 Forward Converter	3 hours	7.5 Full-Bridge Converter	6 hours
3.5 Push-Pull Converter	3 hours		
3.6 Full-Bridge Converter	3 hours		
4. Selected Special Simulation Projects	9 hours		

TABLE 5. Course contents for course modules and objectives.

Course Contents	Course Objective	Course Modules
Open loop simulation	(1) Appreciate the theory of power converter with the aid of the state-of-art simulation tools	1. Introduction to PSIM Software Package 2. Open Loop Circuits
Modeling using PSIM and MATLAB	(2) Derive the converter model and design the controller	1. Closed-loop Circuits 2. Selected Special Simulation Projects
Controller design using MATLAB/SISO TOOL	(3) Derive the converter model and design the controller	1. Closed-loop Circuits 2. Selected Special Simulation Projects 3. Practice of Converters
Closed-loop simulation	(4) Understand the closed-loop control of power converter, and confirm the modeling and controller design	1. Closed-loop Circuits 2. Selected Special Simulation Projects 3. Practice of Converters
Hands-on realization of converter	(5) Realize the power converters by PCB layout, magnetic components implementation and debug, by the designed modular course	1. Introduction to Basic Concept 2. Introduction to Layout Software 3. Practice of Converters

As shown in Table 2, the magnetic components addressed in this course include various types of transformer for almost all essential converters, inductors, driver transformers. The magnetic components study is reinforced by designing, implementing, and testing transformer, inductor and driver transformer. Due to the paper length limitation, more details of a transformer and inductor design and implementation are illustrated in [19].

Furthermore, the controllers for power converter include, peak current mode control, average current mode control and voltage mode control. Due to the limitation of discrete control power IC for implementation of laboratory work, only peak current mode and voltage mode control are designed in this course as indicated in Table 3.

Based upon the above-mentioned frame, the outline of the designed module-based laboratory course is listed in Table 4.

The designed course is given in two semesters for 36 weeks. In the first semester, "theory and simulation course" are focused and then "Experiments (hands-on) course" is given in the second one. This course includes simulation, experiments and the final test. The course for simulation includes open and closed-loop converters. The course modules of buck, boost, flyback (buck-boost), forward, push-pull, half-bridge and full-bridge converters are included in both open and closed-loop simulation.

For the experiments, basic concept to the control of converters and feedback circuits are given first. And followed by the introduction of layout software, which is based upon Altium Designer software [20]. And finally, five modules with closed-loop control of converters are designed for practice. To design the closed-loop controller, PSIM used to derived the converter model and MATLAB/SISO Tool is applied to design the controller for a given specification. The students are required to fulfill the power converters by PCB layout, magnetic components implementation and debug. Therefore, the students can see the consistence among theory, simulation results and implemented results, and thereby achieving the objective of this course.

III. ILLUSTRATION OF THE DESIGNED MODULE-BASED LABORATORY COURSE

Since flyback converter is one of the most popular topologies, especially for the low power applications, the course module of flyback circuit is illustrated as an example to fully explore the special features of the designed module-based laboratory course. Similar course contents are designed for other modules.

Without invoking safety regulations nor requiring high power source and electronics load, 48V/12V is specified for input and output voltage rating and the power rating for each module is 60W. For the students to fully see the importance of layout, the switching frequency is 100 kHz. The specifications of each module are as follows.

➢ Input Voltage: 48 V

- ➢ Output Voltage: 12 V
- ➢ Output Current: 5 A
- ➢ Output Power: 60 W
- ➢ Switching Frequency: 100 kHz

To achieve the mentioned course objectives the contents of the designed module-based laboratory course include:

1) Open loop simulation
2) Modeling using PSIM and MATLAB
3) Controller design using MATLAB/SISO TOOL
4) Closed-loop simulation
5) Hands-on realization of converter

Table 5 shows the course contents corresponding to the course modules and objectives. Although the contents are illustrated using flyback module as an example in this section, the same contents are designed for the course modules of other converters.

A. OPEN LOOP SIMULATION USING PSIM

The objective of each course module with "Open loop simulation using PSIM" is to facilitate the students to "appreciate the theory of power converter with the aid of the state-of-art simulation tools" as mentioned.

As illustrated in Table 4, non-isolated rectifier and DC-DC converters are included in this program. For inverter, both single and three-phase inverters were included as this program received sponsors working in the area of motor drives. Recently, due to the change of sponsors, it was removed to focus more on the power converters. An example of non-isolated buck-boost converter circuit used in this program is added in Fig. 2(c) and Fig. 2(d). Since flyback is a kind of buck-boost converter, most of the contents are similar to that of flyback converter. Moreover, due to the paper length limitation, the details of this non-isolated buck-boost converter are no more repeated.

For the flyback converter module, it is designed to facilitate the students to learn theory and operation of a uni-directional excitation transformer with air gap. Figure 2 shows the related circuit and PSIM circuit used for open loop simulation. The magnetized energy is stored in the exciting duty cycle while being released in the remaining duty-off period. Thus, the transformer also functions as an inductor. To prevent from potential saturation and clamping the voltage spike, a demagnetizing path, RCD clamping circuit [21]–[23] is used as shown in Fig. 2.

B. MODELING USING PSIM AND MATLAB

The objective of each course module based upon "*Modeling using PSIM and MATLAB*" is to facilitate the students to "**derive the converter model for controller design**". PSIM is used to derive the transfer function based upon perturbation method, "AC SWEEP" function. The perturbation signal with wide frequency range is "injected" to derive the data of transfer function in Excel file format. And these data are "read" by MATLAB using the function of "Input Data" to get the transfer function using "curve fitting" of MATLAB.

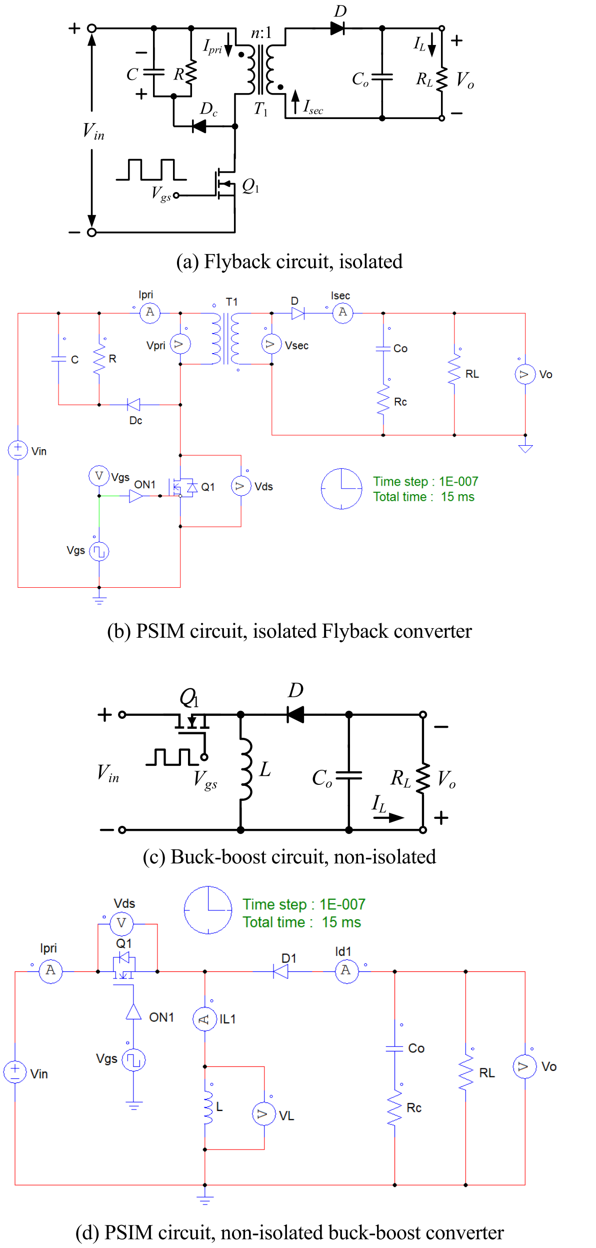
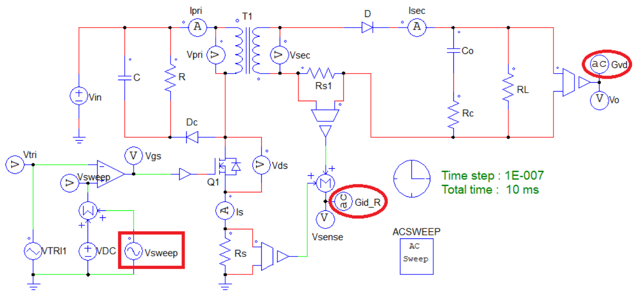
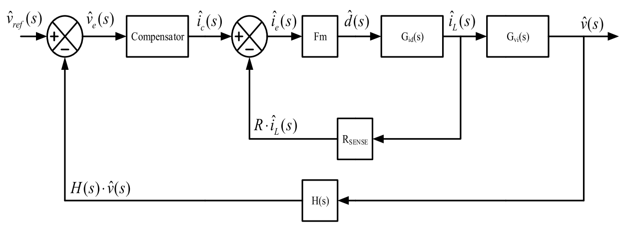


FIGURE 2. Course module illustration, isolated and non-isolated buck-boost converter, open loop simulation.

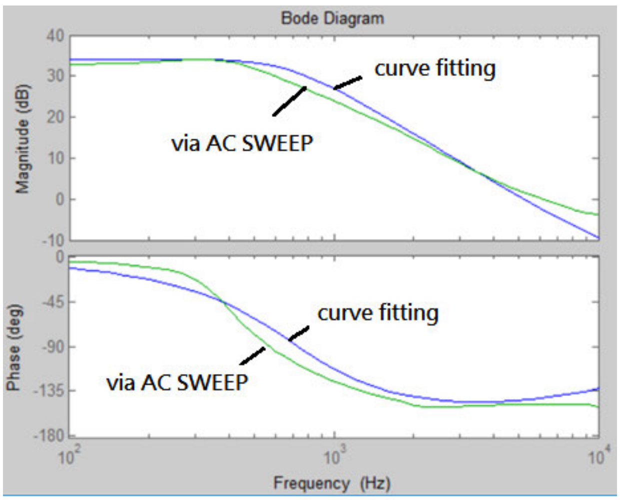
Figure 3 illustrates the modeling using flyback converter as an example. As shown in Fig. 3(a), "*Vsweep*" is the perturbation signal with the sweep frequency from DC to the Nyquist frequency. Since the illustrated flyback converter is with average current mode control, the block diagram is illustrated in Fig. 3(b) As shown in Fig. 3(b), the $G_{id} = \hat{i}_L \big/ \hat{d}$, the numerator $\hat{i}_L$ is the current and the denominator, $\hat{d}$, indicates the duty. Similarly, the transfer function of G_{vi} in Fig. 3(b) can be derived by $G_{id-R} \times G_{vd}/R_s$ in Fig. 3(a). In Fig. 3(c), the results of modeling by the AC sweep and curve fitting are illustrated. If the specified order of transfer function for curve fitting is increased, the curves will become



(a) PSIM circuit, flyback converter



(b) Control block diagram, average current mode control



(c) Curve fitting results

FIGURE 3. Course module illustration, modeling of flyback converter.

more consistent. The analytic form of G_{vd} can thus be derived by curve fitting function of MATLAB.

Therefore, the process of converter modeling course module can be summarized as follows.

Step 1: Start "AC SWEEP" in PSIM for deriving the Bode plot of G_{vd} and save the data in Excel file

Step 2: Import the Excel file to MATLAB

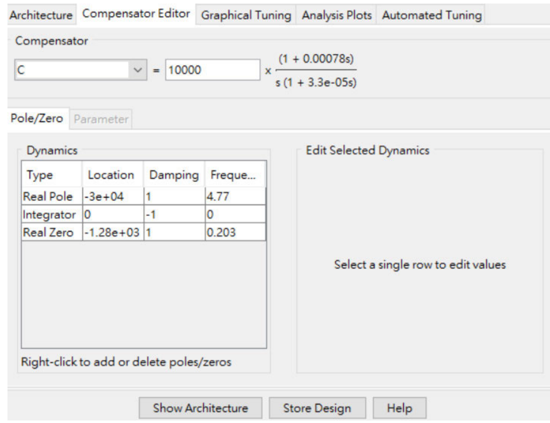
Step 3: Derive the analytic form of G_{vd} by Curve Fitting function of MATLAB

Step 4: Derive the analytic form of G_{id-R} by Repeating Step 1-3

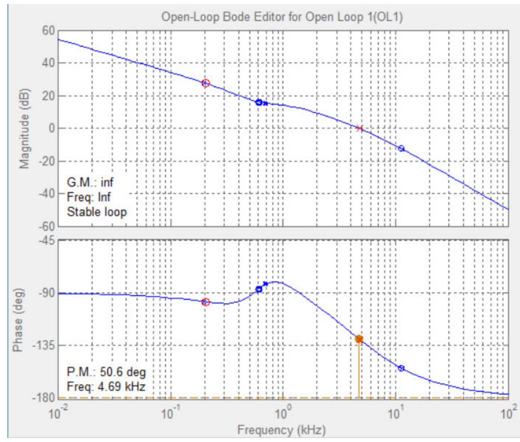
Step 5: Get the transfer function of $G_{vi} = G_{id-R} \times G_{vd}/R_s$

C. CONTROLLER DESIGN USING MATLAB AND SISO TOOL

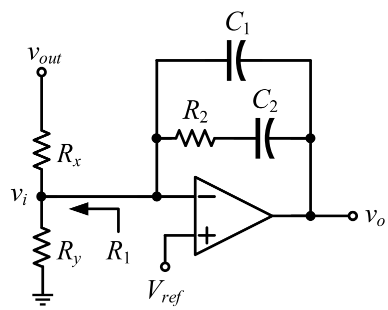
The objective of the course modules designed for "*Controller design using MATLAB and SISO TOOL*" is to provide the



(a) Controller transfer function



(b) Adjusting of poles and zeros of controller

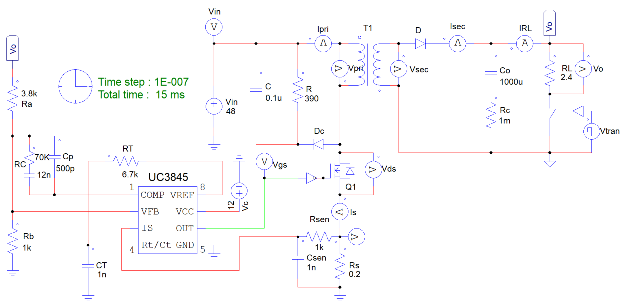


(c) Implementation of controller

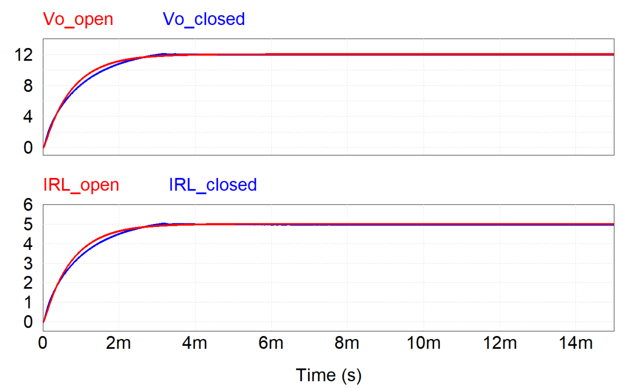
FIGURE 4. Course module illustration, controller design, flyback converter.

students "**a systematic design of the controller based upon the derived model**". For power supply engineer, it is requested to design the controller for the specified controller specifications. Trial-and-error approach may be used in general. In this course module, a systematic approach is brought to the students to see why and how the controller can meet the specified controller specifications.

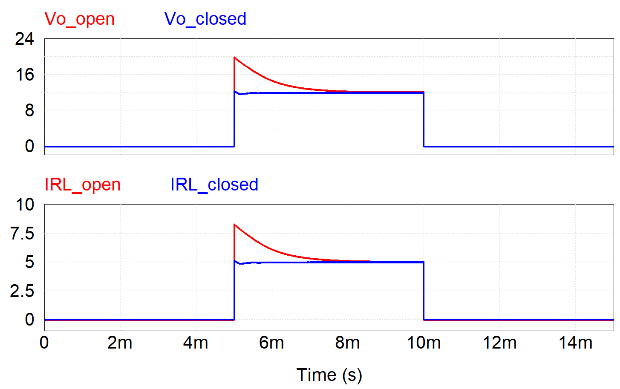
For the given design specifications and converter model, the controller can be designed using SISO tool in MATLAB. Figure 4 illustrates the controller course module using flyback converter as an example. Figure 4(a) shows the controller transfer function meeting the controller specifications which is derived by adjusting the poles and zero as shown



(a) PSIM circuit

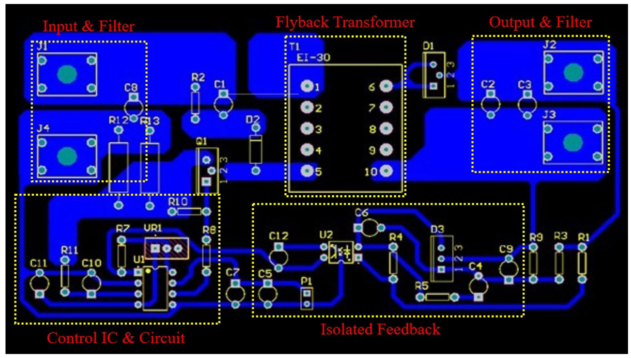


(b) Output voltage and current

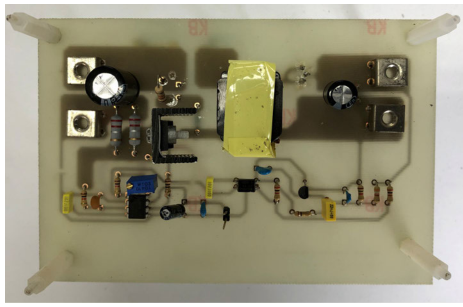


(c) Output voltage and current with sudden load change at the time of 5 millisecond

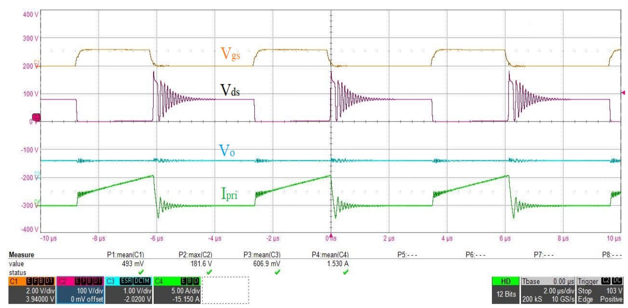
FIGURE 5. Course module illustration, open loop (in red) and closed-Loop (in blue) simulations, flyback converter.



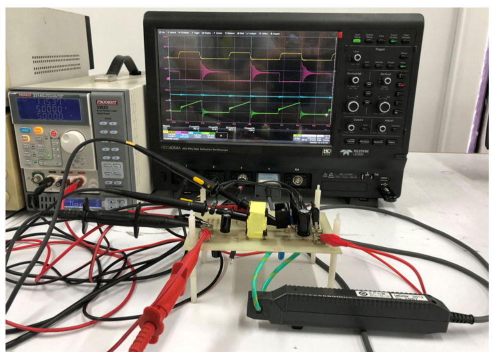
(a) Layout



(b) Photo



(c) Measured signals



(d) Photo of experimental set-up

FIGURE 6. Results of *Hands-on realization of converter*, closed-loop flyback converter.

in Fig. 4(b). In Fig. 4(b), the results show the phase margin (PM) is 50.6 degrees and the cross-over frequency is 4.69 kHz which meets the specifications of PM $>$ 45 degrees and cross-over frequency $<$ 10 kHz. The transfer function shown in Fig. 4(a) is realized by the controller with operational amplifier, as shown in Fig. 4(c). The controller design is to give the R_1, R_2, C_1, and C_2, based upon the controller, $C(s)$.

Therefore, the process of controller design course module can be summarized as follows.

Step 1: Input the transfer functions of converter, type "SISO" tool function or load the m file of SISO tool in Command Window of MATLAB, select "EDITOR" then "Run" this function or m file. The Bode plot can be obtained

Step 2: Select the type of controller (compensator), for example, 2 Poles - 1 Zero compensator

Step 3: Drag and drop the point(s) of Pole(s)/Zero in Bode plot shown in Fig. 4(b) then design the controller using SISO tool to meet the required design specifications

TABLE 6. Results of feedback and survey statements, average points = 4.65 out of 5.

The Designed Power Electronics Laboratory Course	Strongly Agree (5 points)	Agree (4 points)	Neutral (3 points)	Disagree (2 points)	Strongly Disagree (1 point)	Points 2018 to 2020	**Total Average Points**
1. The course is helpful for me to get more familiar with *power converter topologies*.	9 8 6	2 2 5				4.82 4.80 4.55	4.72
2. The course is helpful for me to appreciate the power converter *control*.	9 7 5	2 3 5	 1			4.82 4.70 4.36	4.63
3. The course provides me more understanding of the *power converter modeling used in the industry*.	7 7 5	3 2 5	1 1 1			4.55 4.60 4.36	4.50
4. The course is helpful for me to appreciate the *design of controller and magnetic component* of power converters.	7 5 3	4 3 6	 2 2			4.64 4.30 4.09	4.34
5. The course is helpful for me to *realize the* power converters.	10 7 7	1 3 4				4.91 4.70 4.64	4.75
6. The course is helpful for me to appreciate the theory of power converter with the aid of the state-of-art simulation tools.	11 6 4	 4 7				5.00 4.60 4.36	4.65
7. This course gives me a *turn-key solution* to power converter training.	11 9 6	 1 5				5.00 4.90 4.55	4.82
8. Over all, I am pretty satisfied with this course.	11 8 7	 2 3				5.00 4.80 4.55	4.78

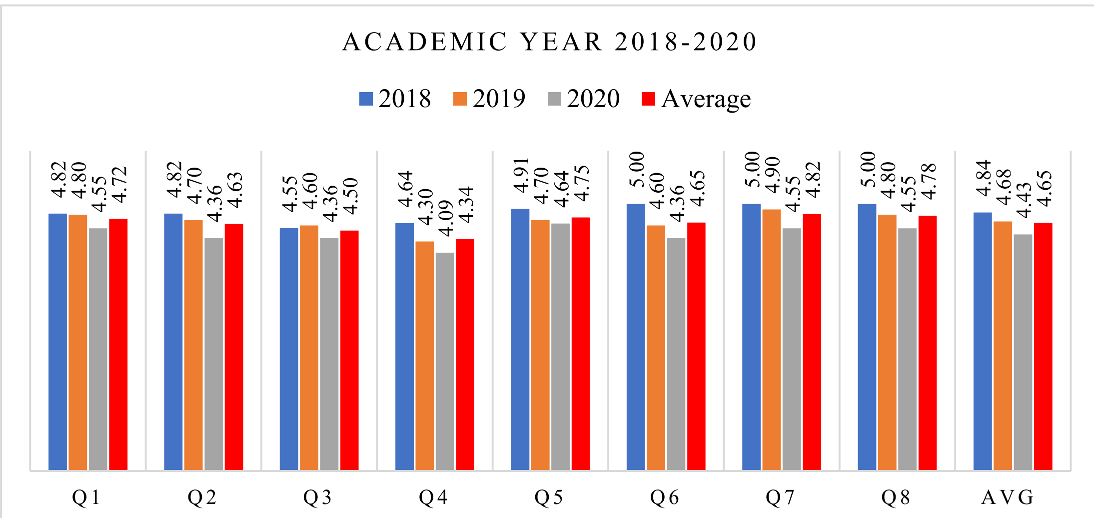


FIGURE 7. Survey results, 2018-2020, 5 points = 100%.

Step 4: Derived the *RC* network for the designed controller
Step 5: Use the control IC, UC3845 for example, with *RC* network to realize the closed-loop control

D. CLOSED-LOOP SIMULATION USING PSIM

The course modules designed based upon "*Closed-loop simulation using PSIM*" are aimed at bringing the students to **"understand the closed-loop control of power converter, and confirm the modeling and controller design"**. In the related course modules, the simulation using PSIM will help the students to have a "closed-loop" check of the modeling and systematic approach of controller design.

Figure 5(a) illustrates the PSIM circuit of closed-loop simulation for the course module using flyback converter as an example. As shown in Fig. 5(a), the control IC, UC3845, is used as the controller which is with the designed *RC* network to realize the controller. The simulation results are shown in Fig. 5(b) and Fig. 5(c). It is confirmed the output voltage of 12V can be achieved approximately at 3.5 millisecond in open loop and closed-loop simulations even with sudden load change at the time of 5 millisecond.

E. HANDS-ON REALIZATION OF CONVERTER

The course modules designed based upon "*Hands-on realization of converter*" are to achieve the objectives of **"Understand the magnetic components, and realize the power converters by PCB layout, magnetic components implementation and debug"**. Each converter course module related to "*Hands-on realization of converter*" will include realization of magnetic components as shown in Table 3, layout and making PCB, and test and debug.

The magnetic components include inductor, transformer and driver transformer are designed to be realized by the students. Skin effect and Litz wire etc. are highlighted for magnetic components implementation. The measurement of stray inductance and magnetic inductance will be addressed to students and is mandatory for the students to do such measurement.

The **Altium Designer** software is used for the PCB layout. Some notes and practical experience for layout are introduced to avoid large loop area, reduce noise, and separate power ground from signal ground, etc.

After that, the PCB for each converter with closed-loop controller is made by using either PCB etching machine or PCB mining machine on site. After that, the converter is tested and signals are measured. One of the final step is debug which is also a very valuable experience and quite helpful for the future career of students, as reflected from the graduated students taking this course.

The PCB layout and photo of the implemented flyback converter made by the student taking this course are shown in Fig. 6(a) and Fig. 6(b), respectively. A capture with experimental signals of the selected example is included in Fig. 6(c) and a photography of an experimental set-up is added to Fig. 6(d), respectively. This hands-on course is much appreciated by the students as confirmed in the assessment results.

IV. COURSE FEEDBACK AND ASSESSMENT

The formative and summative assessment methods are combined and used throughout this designed course. In the first semester, the students are required to finish the simulation with some assigned questions then upload their results to the internet server for each course module (70%) weekly, and are assessed by the final examination (30%) in which the design and simulation for one open loop and one closed loop modules should be done within 3 hours.

The formative assessment is used in the second semester, all students should demonstrate the implement converters for each course module (70%) and submit the related report (30%), no paper and final examination is given in this semester.

A survey is conducted in 2018, 2019 and 2020 to assess the course objectives. Survey statements and associated feedback from students are given in Table 6 and highlighted in Fig. 7. The overall average is 4.65 points out of five. The students showed really positive reaction to this course and are satisfied to this course arrangement. In 2020, due to the effect of COVID-19, some course modules are not fully explored which may result in all the questions are lower than the average and are the lowest in the recent three years. However, by the survey results, the students recognize that this course provides them a turn-key solution to power converter training, including the converter topology, control theory, magnetic component design, simulation and confirmation, and realization based upon hands-on training. Of course, more work in this course, including the design of controller and magnetic component of power converters, will be enhanced.

The authors will report on this in the near future, including the application of Finite Element Analysis software to the magnetic component design and analysis, especially for the applications to planar transformer.

In short, the feedback from the students indicates that this designed course receives excellent acknowledgment for providing practical training and covering the wide range of magnetic components as well as controller design in power converter learning. The designed course really facilitates the students to fully appreciate the power converter design, magnetic components and controller design as acknowledged.

V. CONCLUSION

A modular laboratory course for the industry sponsored research and design master program in power electronics is designed and presented with assessment. The course is designed for those students will join the power supply industry after graduation. Therefore, the objectives of the course will facilitate the students to (i) Appreciate the theory of power converter with the aid of the state-of-art simulation tools, (ii) Derive the converter model and design the controller, (iii) Understand the magnetic components, (iv) Realize the power converters by PCB layout, magnetic components implementation and debug, by the designed modular course. The contributions of this paper include:

1) Propose a module-based laboratory course mainly focusing on the application of various magnetic components, including inductor, transformer and driver to power converters.
2) Provide a systematic learning approach to simulation, modeling and controller design for each course module with the aid of the circuit-based software and model-based software.
3) Design the hands-on course modules for the students to realize the power converters by PCB layout, magnetic components implementation and debug.

The designed module-based laboratory course has been given for more than 15 years and assessed. Quite positive assessment results for providing systematic and practical training for learning power converters have been acknowledged from the students.

Further improvement of this course will be done based upon the survey results of student. Moreover, due to limited course hours, heat sink design is not covered in this course. It will be covered using ANSYS or FEM (Finite Element Method) software for further thermal analysis in the future as an optional course module.

Hoping this successful experience can be shared with our colleagues in this field and receive comments for our humble improvement.

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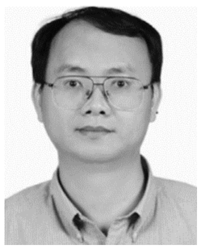

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