MasterEngineer: A Game-based technique in Power Electronics and Drives Teaching

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***Abstract-* Power electronics and drives have increased their presence at industry both in renewable energies, power systems and electric traction. For this reason, future electrical engineers need to acquire advanced competences in this field. Although chalk-and-board and slides can be used at degree and master level, the inclusion of game-based activities improve the motivation and life-long learning of students. This paper presents a newly design game to deeply understand the different arrangements and performance of power converter and electric machines. The game-based approach favors the acquisition of cross competences and promotes technical discussion and exposition abilities.**

Index Terms- ***Power electronics, drives, education, game-based.***

I. Introduction

The role of electric engineers at industry has evolved in the last decades with the ever increasing penetration of power electronics both in power systems and electrical drives [1]. The transition from fossil fuels to renewable energies, the evolution from internal combustion engines to electric vehicles and the change of paradigm from concentrated power systems to micro- and smart-grids is fully modifying the manner to generate and consume energy. New electric engineers need new competences in order to be useful in this renewed scenario.

Aiming to adapt to the new requirements, the curriculum has been renewed at degree and master level, including new subjects that deal with wind energy systems, electric vehicles and smart grids, to name a few [2]. Nevertheless, the teaching methodology has been maintained in most cases as it was in the past: chalk-and-board lectures with the help of slides following a teacher-centred approach [3-4]. Different attempts have been made to include new technologies in the form of simulation activities or lab teaching [5-6], but in most cases the interaction of students with the teacher or other students is kept low. Although, there is no doubt that standard lectures are extremely useful and efficient to *deliver knowledge*, especially in groups with a high number of students, it maintains the student in a passive role and this limits the creative thinking and the training of cross competences (e.g. team work) [7].

With the objective to increase the motivation and promote creative thinking and team work abilities, gamification based techniques in different versions can be useful tools [8]. The idea is not to replace traditional methodologies, but to complement them in specific sessions. The use of game-based approaches brings special benefits when the lecture sessions are prolonged beyond two hours, since they can break the monotony and bring the attention back to the content of the course (this is the case of the present experience).

This work presents the proposal of a game specifically designed to train students in the use of power electronics and electrical machines. It is used in a wind energy course at the University of Malaga, but the same game-based technique can be used in any subject dealing with high-power systems or in any course on electric drives or power electronics. The proposed game divides the class in two halves and males both team compete using rules that are inspired in the popular television program *MasterChef*. In this case the structure of the game is adapted to the creation of topologies for high-power energy conversion systems, and it is thus entitled *MasterEngineer*.

The details of the context and the course where this experience was tested are described in section II, whereas the game itself is detailed in section III. Some comments on the educational impact of the tool are discussed in section IV and the main conclusions from the implementation of this game-based techniques are summarized in section V.

II. Academic Context and motivation

The University of Malaga offers specialization courses for all kind of students and professionals [9]. Among them, the electrical engineering department lectures a course on wind energy conversion systems (WECS) from the point of view of the power conversion, placing the focus on the different types of electric generators and power converters used in the wind industry [10]. Since these courses need to be attended after the degree lectures or working days, they are typically placed on Friday evenings and Saturday mornings in 5-hours long lectures. According to the standard pedagogic guidelines and common sense, it becomes apparent that lecturing for five hours is not an ideal scenario to capture the students' attention. Nevertheless, in this case it is mandatory to concentrate the teaching in rather long sessions because it is not reasonable to prolong the course in excess (2-hour sessions would extend the course for 8 weeks in a 30-hour course). In order not to discourage students, the teaching approach needs to be as dynamic and interactive as possible.

The course on wind energy systems lasted for 20 hours that were split in 4 sessions with the following content:

- Session 1: Introduction to wind energy systems. The current status of WECS is described and some generalities are explained.

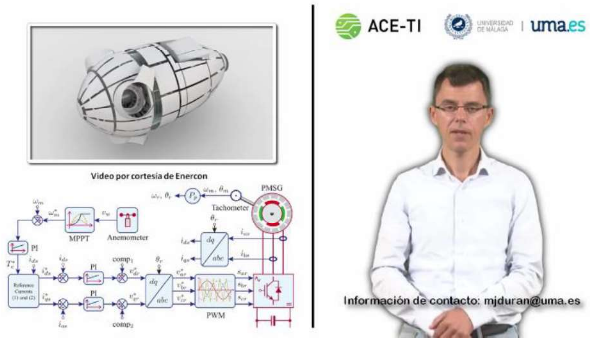
- Sessions 2: Technical aspects of WECS. The different parts of the energy conversion system inside the nacelle are described and some basic background about electric generators and power electronics is included.
- Sessions 3: Topologies in WECS. The arrangement of machines and converters is explained in this session for partial and full-power WECS.
- Session 4: Industry cases and future. Industrial products with the corresponding datasheet are reviewed and some comments on the foreseeable trends are given. Lab-scale and low-power WECS inside the school are visited.

In this context, the teaching methodology has been adapted to break the monotony of the speech. The dynamic methodology was achieved in the past by using numerous videos and intermediate tests during the course. This work reasonably well for the first two sessions (more descriptive) and for the fourth session (including a visit to the wind mill of the School and the WECS demonstrator at lab scale). Fig. 1 shows photos of the videos, the lab-scale WECS and the wind mills of the School at UMA which are visited in session 4. However, the third session was quite technical and arid and the teachers involved in the course realized that part of the class lost attention during this session in spite of its technical interest. For this reason, the organizers of the course decide to include a methodological change in the edition of 2017.

The new experience for session 4 had some requirements:

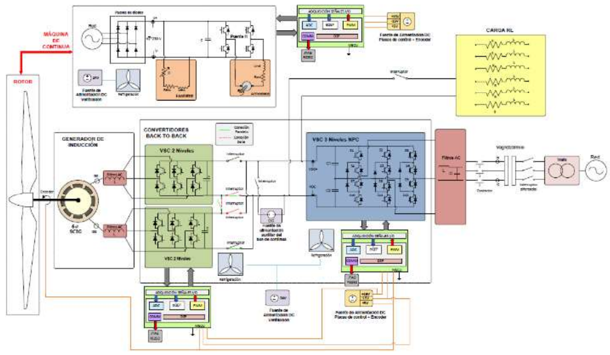
- It had to be as dynamic as possible.
- Opposite to the use of videos and visits, it should be interactive.
- It should help the students understand the content of the session, i.e., the possibilities to arrange converters and machines to get the desired performance from the energy conversion system.
- It should be entertaining. It is an extension course placed on Friday evening, typically after morning classes or working day at a company. Hence, getting some fun out of the lecture is advantageous from the didactic point of view.

With these characteristics in mind, the organizers of the course decided to build some thick cardboards that included the different elements that can be used in the creation of an energy conversion systems (converters, machines, etc.), so that students could have physically the elements on the table and try to build their own topologies. However, providing the cardboards might be helpful to excite creativity, but did not promote interaction. At this stage it seemed a good didactic approach the inclusion of a game together with the cardboards to increase the level of fun and technical discussion. Since cardboards and topologies could be seen as ingredients and recipes, respectively, the analogy with cooking was simple and effective.



(a)

(b)



(c)

(d)

Fig. 1. Elements used in the past to include dynamism in the lecture hours: (a) Videos, (b) lab-scale WECS, (c) Scheme of the lab-scale WECS and (d) wind mills on the roof of the School of Engineering at UMA.

This fact led to the design of the *MasterEngineer* game as a parody of the popular cooking competitions shown in television programs. The elements and structure of the game is detailed next.

III. *MASTERENGINEER*: THE GAME STRUCTURE.

MasterChef is a competitive cooking show television originated in UK in 1990 and later on exported to more than 40 countries and aired in more than 200 territories. In this program, amateur chefs design recipes and cook dishes under certain specifications and rules.

Due to the popularity of the competition and the possibility to use an analogy between cooking and designing a certain topology for WECS, this game structure was taken as a basis, and experience was termed *MasterEngineer* and tested in specialization courses at the University of Malaga (see section II). Most students presumably knew the game, and this could increase the motivation and allow the teachers to include some humoristic hints during the sessions by making a parody of the *MasterChef* format.

In this case, the students are challenged to design a certain topology (recipe) for wind energy conversion systems (WECS) using available devices (ingredients). This approach aims to promote the creative thinking, interactivity and motivation. The elements used for the game, some examples of the topologies that can be built and the game structure are described next.

A. Elements of the game.

The elements of the game or *ingredients* are thick cardboards that include different elements typically used in energy conversion systems (see Fig. 2). These elements included different electric generators (induction, doubly-fed, permanent magnet, multiphase, to name a few), converters (two-level and three-level voltage source converters, boost converters, diode rectifiers, to name a few), grid-connection systems (onshore, offshore, DC, AC, etc.) and other elements (blades, gearbox). A minimum of 4 and a maximum of 10 thick cardboards for each element were created for the purpose of the game. Fig. 2 show some examples of selected elements for illustrative purposes. It must be highlighted that during the game (see section III.C) each element was associated with some technical data (power rating, nominal voltage, etc). Cardboards are however kept empty and it is the responsibility of the teacher to associate the technical data with each element before he/she challenges the student.

All the elements were created based on the organizers' knowledge of the current state of the art in WECS. In other words, the different solutions adopted for the top ten wind turbine manufacturers were examined and their elements were replicated in the cardboards. In this way, it was possible to create the topologies of WECS from Vestas, Gamesa-Siemens, and the rest of major world manufacturers. Some further information about the possible topologies that can be obtained from the proper arrangement of the elements in Fig. 2 is described next.

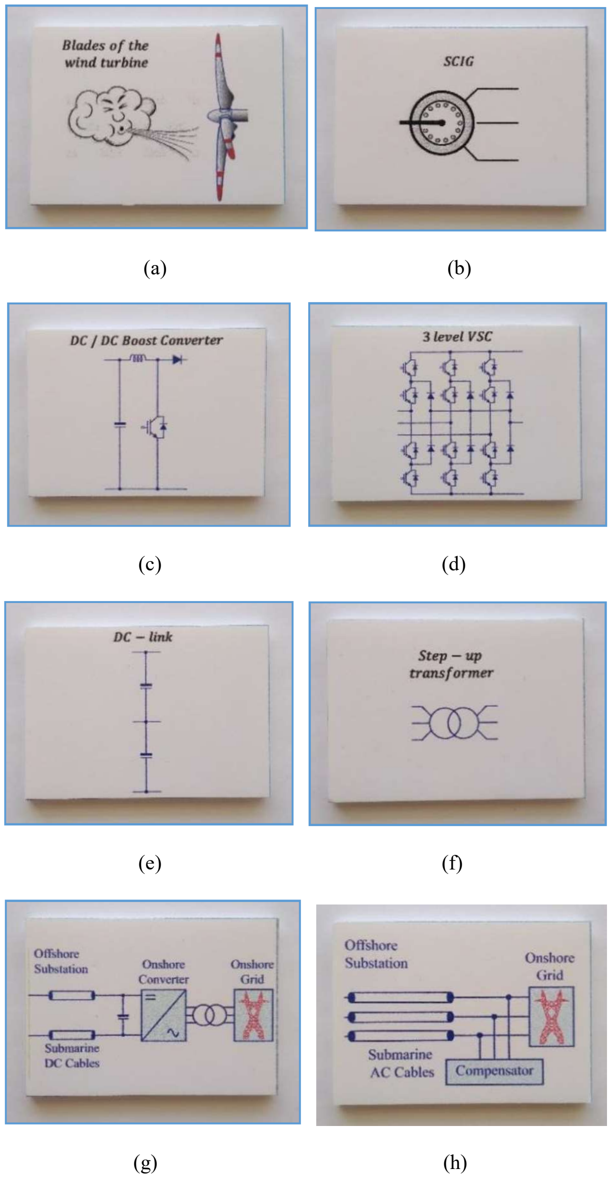


Fig. 2. Some selected examples of thick cardboards used as elements for the proposed game: (a) Blades of the wind turbine, (b) squirrel-cage induction generator, (c) Boost DC/DC converter, (d) three-level voltage source converter, (e) DC-link, (f) step-up transformer, (g) offshore DC transmission system and (h) offshore AC transmission system.

B. Topologies

One of the interesting things about the current state of the art of WECS is that a standard solution has not been reached yet [10]. As a matter of fact, different manufacturers are using very different solutions to convert the wind energy extracted by the blades in electric energy delivered to the network. This wide variety includes different:

- voltage ratings (low/medium)
- number of converter levels (two/three level)
- generator speeds (low, medium and high)
- options for the gearbox (geared/direct-drive)
- number of generator phases (3-phase/multiphase)

- amount of regulated power (partial/full-power)
- type of cables (standard/superconductors)
- type of location (on/off shore)
- type of transmission (AC or DC)
- type of rectifier (passive/active diode/IGBT)
- Power direction (uni/bidirectional)

This heterogeneity leads to significant number of different topologies in WECS already implemented at industry and even more of we consider other topologies that are proposed in the research stage. Apart from different strategies of manufacturers, it is worth highlighting that the increasing level of requirements from network operator worldwide (e.g. capability to handle voltage sags and provide reactive/active power for voltage/frequency control) is constantly modifying the scenario. Hence, solutions for WECS need to be adapted, this resulting in new topologies that better suit the new and demanding requirements.

Since the elements built in the cardboards (Fig. 2) reflect all the necessary elements to replicate industry products, it is possible to create multiple topologies. As an example, Figs. 3a and 3b show the case of a full-power topology at low-voltage with permanent magnet synchronous generator (PMSG) and two-level converters. The conceptual scheme is depicted in Fig. 3a whereas the topology created with the cardboards is shown in Fig. 3b. Similarly, Figs. 3c and 3d show the case of a multiphase generator with two back-to-back (B2B) power modules and a multiphase step-up transformer. The latter case replicates the latter 5MW WECS from manufacturer Gamesa-Siemens (with 12-phase generator and 4 B2B modules). Cases shown in Fig. 3 are just two examples of a wide variety of possibilities that can be obtained with the elements from Fig. 2.

C. Game structure.

A schematic of the game structure is shown in Fig. 4, detailing the different stages that are followed in a sequential manner. First of all, the teachers explain the structure of the game and divide the class in two groups that are subsequently named as red team and blue team (preserving the colours of the original *MasterChef* competition).

Then, the first stage is the challenge. The teachers provide some clear specifications for the WECS that needs to be designed (power rating, voltage level, price, reliability, etc.) and the students are challenged to find the topology that better suits the specified requirements. Most of the requirements are selected by the teachers on the basis of commercially available WECS. After the challenge is posed, time is given to both teams in order to think about the possible arrangements. This thinking time must be a period of discussion among students and the teacher role is just to observe and, if necessary, encourage the technical discussion. After this period of time, the students must go to the *supermarket* and select the most suitable *ingredients* (elements from Fig. 2) for the topology they have in mind

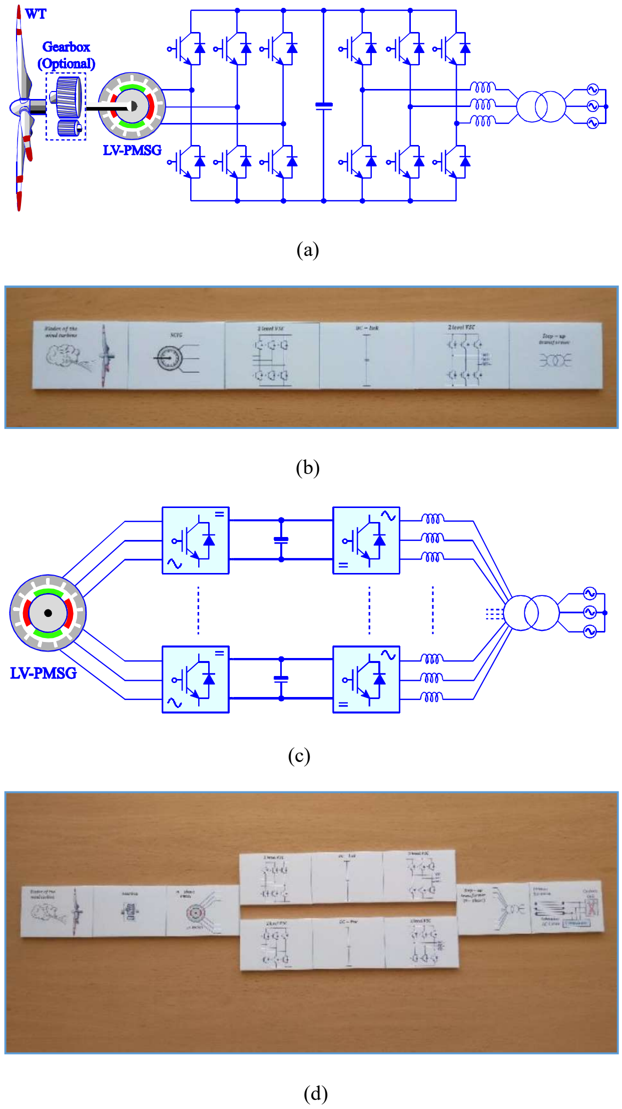


Fig. 3. Example of a full-power topology based in PMSG and two-level VSCS: (a) scheme and (b) topology created with the cardboards.

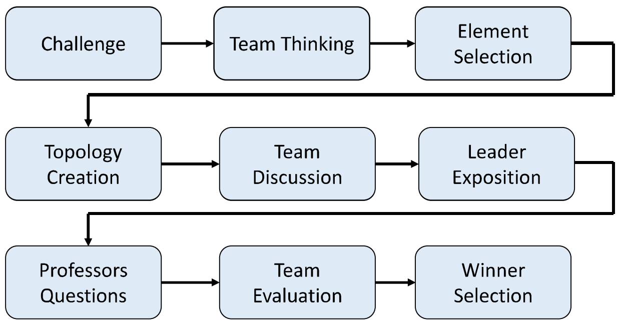


Fig. 4. Scheme of the *MasterEngineer* game structure.

after the discussion of the previous stage. At this point there are some variations of the game, according to how many elements are allowed to take. The number must exceed the number of cardboards that are necessary and the teacher can discard one element (optional). Once they have the elements, it is time for each group to create the topology and prepare the exposition (see Fig. 5). The group has to firstly select the leader/spokesperson, who will be in charge of the exposition, and then carefully prepare all the arguments for the defence. This task is done in parallel by both groups, red and blue.

After this period, the representative of both groups sequentially have to expose the selected topology and justify why their choice matches the requirements of the challenge. The teachers firstly listen to the exposition and then ask questions with the aim to verify if the arguments are solid or not. The time for questions can be done in tough but rather informal mode, resembling the mechanism used in the original *MasterChef* game (typically with one teacher acting as the *bad guy*). The evaluation of each team will not only be based on the right selection of the topology, but also on the manner they have defended their choice. In some cases, the topology can be right but the defence is poor and vice versa. After both teams have been scored, a winner of the challenge is awarded and gets one point for the final score.

The same structure from Fig. 4 is repeated for each challenge (in the 2017 edition the game had 4 different challenges), rotating the team representative so that the maximum number of students do an exposition and have to defend their technical arguments against the teachers. At the end of all challenges one of the teams is the final winner and the game ends. A symbolic award can be given to the winner team and to the best member of both groups. It is important to keep a relaxed atmosphere during the game so that students feel free to think, discuss among them and get joy from the learning process. If correctly done, the methodology can provide some competences which are not fully excited with the traditional teaching. Some further details on this benefits are commented next.

IV. EDUCATIONAL IMPACT.

Traditional lectures based on chalk-and-board and slides within a teacher-centered methodology are very useful to inform the students about the current status of wind energy systems. However, many competences which are highly demanded by industry are not properly excited. The use of game-based techniques can promote certain cognitive dimensions and competences and complement in this manner the traditional methodology. Table I summarizes the degree of achievement with lectures and the proposed *MasterEngineer* game in different dimensions.

Lectures provide a very good performance in technical aspects related to the content and problem solving involving maths (e.g. traditional problems and examples). However, the interaction, speech abilities and team work competences kept low. The game proposal based on the described *MasterEngineer* game formerly brings some additional benefits in the student training:

- Interaction: the team thinking and team discussion stages promote the student-student interaction. This is mostly avoided in standard lectures and brings an interesting cross compentence.

Fig. 5. Students involved in the Team Discussion stage after the topology has been designed and created with the selected cardboards.

Table I: List of competences and a qualitative evaluation of the degree of excitement with standard lectures and with the proposed *MasterEngineer* game.

Dimensions	Lectures	*MasterEngineer*
Technical content (concepts)	↑↑	↑↑
Technical calculations (math)	↑↑	—
Technical discussion	↑	↑↑
Motivation	↑	↑↑
Student-student interaction	↓↓	↑↑
Student-Teacher interaction	↑	↑↑
Application oriented	↑	↑↑
Speech abilities	↓	↑
Creative thinking	↑	↑↑
Problem solving competences	↑↑	↑↑
Team work competences	↓↓	↑↑

- Motivation: although standard lectures can be motivating if properly designed, it is difficult to compete with the degree of motivation that is obtained with game-based techniques. The *MasterEngineer* game proved to capture the attention of the students who were highly involved in the aim of winning the game (regardless of the age or previous training). In a sense all participants of the course behaved like children playing to win the game and beat the other team.
- Creative thinking: while problems in standard courses are closed in many cases, the challenges of the proposed game are quite open and this forces students to be creative and use the main concepts to fulfill the requirements.
- Technical discussion: the game brings helps the student to train how to behave in a technical discussion, make an exposition with correct terms, etc.

Since the proposal has only been tested in 2017 and inside a course with low number of students (15-20), there are no statistical data to quantify the success of the experience, but the subjective perception of the game implementation is highly satisfactory. Students got extremely involved on the game process and the informal interviews after the course provided a highly positive feedback about the methodological change.

V. CONCLUSIONS

Standard lectures have some deficiencies related to the interaction among students, motivation and capability to promote creative thinking. Furthermore, in courses lasting more than two hours the teacher-centered approaches are not the best choice since they typically lead to low attention from the students' side. Aiming to enhance the dynamism of the 5-hours sessions in a WECS course at the University of Malaga, a game-based technique termed *MasterEngineer* has been implemented in 2017 and presented in this work. The game-based approach and the structure of the game promotes the technical discussion both among students and with the teacher. The open-type challenge promotes creative thinking and the competition typically brings some additional motivation. With no aim to fully replace the traditional methodology, the current proposal becomes a tool to complements standard lectures and fill the gap related to some cross competences which are mostly neglected in previous methodologies within the same course.

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