

23 First, we propose a project which combines all the theoretical aspects related to the
24 subject Power Electronics, namely. “Power, Control, Monitoring and Supervision (PCMS)
25 System of an Electric Motor”. Second, each subsystem of the final project is analyzed during
26 each practical lesson, and simulation environments and real circuit manipulations are used for
27 introducing complex Power Electronics concepts to undergraduate students.

28 **RESULTS:**

29 This project-based methodology has been compared with the demonstration method
30 followed in the previous course by using the validated SEEQ (Students' Evaluations of
31 Educational Quality survey).

32 **CONCLUSIONS**

33 The results show that the adopted methodology has clearly improved the SEEQ results
34 with respect to the demonstration method.

35 **Keywords**

36 Power electronics; Project-based learning; Demonstration method.

37 **Main Text**

38 **Background**

39 The recent study of 2016 conducted by the European Commission “Developing
40 Computational Thinking in Compulsory Education, Implications for Policy and Practice” argues
41 that in the last decade, computational thinking and its related concepts are receiving increased

42 attention in the educational field. Despite this widespread interest, the successful integration of
43 computational thinking in education still faces unresolved issues and challenges [1].

44 Science, Technology, Engineering, and Mathematics (STEM) education in the U.S. has
45 been identified as a significant national reform in K-16 education and curriculum in order to
46 prepare students for the global economy of the 21st century. However, the introduction of Arts in
47 Science, Technology, Engineering, Arts, and Mathematics (STEAM) education has become a
48 crucial issue in education system [2]. In STEAM academic programs, some subjects should
49 present strong correlation among different related subjects during several courses, as well as
50 among subjects in the same course due to the particular characteristics of the specialization being
51 studied. Such subjects should share both theoretical concepts and didactic methodologies.

52 Traditionally, there is no well-established coordination, neither horizontally nor
53 vertically, among the different subjects of a certain specialization since the lecturers are limited
54 to follow the strictly close subject syllabus without taking into account the contents of the other
55 subjects lectured in the same degree. Thus, no coordination between subjects is performed,
56 producing that students do not acquire the entire knowledge in a proper way.

57 In particular, the coordination among several subjects taught in the same semester and
58 course has several advantages, such as resources optimization, global learning and
59 complementary knowledge acquired by the students between different subjects, among others.
60 However, this horizontal coordination involves challenges due to the normal disparity of the
61 close subject projects, in addition to the different point of views of the different lecturers. In this
62 case, it is mandatory that professors keep in mind that the common interest of the student
63 learning has to be the primary goal.

64 Beyond the advantages of vertical and horizontal coordination among subjects, the use of
65 novel didactic approaches in STEAM academic programs is a relevant topic in current
66 educational research. Musing et al. proposed the use of an open online simulation tool for
67 teaching power electronics [3]. One of the major challenges of simulation-based educational
68 approaches for the students is to provide a computer interface where the concepts of power
69 electronics can be explored without requiring a skilled usage of the software environment.
70 Córdova-Acosta et. al demonstrated the use of intuitive simulation environments to be useful
71 tools to introduce complex Power Electronics concepts to undergraduate students, e.g. time-
72 domain oscillatory modes [4] . Other novel approaches proven to improve the education on
73 Electronics are the use of virtual instrumentation environments [5], and more modern approaches
74 are introducing the use of Artificial Reality (AR) to this end [6].

75 Besides the use of simulators or virtual environments, Bonisławski et al. proposed an
76 approach for teaching Power Electronics based on hardware modules, a and computerized
77 control [7]. The prebuilt hardware modules were demonstrated to alleviate the efforts in the pre-
78 configuration of devices, making possible for the students to increase the time spent on
79 experimental tasks. One of the main contributions of this approach is an intuitive Graphical User
80 Interface (GUI) for controlling the modules.

81 In this manuscript, we present a project-based approach for lecturing Power Electronics.
82 The final goal is to develop a subsystem, which will eventually be a part of a biggest system
83 where the Power Electronic stage is used in a higher level of abstraction. The manuscript is
84 organized as follows: firstly the course design and implementation is described including the
85 context, objectives and followed methodologies; secondly the results based on a SEEQ
86 (Students' Evaluations of Educational Quality) survey [8], an instrument and program for

87 collecting students' evaluations of college/university teaching, are presented, and finally relevant
88 conclusions are highlighted.

89 **Objective**

90 As previously explained, the main objective of this methodology applied in the subject of
91 Power Electronics is to enhance the attention and motivation of the students in the practical
92 lessons, increasing their knowledge about the subject and, hence, improving the results in the
93 theoretical part of the subject. The main problem related to the practical lessons of the diverse
94 laboratories is the non-effective application of the individual practical lessons in a global system
95 where the student could learn how the different theoretical and practical lessons could interact
96 with each other in a real application.

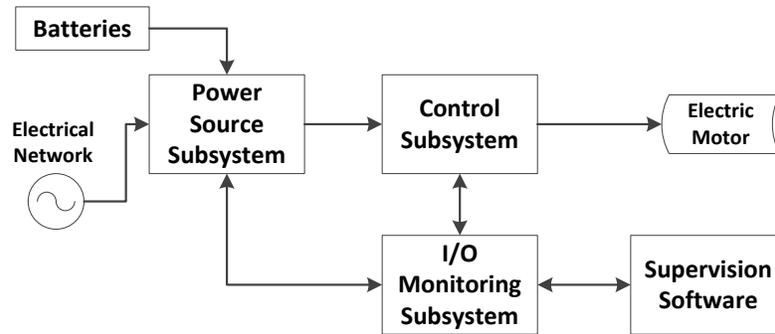
97 The target of this specific project is to emulate the power subsystem of an Electronic
98 Vehicle (EV). This is a highly demanded application in today's automotive industry. The project
99 covers the syllabus of an entire subject. Such syllabus includes power supplies (linear and
100 switched), DC (Direct Current) Boosters and Buck converters, three phase inverters, and
101 electronic control applications using ARM (Advanced RISC Machines) microcontrollers at a
102 basic level. Besides the aforementioned topics, the use of this PBL (Project-Based Learning)
103 project allowed the lecturers to introduce student in several skills which are not strictly in the
104 standard curriculum of Power Electronics. For example, in this project, students are introduced to
105 the concepts and usage of batteries and their respective motors, motor controllers with Hall
106 sensors, and basic programming with ARM microcontrollers. Finally, all the subsystems are
107 assembled in order to achieve a fully functional battery management module.

108 The main goal of the implementation of this PBL methodology is to provide the students
109 with a real-world project, which may motivate them, with the goal of providing an improved and
110 efficient learning experience. As mentioned before, the proposed real-world project consists of a
111 basic prototype of an EV. The EV has a power system composed of a charger, a DC-DC
112 converter, a BMS (Battery Management System) and the batteries. The behavior of this EV
113 prototype is as follows. The energy stored in the batteries is delivered to the Boost through the
114 BMS. The use of a BMS is necessary to ensure the energy charging and discharging of batteries
115 based on Lithium technology are carried out safely. Any small deviation from the minimum or
116 maximum voltage of such type of batteries can cause non-reverse damage in the batteries. The
117 Boost keeps the voltage constant at the input of the BLDC (Brushless Direct Current) inverter at
118 24 V. This is important since the voltage in the batteries will be reduced as the energy stored in
119 them is used. This 24 V will be applied to the Buck converter, which will perform the
120 appropriate switching to correctly excite the three motor windings, depending on the target speed
121 and position in which the moving part of the motor is located (this position is detected by the
122 Hall sensors inside the motor). Different parameters, such as the motor starting, the speed, the
123 braking, the direction changes, and the charging and discharging of the batteries, are configured
124 through the ARM microcontroller programmed by the student. All the aforementioned
125 parameters are also continuously monitored using the microcontroller.

126 The project was called “Power, Control, Monitoring and Supervision (PCMS) System of
127 an Electric Motor”. Figure 1 shows the block diagram of the proposed modular system. The three
128 subjects included in this project should have well-defined tasks within the project. Within this
129 manuscript, only the work performed in the Power Electronics subject will be presented and
130 discussed. The other two subjects will be addressed in future works in order to achieve a better
131 horizontal coordination between the different subjects. The Industrial Computing subject will be

132 mainly focused in the development of the supervision software of the system, while the Project
133 Management subject will be in charge of the concepts related to the scheduling and coordination
134 of the different tasks performed in the other two subjects, as well as the supervision of the overall
135 progress of the project.

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138 **Figure 1. Block diagram of the Power, Control, Monitoring and Supervision System of an**
139 **Electric Motor.**

140

141 *Research Objectives and Questions*

142 Following the main objective of increasing the motivation and attention of students, the
143 research objectives and associated questions are based on the following topics:

- 144 • Presenting the practical lessons in detail in order to clearly state how the sessions
145 were organized based on two different methodologies: demonstration method and
146 power-based learning. The idea is to answer the question: what are the main
147 characteristics of our adapted PBL approach and the differences with respect to the
148 previous method?
- 149 • Checking if a change of methodology from the demonstration method to a project-
150 based learning method in the mentioned subject of Power Electronics enhances

151 students' perception. It answers the question: on a general basis, is there a change in
152 students' perception?

- 153 • Categorizing the main differences between the previous approach of the subject and
154 the current proposal, based on a validated questionnaire. The question to answer is:
155 what are the main differences between the demonstration method and the adapted
156 PBL approach?

157 **Methods**

158 *Context*

159 This work is focused in the subjects called “Power Electronics” (60 hours), “Industrial
160 Computing” (60 hours) and “Project Management” (30 hours); held in the first semester of the
161 fourth course of “Automatic and Electronic Industrial Engineering” bachelor degree. These
162 subjects were taught in the campus of Tafira of the University of Las Palmas de Gran Canaria,
163 Canarias, Spain. The practical lessons were carried in a laboratory composed by 20 laboratory
164 benches. Each bench was equipped with a desktop PC, a DC power supply, a multimeter, an
165 oscilloscope, a signal generator, a protoboard and several connection cables and electronic
166 devices.

167 Particularly, this paper is focused on the implementation of a methodology to teach the
168 practical lessons of the subject Power Electronics based on a modular system of a “Power,
169 Control, Monitoring and Supervision System of an Electric Motor”. This methodology was
170 applied during the 2019-2020 academic year, comparing the results obtained with the
171 methodology of the previous academic year (2018-2019), based on demonstration method. The
172 average number of students in this subject per academic year is 30.

173 The proposed survey based on the validated SEEQ. SEEQ is an instrument and program
174 for collecting students' evaluations of college/university teaching. It measures nine distinct
175 components of teaching effectiveness that have been identified in both student ratings and
176 faculty self-evaluations of their own teaching. Bases on previous SEEQ results, it is considered
177 that reliability is good when based upon 10 to 15 or more students [8].

178 ***Previous methodology: demonstration method***

179 The traditional methodology employed for the learning of the Power Electronics subject
180 was based on the demonstration method. This method provides lessons by exhibiting and
181 demonstrating. It demonstrates things, events, rules, and sequences of activities, either directly or
182 through using instructional media which is relevant to the subject matter or material that will be
183 presented. The purpose of teaching using a demonstration method is to show the process of
184 occurrence of an event according to the teaching materials, how they are attained and the ease to
185 be understood by the students in teaching learning process [9].

186 Therefore, laboratory practices were mainly based on simulations and were intended to
187 reinforce theoretical concepts, following the subject syllabus.

188 ***Proposed project-based power electronics laboratory methodology***

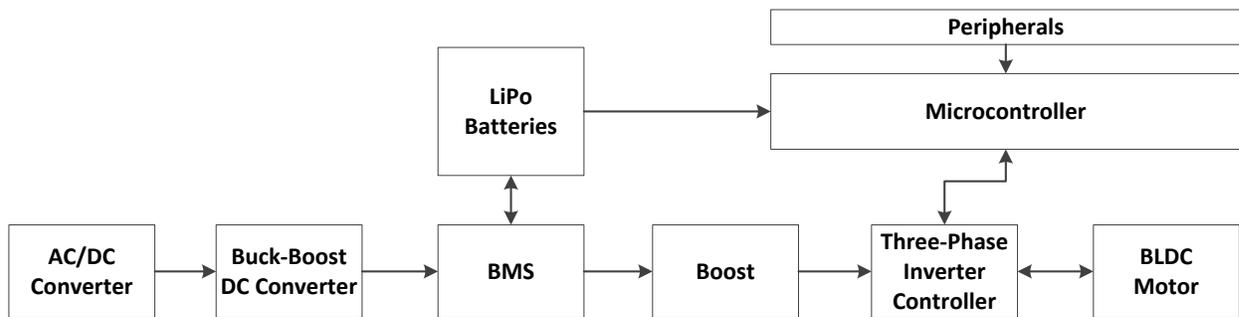
189 In the present education system an adequate complement is PBL [10,11]. PBL is based on
190 an experience concept. It consists of a dynamic view, proposed by John Dewey, who presented a
191 vision of PBL not only related to knowledge, but as an exchange between the human being and
192 his social and physical environment [12]. Currently knowledge is available on the Internet in free
193 and open format. Therefore, learning organized by skills should be encouraged.

194 Several PBL experiences at university level in the scope of computer applications in
195 engineering education have been considered in the past. In [13], a distributed 3D lab system was
196 based on project-based learning method, supporting knowledge-based instant conversation and
197 semi-automatic experiment creation. Similarly, in [14], an innovative project-based learning
198 approach using an FPGA-based tool in order to teach image processing algorithms was
199 presented. This article describes an approach that integrates a student teamwork methodology
200 (TSPi) and project-based learning (PBL) to improve software project managerial skills in
201 undergraduate students. Project-Based learning has been also used together with other
202 methodologies as student teamwork methodology (TSPi) to enhance software project managerial
203 skills in undergraduate students [15].

204 More specifically, in terms of Power Electronics PBL, there are some experiences in the
205 state of the art which include statistics based on several aspects, but not using a validated
206 questionnaire. In [16], a power electronics course addressing the topics of DC/DC and DC/AC
207 (Alternating Current) converters to build a complete system details how to use project-based
208 learning to increase student performance and satisfaction. Results were based on several Likert-
209 scale questions and students' marks. Belu et al. [17] proposed a project-based teaching approach
210 combining undergraduate and graduate courses in Power Electronics, based on learning
211 objectives of university and college students. A specific questionnaire for the course evaluation
212 was designed. Finally, Lamar et al. [18] presented a PBL approach to teach power electronics,
213 highlighting the main difficulties found and comparing students' marks with previous courses
214 not using PBL. Their approach consists in producing a switching-mode power supply. Our
215 proposal follows a global strategy in the subject, and is developed from scratch, and the rationale
216 for the schedule and conceptualization of the laboratory lessons consisted in the application of

217 specific contents of the Power Electronics subject in different stand-alone subprojects, which
218 cover the syllabus of the subject.

219 The proposed system shown in Figure 1 will compose the main part of the project, which
220 involves the Hardware modules employed during the practical lessons. In Figure 2, the block
221 diagram of the complete system assembly is shown. The system is divided into several self-
222 contained practical lessons. However, they are joint in order to achieve the final complete
223 system, which is based on the development of a BMS for a BLDC motor and its control system
224 using an Arduino microcontroller.



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226

227 **Figure 2. Block diagram of the modules that compose the complete system. Each one of**
228 **these modules will be developed throughout several laboratory practices.**

229

230 Prior to each laboratory session, the students perform a previous study about each module that
231 will be used. This previous study involves theoretical calculations, the selection of the electronic
232 components, and also a set of simulations devoted to perfectly understanding each model before
233 using it in the laboratory. Next, in the laboratory, the students have to identify the different
234 components in each module and verify its behavior through different measurements and
235 modifications performed to the module itself.

236 Table 1 shows a summary of the contents and schedule of the practical lessons for both the
237 previous lecturing methodology (based on a theoretic demonstration method), and for the

238 project-based lecturing methodology. Some of the practical lessons involve complex Power
 239 Electronics concepts, such as the DC/AC converter control and boost feedback control. At the
 240 time the Power Electronics practical lessons are lectured, the students have already learned the
 241 required background to understand and apply such complex concepts targeting a realistic
 242 application. The practical lessons allow the students to get further intuitions and implications
 243 about such theoretical concepts. In Appendix 1, each practical lesson for the project-based
 244 methodology are detailed.

245 **Table 1. Summary of practical lessons in the previous methodology and the current**
 246 **methodology.**

Session	Previous methodology	Current Methodology
1	AC-DC Converters	AC-DC Converters
2	DC-DC Buck regulator	DC-DC Converters. Buck-Boost
3	DC-DC Boost regulator	BMS with and LiPo battery.
4	DC-DC regulators: feedback and compensation	DC-DC Boost with feedback and compensation connected to BMS with LiPo Battery
5	Single and three-phase AC-DC converters. Pulse with Modulation techniques	BDLC motor with Three Phase DC Inverter and System Control with Hall Position Sensor

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 248
 249 Regarding the implementation of this project, the number of groups in the laboratory is
 250 10, and each group is formed by two students. The subject is divided in two differentiated parts.
 251 First, theoretical lessons are lectured, and then the concepts which have been acquired are
 252 applied to realistic examples of usage of the different power electronic circuits and devices
 253 during the laboratory lessons. Regarding the evaluation of the subject, each part is evaluated
 254 independently. For the theoretical part of the subject, a final written exam was performed. On the
 255 contrary, for the laboratory lessons, the evaluation consisted in the continuous assessment of the
 256 success realization of the practical lessons. In order to pass the laboratory lessons, the students
 257 have to prove valid skills in: 1) the usage of simulation tools; 2) the assembly of different
 258 electronic parts and devices; 3) the correct utilization of the electronic instrumentation; and 4)

259 the adequate procedures to perform measurements. This strategy supports PBL advantages such
260 as students' motivation and enthusiasm, better group interaction and practical learning as
261 demonstrated by the results shown in this paper. Beyond demonstrating the aforementioned
262 skills, the most important criteria to evaluate the students is the correct application of the
263 theoretical concepts in real-world projects. Some examples of the improved understanding of
264 real-world concepts are the following:

- 265 • **Duty cycle:** The students are capable to realize about the difference in the
266 theoretical, simulated, and real duty cycle. This effect can be further observed when
267 visualizing the squared pulse signal after the MOSFETs transistors switching.
- 268 • **Circuits performance:** The efficiency of the circuit is calculated through the
269 quotient between the measured output and input power. The students can learn about
270 the improved efficiency of the circuit compared with a linear stabilizer. Beyond the
271 measures using instrumentation, the students also get an intuition about the efficiency
272 of the proposed circuit compared with a linear stabilizer by measuring the power
273 dissipation using a temperature measurement system.
- 274 • **Use of real components:** The students make use of surface-mount technology
275 (SMD) for all the electronics components, including the inductors and the capacitors
276 used in the filters. The students can realize how the welding quality can influence the
277 efficiency of the circuit. This is observed by comparing the efficiency of different
278 PCB (Printed Circuit Boards) with different welding quality.

279 **Results**

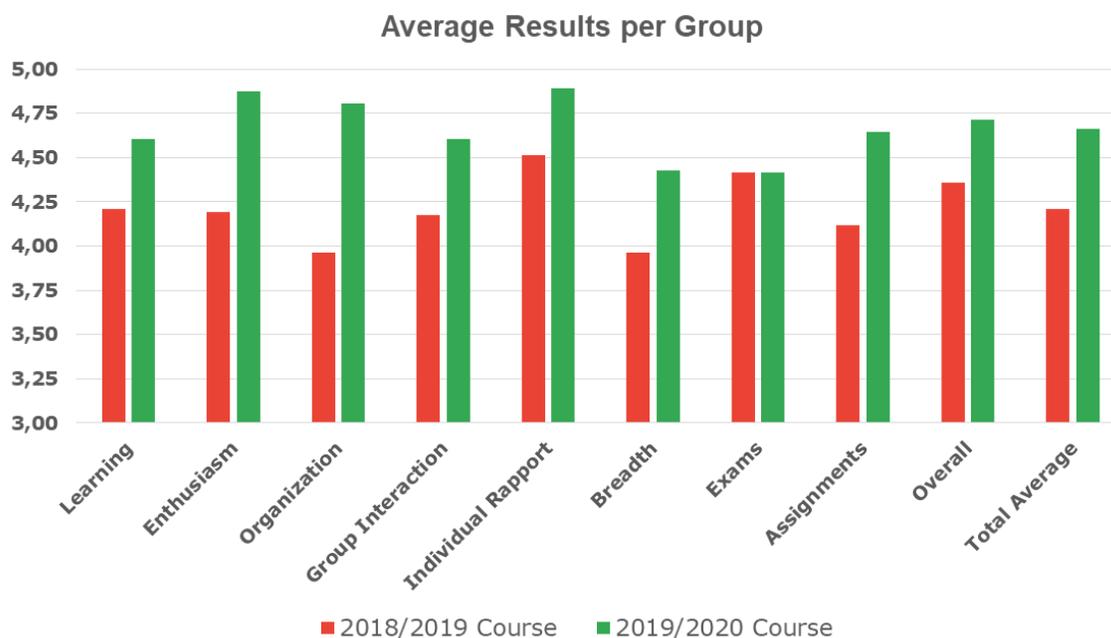
280 The considered results are based on a satisfaction survey which was sent to students who
281 passed the course in which the presented methodology was considered (sample of 14 students)
282 and the previous course students (in which it was not considered and the sample was 18
283 students).

284 A total of 32 Likert type questions with a range from 1 to 5 (strongly disagree to strongly
285 agree) were proposed. These questions are organized, as commented before, in nine different
286 groups, presented in Table 2, whose complete results are presented in Table 3 and average results
287 per group in Figure 3.

288 **Table 2. SEEQ questions and groups.**

ID	Group	Questions
1	Learning	1-4
2	Enthusiasm	5-8
3	Organization	9-12
4	Group interaction	13-16
5	Individual Rapport	17-20
6	Breadth	21-24
7	Exams	25-27
8	Assignments	28-29
9	Overall	30-32

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Figure 3. Average results per group according to SEEQ.

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As presented in Figure 3, the adopted methodology has improved the SEEQ results in all areas, excepting on exams, whose average result (4,42) did not change.

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With respect to the detailed results in Table 2, several questions were highly marked, with more than 4.8 points in the Likert scale: 2, 5, 6, 7, 9, 10, 17, 19, 20 and 31. Special attention should be given to the change in the answers to question 10 (“Subject materials were well prepared and carefully explained”), passing from 3.69 to 4.86 points, giving a difference of 1.17 points.

297

298

Table 3. SEEQ Results before and after applying the methodology.

Question	Course 2018/2019	Course 2019/2020	Difference 2019/2020 - 2018/2019
1.- I have found the subject intellectually challenging and stimulating	4,23	4,64	0,41
2.- I have learned something which I consider valuable	4,46	4,86	0,40
3.- My interest in the theme has increased as a consequence of this subject	4,00	4,50	0,50
4.- I have learned and understood the contents of this course	4,15	4,43	0,28
5.- The teacher was enthusiastic about teaching the subject	4,15	4,93	0,78
6.- The teacher was dynamic and energetic in conducting the subject	4,15	4,93	0,78
7.- The teacher enhanced presentations with the use of humor	4,46	4,93	0,47
8.- Teacher's style of presentation held my interest during class	4,00	4,71	0,71

9.- Teacher's explanations were clear	4,08	4,86	0,78
10.- Subject materials were well prepared and carefully explained	3,69	4,86	1,17
11.- Proposed objectives agreed with those actually taught so I knew where the subject was going	4,15	4,79	0,63
12.- The teacher gave lectures that facilitated taking notes	3,92	4,71	0,79
13.- Students were encouraged to participate in class discussions	4,00	4,71	0,71
14.- Students were invited to share their ideas and knowledge	4,31	4,50	0,19
15.- Students were encouraged to ask questions and were given meaningful answers	4,46	4,64	0,18
16.- Students were encouraged to express their own ideas	3,92	4,57	0,65
17.- Teacher was friendly towards individual students	4,54	4,93	0,39
18.- The teacher made students feel welcome in seeking help/advice in or outside of class	4,69	4,79	0,10
19.- The teacher had a genuine interest in individual students	4,23	4,86	0,63
20.- The teacher was adequately accessible to students during office hours of after class	4,58	5,00	0,42
21.- The teacher contrasted the implications of various theories	4,15	4,50	0,35
22.- The teacher presented the background or origin of ideas/concepts in our outside of class	3,62	4,21	0,59
23.- The teacher presented points of view other than his/her own when appropriate	3,85	4,36	0,51
24.- The teacher adequately discussed current developments in the field	4,23	4,64	0,41
25.- Feedback on examinations / graded materials was valuable	4,33	4,42	0,09
26.- Methods of evaluating student work were fair and appropriate	4,23	4,42	0,19
27.- Examinations / graded materials tested course content as emphasized by the instructor	4,69	4,42	-0,27
28.- Required readings / texts were valuable	3,92	4,57	0,65
29.- Reading, homework, laboratories contributed to appreciation and understanding of subject	4,31	4,71	0,40
30.- Compared with other subjects I have had at the university, I would say this subject is:	4,23	4,50	0,27
31.- Compared with other teachers I have had at the university, I would say this instructor is:	4,46	4,86	0,40
32.- As an overall rating, I would say the teacher is:	4,38	4,79	0,41

300

301 Discussion

302 Considering the research objectives of this study, and after evaluating the results, it is
303 clear that the PBL approach requires an extra effort in terms of organization and assignments
304 preparation. This can be understood from the required level of detail in order to conform a
305 coherent project, as presented in section “Proposed project-based power electronics laboratory
306 methodology”.

307 However, with this study, and based on the performed quantitative analysis, it has been
308 verified that a change of methodology from the demonstration method to a project based learning
309 method in the mentioned subject of Power Electronics enhances students perception. As a matter
310 of fact, this is true for all the categories considered according to the SEEQ methodology.

311 Moreover, there are some aspects specially highlighted by students when comparing PBL with
312 respect to the demonstration method. Following the initial research objective, based on
313 categorizing the main differences between the two proposed methods, the groups with a relevant
314 improvement (more than 0.5 points in the Likert scale) are:

- 315 • Organization: 0.84 points, from 3.96 to 4.8.
- 316 • Enthusiasm: 0.68 points, from 4.2 to 4.88.
- 317 • Assignments: 0.54 points, from 4.12 to 4.64.

318 Therefore, although the PBL approach requires probably more preparation time than the
319 demonstration method approach, not only the organizational and tasks assignment aspects are
320 highlighted by students, but also the enthusiasm. In fact, when an open question devoted to
321 providing any comment/feedback was reviewed, students highlighted the subject laboratory
322 lessons as quite enriching as well as the relation of the subject with real life problems. However,
323 on the one hand, 2018/2019 students commented that the theoretical and practical lessons were
324 not well aligned and thus the subject material could be improved. On the other hand, 2019/2020
325 students considered that subject teachers were very involved, improving student's participation
326 due to motivation. As teachers did not change from one course to the following, it can be
327 concluded that the project-based approach not only motivate students, but also teachers, as they
328 probably feel that the teaching method is more appropriate considering the subject objectives.

329 **Conclusions**

330 After assessing a comparative between two different courses using two methodologies:
331 project-based learning and demonstration method for lecturing Power Electronics, it can be
332 concluded that the use of project-based learning improves the teaching-learning process

333 according to the validated SEEQ. In fact, the adopted methodology has improved the SEEQ
334 results in all areas, excepting on exams, whose average result (4,42) did not change. This
335 demonstrates that the final goal, which was to develop a subsystem considering project-based
336 learning clearly motivated students. Therefore, the research objectives related to the
337 methodologies presentation, the enhancement of students' perception due to the change of
338 methodology and the categorization of the main differences between the two proposed methods
339 (organization, enthusiasm and assignments) have been accomplished.

340 Thus, the presented project-based learning approach can be considered as a successful
341 case of correlation among different related subjects during several courses, as well as among
342 subjects in the same course due to the particular characteristics of the specialization being
343 studied. Moreover, students have highlighted that subject teachers were very involved,
344 motivating students' participation.

345 Future studies will consider collaboration approaches among different faculties in the
346 same university, in order to even enrich more the learning process and make the student
347 conscious of the relationship among Science, Technology, Engineering, Arts and Mathematics
348 competences.

349 **Data Availability Statement**

350 The data that support the findings of this study are available from the corresponding author upon
351 reasonable request.

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417 **Tables**

418 **Table 2: Summary of practical lessons in the previous methodology and the current.**
 419 **methodology**

Session	Previous methodology	Current Methodology
1	AC-DC Converters	AC-DC Converters
2	DC-DC Buck regulator	DC-DC Converters. Buck-Boost
3	DC-DC Boost regulator	BMS with and LiPo battery.
4	DC-DC regulators: feedback and compensation	DC-DC Boost with feedback and compensation connected to BMS with LiPo Battery
5	Single and three-phase AC-DC converters. Pulse with Modulation techniques	BDLC motor with Three Phase DC Inverter and System Control with Hall Position Sensor

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Table 2. SEEQ questions and groups.

ID	Group	Questions
1	Learning	1-4
2	Enthusiasm	5-8
3	Organization	9-12

4	Group interaction	13-16
5	Individual Rapport	17-20
6	Breadth	21-24
7	Exams	25-27
8	Assignments	28-29
9	Overall	30-32

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Table 3. SEEQ Results before and after applying the methodology.

Question	Course 2018/2019	Course 2019/2020	Difference 2019/2020 - 2018/2019
1.- I have found the subject intellectually challenging and stimulating	4,23	4,64	0,41
2.- I have learned something which I consider valuable	4,46	4,86	0,40
3.- My interest in the theme has increased as a consequence of this subject	4,00	4,50	0,50
4.- I have learned and understood the contents of this course	4,15	4,43	0,28
5.- The teacher was enthusiastic about teaching the subject	4,15	4,93	0,78
6.- The teacher was dynamic and energetic in conducting the subject	4,15	4,93	0,78
7.- The teacher enhanced presentations with the use of humor	4,46	4,93	0,47
8.- Teacher's style of presentation held my interest during class	4,00	4,71	0,71
9.- Teacher's explanations were clear	4,08	4,86	0,78
10.- Subject materials were well prepared and carefully explained	3,69	4,86	1,17
11.- Proposed objectives agreed with those actually taught so I knew where the subject was going	4,15	4,79	0,63
12.- The teacher gave lectures that facilitated taking notes	3,92	4,71	0,79
13.- Students were encouraged to participate in class discussions	4,00	4,71	0,71
14.- Students were invited to share their ideas and knowledge	4,31	4,50	0,19
15.- Students were encouraged to ask questions and were given meaningful answers	4,46	4,64	0,18
16.- Students were encouraged to express their own ideas	3,92	4,57	0,65
17.- Teacher was friendly towards individual students	4,54	4,93	0,39
18.- The teacher made students feel welcome in seeking help/advice in or outside of class	4,69	4,79	0,10

19.- The teacher had a genuine interest in individual students	4,23	4,86	0,63
20.- The teacher was adequately accessible to students during office hours of after class	4,58	5,00	0,42
21.- The teacher contrasted the implications of various theories	4,15	4,50	0,35
22.- The teacher presented the background or origin of ideas/concepts in our outside of class	3,62	4,21	0,59
23.- The teacher presented points of view other than his/her own when appropriate	3,85	4,36	0,51
24.- The teacher adequately discussed current developments in the field	4,23	4,64	0,41
25.- Feedback on examinations / graded materials was valuable	4,33	4,42	0,09
26.- Methods of evaluating student work were fair and appropriate	4,23	4,42	0,19
27.- Examinations / graded materials tested course content as emphasized by the instructor	4,69	4,42	-0,27
28.- Required readings / texts were valuable	3,92	4,57	0,65
29.- Reading, homework, laboratories contributed to appreciation and understanding of subject	4,31	4,71	0,40
30.- Compared with other subjects I have had at the university, I would say this subject is:	4,23	4,50	0,27
31.- Compared with other teachers I have had at the university, I would say this instructor is:	4,46	4,86	0,40
32.- As an overall rating, I would say the teacher is:	4,38	4,79	0,41

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Figure legends

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Figure 1. Block diagram of the Power, Control, Monitoring and Supervision System of an Electric Motor

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Figure 2. Block diagram of the modules that compose the complete system. Each one of these modules will be developed throughout several laboratory practices.

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Figure 3. Average results per group according to SEEQ.

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Appendix 1: Description of the laboratory lessons

Practical lesson 1

The objectives of this lesson are related with the following concepts:

- a) To manage and understand the concepts related to the rectifier circuits explained in theory class.
- b) To implement the design of an uncontrolled AC-DC converter based on initial operating specifications.
- c) To apply the right criteria in the choice of the components that conform the power converter circuit.
- d) To check with the measures deemed appropriate that the circuit designed and mounted on a board meets the operating specifications.

Figure 4 shows the electronic scheme to be used in this lesson. In this lesson, the student will necessarily calculate and select, among other elements, the correct filtering capacity. The minimum filtering capacity must comply, within the limitations of the previously chosen transformer and bridge rectifier circuit (Figure 5).

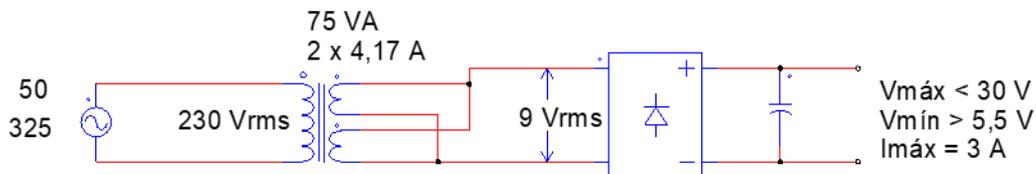
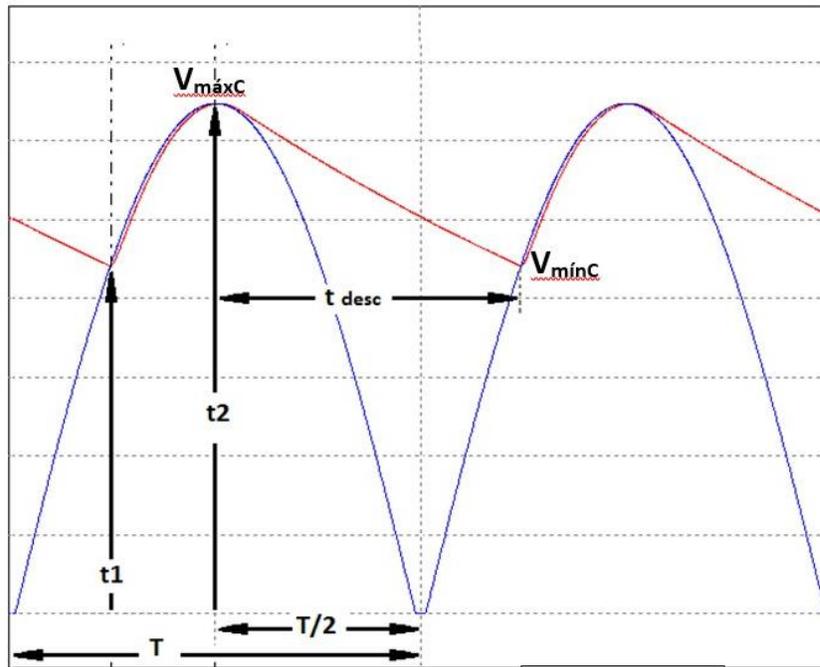


Figure 4. Circuit scheme employed in the practical lesson 1



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Figure 5. Output voltage of the rectifier without filter (blue line) and with the capacitor filter (red line)

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Practical lesson 2

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In this lesson, the objectives are related with the following concepts:

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a) To design an open loop DC-DC converter circuit based on the operating specifications.

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b) To simulate the elevator circuit employing the selected components and to adjust the duty cycle to meet the operating requirements. The components will be selected taking into account the information available in their datasheets.

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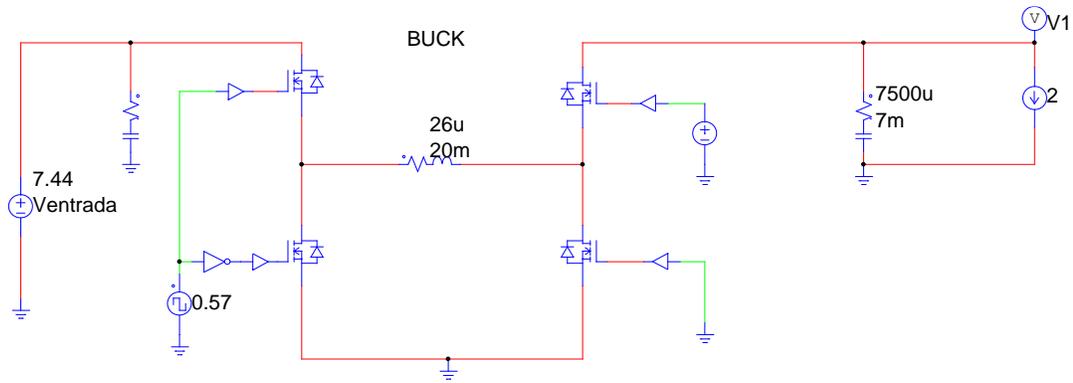
c) To connect the linear power supply of the previous lesson to the input of the Buck-Boost DC converter available in the laboratory.

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d) To adjust the output voltage of the converter with the right load to the value indicated by the professor in the laboratory.

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487

488 **Figure 6. Electrical scheme of the Buck-Boost converter running in voltage reduction**
 489 **model**

490 As in the previous lesson, the students have to design, select the real components,
 491 simulate and work with the module, adjusting the value of the output voltage to the maximum
 492 charge value of the lithium polymer (LiPo) battery pack that will be used in the next lesson. The
 493 circuit is simulated after selecting the components and performing the calculations in the two
 494 possible operation modes: Buck (Figure 6) and Boost.

495 **Practical lesson 3**

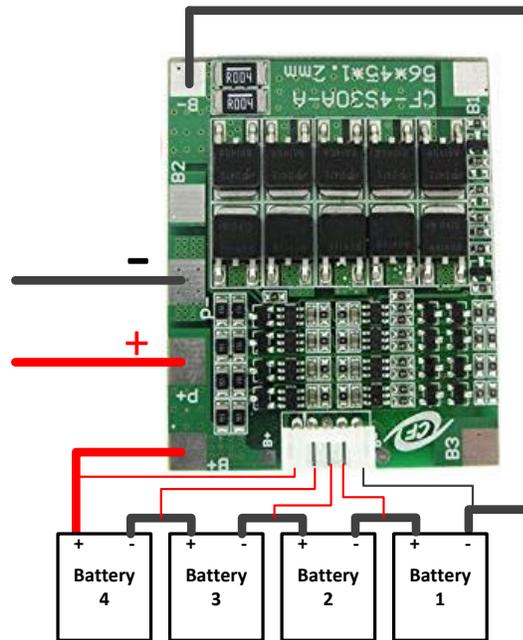
496 The objectives of this lesson are the following:

- 497 a) To connect the linear power supply developed in the previous practice to the input
 498 of the Buck-Boost DC converter and then the BMS with the LiPo battery.
- 499 b) To adjust the output voltage and current of the converter with the appropriate load
 500 to the value indicated by the professor in the laboratory.
- 501 c) To verify the correct operation of the BMS.

502 The main work performed in this lesson is based on the verification of the operation of
 503 the BMS. Despite this, during the lesson, there were many accidents due to the burning of the
 504 thin wires. This experience resulted in a learning of the students about the carefully management

505 of this type of systems, which work with considerable high currents of the order of 100 A. In
506 addition, the students had the opportunity to discuss the different technologies of electrical
507 energy storage with their advantages and disadvantages, opening the way to new intelligent
508 systems of BMSs.

509 The assembly of the system in this lesson can be seen in Figure 7.



510

511 **Figure 7. Wiring diagram of a BMS with 4 rechargeable LiPo battery cells**

512 **Practical lesson 4**

513 This lesson has the following main objectives:

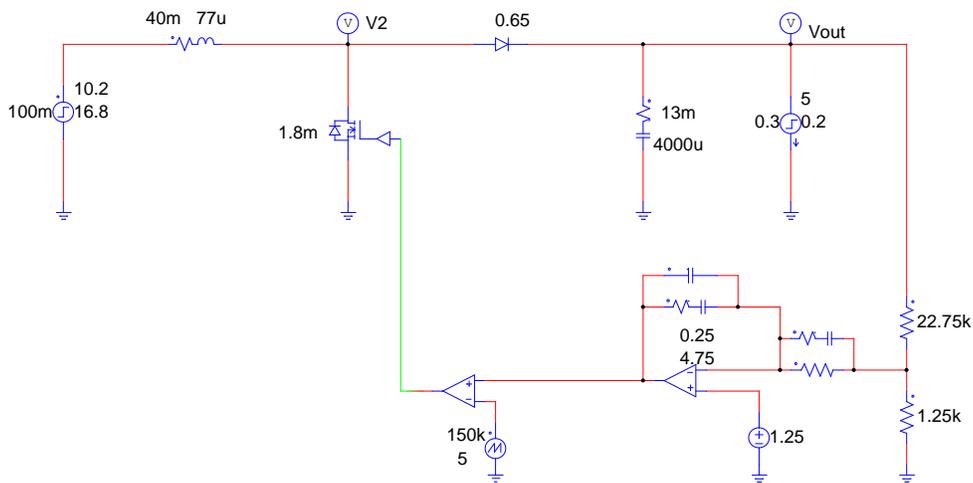
514 a) To design an elevator DC-DC converter circuit based on the operating
515 specifications.

516 b) To simulate the elevator circuit employing the selected components and to adjust
517 the duty cycle to meet the operating requirements. The components will be
518 selected taking into account the information available in their datasheets.

- 519 c) To incorporate a feedback with the corresponding compensation in the fully
 520 designed system in order to achieve a fully controlled system.
- 521 d) To interconnect the LiPo battery, the BMS and the Boost.
- 522 e) To adjust the output voltage and current of the converter with the appropriate load
 523 to the value indicated by the professor in the laboratory.
- 524 f) To verify the correct operation of the Boost.

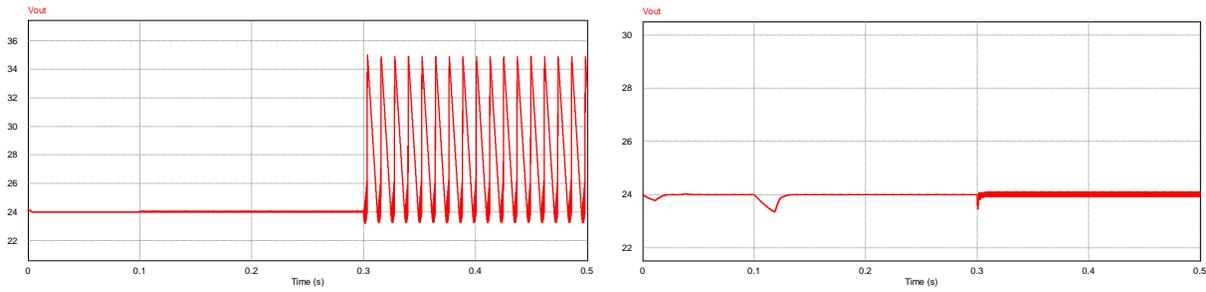
525 This lesson is focused in the additional difficulty of the transfer function that can be
 526 found in a feedback booster converter to learn how to make an adequate compensation in the
 527 most difficult way. The feedback will be performed in voltage mode, achieving the best
 528 compensation possible. The circuit scheme of the voltage booster converter employed in the
 529 simulation is presented in Figure 8. The result of the uncompensated and compensated system
 530 can be seen in (a) (b)

531 Figure 9. When assembling the complete system (Figure 10), the output voltage is
 532 adjusted to 24 V and the protection of the LiPo battery discharge is verified by the BMS, as well
 533 as the stability of the output voltage.



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535 **Figure 8. Electronic scheme of the voltage booster converter with the values of the actual**
536 **components, including the proposed disturbances**

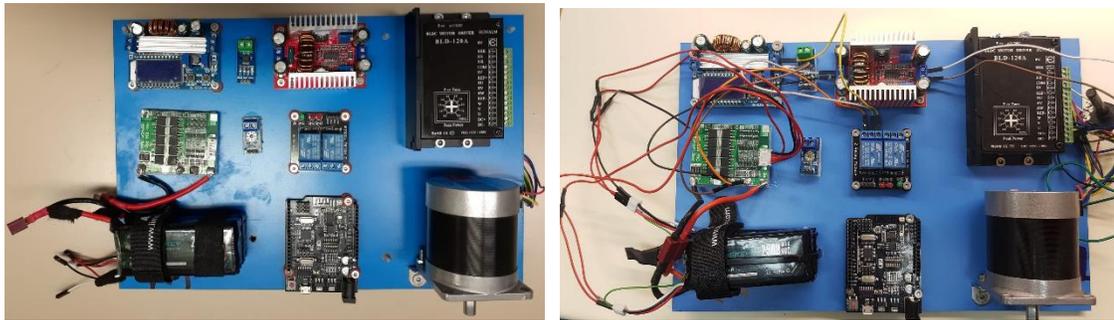


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538 (a)

(b)

539 **Figure 9. Output voltage obtained from two different disturbances, one disturbance voltage**
540 **at 100 ms and another one disturbance current at 300 ms. (a) Uncompensated System. (b)**
541 **Compensated system**



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(a)

(b)

544 **Figure 10. Developed final modular system. (a) Unassembled. (b) Assembled**

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546 **Practical lesson 5**

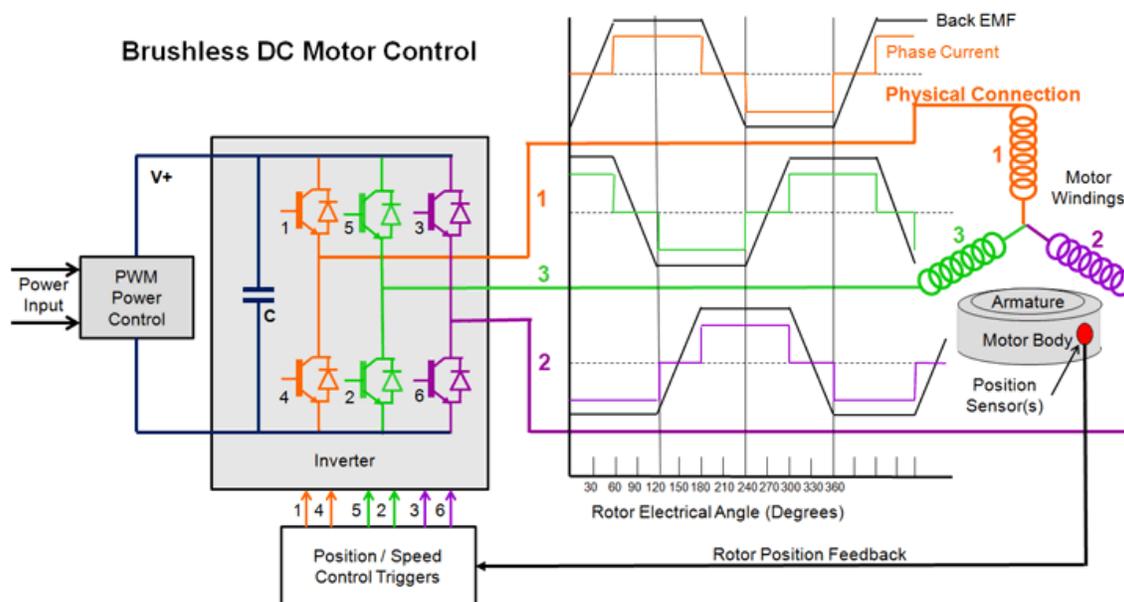
547 The objectives of this final lesson are the following:

548 a) To verify the operation of a BLDC motor.

549 b) To perform the system control programming using a microcontroller (Arduino based
550 system).

551 The students will learn the operation of the three-phase inverter, the controller stage and
 552 BLDC motor. In order to verify the operation of the elements studied in this lesson, all the stages
 553 previously studied are connected in a single complete system. Next, the ENABLE and SV input
 554 signals are enabled, allowing the motor to reach the maximum speed. The voltage between the
 555 different phases and the voltage of the different HALL sensors are visualized using the
 556 oscilloscope (Figure 11).

557 Regarding to the Arduino's programming it will consist on: 1) the use of relay number 1
 558 to activate the battery charge-discharge functions by reading a push-button switch; 2) the use of
 559 relay number 2 to cause motor braking by grounding the BRK input of the controller. To do this,
 560 the relay will read a push-button switch; 3) the use of the PWM (Pulse-Width Modulation)
 561 generator, through D5 or D6 outputs, will produce a square signal of 980 Hz. The work cycle of
 562 this signal can be varied by two procedures to be read from: keyboard or potentiometer position.
 563 The D5 or D6 outputs will be connected to the SV input; 4) the reading and displaying on screen
 564 of the voltage on the BMS terminals and the in/out current of the BMS.



565
 566 Figure 11. Simplified diagram of the BLDC inverter, controller and motor