CDIO – THE STEAM ENGINE POWERING THE ELECTRIC GRID

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ABSTRACT

In building the new DTU B.Eng programme [1] one of the pilots on the 4'th semester is the Design-build project course in Electric Energy Systems. In this course, which is the last Design-build course many of the CDIO Syllabus bullets [2] are addressed starting with problem identification and formulation, experimental inquiry and modelling, finally leading to planning and solution. The goal is to acquire the skills that are needed for an engineer within electric power engineering to analyse a given task, define the necessary steps to solve the task, organize him/her self and others and finally solve the task with success. The concrete work is built up around a miniaturized electric energy system powered by a steam engine. The system mimics an essential sub-section of a real electric power system. The process is realised with a combination of optional lectures, optional exercises, 3 set of self evaluations, weekly supervision and a concluding 3 weeks of intensive lab work. 50+ students are divided in 5 large groups allowing for subsequent sub-organization among 10+ students. The result is well functioning work groups, a robust electric energy system optionally with innovative add-ons such as a solar panel or a cable connection to other similar systems and the acquisition of basic skills within electric power engineering.

KEYWORDS

Electric energy system, steam engine, operation, innovation, group work, self evaluation.

INTRODUCTION

On the background of basic skills in mathematics, physics, electronics and computer science that have already been acquired at this level (4^{th} semester), the students is urged to put their skills into action. The idea behind the course is specifically to encompass aspects of development, project management, teamwork in large teams and communication skills together with engineering fundamentals such as thermodynamics, electric power engineering, power electronics, control and automation. All these elements are combined in one task, generating a work process that mimics the one, the student would face in an internship (6'th semester) and ultimately when taking up his or her professional career, at the same time being guided through innovating steps and being encouraged to innovate add-ons beyond the "expected" training system.
In order to guide the students through the learning steps of the Design-build process the following framework is applied.

- An introductory encounter is arranged where the groups are formed, the ideas behind Design-built are presented and a project goal is set.
- A prefabricated electric energy system with a minimum functionality is provided for each group.
- A data acquisition box containing analogue and digital I/O's is offered including software for commanding the box and ultimately the "power plant".

- A number of lectures including calculations and group exercises are offered within the topics project management, electric power systems and power electronics. These steps provide the means for understanding the fundamentals of electric power systems, among other the prefabricated miniaturized system.
- Three self evaluations are arranged with subsequent feed back to the students on the two first evaluations.
- Based on the first self evaluation and the feed back from the students, lectures and other teaching/learning initiatives can be arranged,
- Lab work and lectures are spiced up with external guest lectures in relevant field and a visit to a real power plant.
- A final three weeks of intensive lab work concludes the Design-built project at the end of which,
- The third evaluation, together with a group-wise poster presentation and demonstration of an operating "power plant", constitutes the ground for deciding whether the student has passed the course or not.
- All communication including lectures, exercises and documentation on the prefabricated system is up-loaded to a common course space. In a sub-space of the course, space documentation and the students self evaluation can also be up-loaded.

The steam engine combined with essential elements from a 3-phase electric power generation system was selected for a number of reasons being in part:

1) The polytechnic character of the task
2) To add a dimension of playing into the learning process
3) Reality reasons, i.e. highly illustrative with respect to the real world challenges
4) Obvious potential for division of the main tasks into subtopics suitable for large groups

In this energy system, a lot of important issues are highlighted and touched upon such as the energy conversion efficiency, how to stabilize grid frequency, 3-phase electric power, 3-phase generators and transformers, ac/dc converters, electric storage, automation and control, measurement techniques, visualisation and graphical presentation etc. These issues become increasingly important when reflected in present day discussion on sustainable energy versus fossil fuel, electric vehicle versus internal combustion engines, smart grid and distributed generation versus conventional centralized power plants.
The added dimension of project management and team work is usually required in order to overcome today's modern and complex reality.
All these aspect the Design-build of the course aims at honouring.

REALISING THE DESING-BUILT PROJEKT

In the following, different elements of the Design-built project are outlined in detail. The objective, goal and targets will be described together with the means and tools reaching the defined objective.

Objective, goal and targets

The objective of the course is, through the Design-built project, to acquire the spelled out skills listed in the course description of the DTU course handbook [3]. This includes classical knowledge within electrical power engineering such as transformers and motors/generators and their equivalent diagrams, real power and reactive power, three phase systems, converters and inverters, pulse width modulation (PWM), buck-boost circuits etc. It is also desired that synergy with other Design-built projects are exploited. In this case, synergy is ensured with the control field by aligning and exchanging expectation and detailed information on the energy system.
The mentioned objective implies that the specific goal of the Design-built project is to understand, expand, optimize and operate the prefabricated electric energy system. In order to challenge the students, an ac/dc converter has to be constructed, providing a maximum number of pulses and hereby creating optional improvement and/or expansion of the system.

In order to reach the goal a number of targets are exemplified for the students. Examples are provided for their convenience and help. The following aspects, communicated to the student, constitute examples of targets in time, process and topics space.

- Sub-divide the goal into topics related to the electric energy system e.g. in understanding the systems thermodynamics, mechanics and electrics, measuring system possibilities and limitations, built ac/dc converter for pulse generation, create a robust control for the system including a graphical user interface
- Loosely sub-divide the group according to identified list of topics or allocate responsible group members for each identified topic
- Lay down a plan including timeline, resources and milestones for reaching the goal
- Create a structure or organization for illustrating, maintaining or adjusting the work process, also for the case of severe organizational/cooperative problems to occur.

Lectures and exercises

A handful of lectures are offered together with related exercises. As any lecture at a university, these are optional, but the character of them should make the relevance of them obvious to the students, seen in the light of the task to be solved. The lectures provide the basis for understanding a modern electric power system and the power electronics that constitutes an increasing fraction of new installations, in particular in distributed energy resources such as wind turbines and photo votaics. Further, solving the offered exercises provides a short cut for the student for documenting their acquired skills when delivering their self evaluations.

Self evaluation and feed back

Three self evaluations are made compulsory with the purpose of:

- Providing a tool for following the progress of the students
- Invoking self awareness with the students of their own professional progress
- Evaluating the acquired professional level of the students in relation to the objective of the Design-built project

Combined with feed back from supervisors to students, the two first self evaluations provide the students with a good project start and help to reveal for he student the status of the their acquired skills. The first self evaluation is placed after about 4 weeks and is focusing on the project management part and feed back from the supervisors is essential at this time. The second self evaluation is placed before the last 3 weeks period with intensive lab work. This self evaluation is intended to help the student conclude their “theoretical” learning objective. The third self evaluation concludes the course together with a demonstration and a poster presentation.

Lab work

At the introductory lecture, the electric energy system is presented for the students. From the first day of the Design-built project, the students have access to the student lab and the energy system. The students are also introduced to the work shop where repairs and ingenious ideas can be realised. The students are encouraged to “play” with the system from day one alongside the offered lectures and exercises. By simple means, the machine can be manually operated. This sparks the student to seek hard information on the components, refresh their thermodynamics and start measuring many different parameters of the system including e.g. boiler temperature, output voltage and rounds per minute (rpm). With the project planning in place, the lab work becomes more focussed and divided in sub tasks. The lab work concludes in a three week intensive period. During this period the supervisors are available almost full time. In the first part of the three week intensive lab period, a lecture is offered on how to report and present their work. Further, a visit to a real power plant is arranged for inspiration in this week.
At the end of the three week period the work is presented on group posters, where each group member has to contribute with one A4 page, which together with the third and last self evaluation and a demonstration of the system in operation concludes the Design-built project.

__Demonstration of system and final evaluation of students__

The final self evaluation together with a successful operation of the system and a presentation of a group poster forms the basis for evaluating, if the student has passed the course or not.

__The electric energy system with prefabricated main components__

An electric energy system based on a steam engine is prefabricated and consists of the following main elements:

1. Power supply from a wall socket
2. Solid state relay for up to 10A
3. 1500W heater for heating the boiler feeding the steam engine
4. Boiler holding a volume ½liter, having an end piece of glass, authorised for up to 2bar overpressure and fitted with a safety valve that releases at 0.8bar overpressure
5. Electronic pressure sensor
6. Manual water feed pump
7. 1liter water reservoir
8. Controllable steam valve with tachometer
9. Two cylinder Wilesco steam engine
10. Chain transmission from engine to generator
11. Three phase generator (Graupner 7709 Compact 9.6V)
12. Three phase transformer
13. Newton meter
14. Power electronics single components as well as standard chips
15. Booster circuit for handling the relay, valve and pressure sensor
16. Data acquisition box with analogue and digital I/O's and USB interface
17. Access to the software LabVIEW

For an overview of the system, see figure 1a and 1b. Figure 1a is a bird's view of the steam engine part of the electric energy system including the step up transformers, but without the power electronics. Figure 1b gives a naturalistic view of the same system.

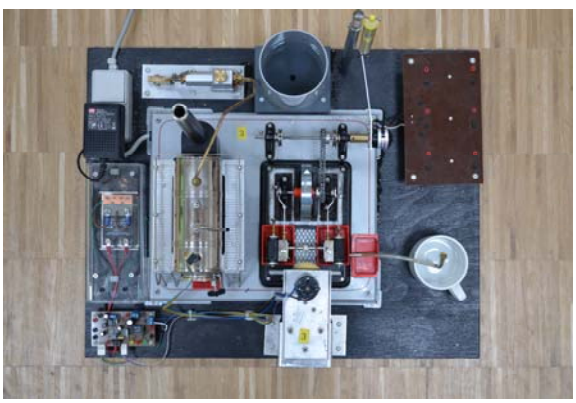

Figure 1a A bird's view of the steam engine part of the electric energy system including the transformer, but without power electronics.

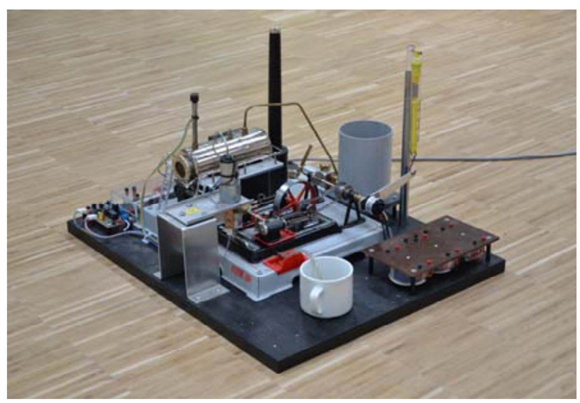

Figure 1b Naturalistic view of the electric energy system shown in 1a.

The following description is the setup as given to the students. A large number of minor and major modifications/extensions can be expected under the course,

The electric energy system is built up around a 2-cylindered Wilesco steam engine. This is basically a toy machine, which we anticipate will not stand the wear in the long run, however, so far it fulfils its purpose. The boiler of the steam engine is heated by a clamp-on heater element powered by a solid state relay that can be controlled by PWM between 0 and a maximum output of 1500W. One end of the boiler is transparent thus exposing the water level. The water can be replenished continuously by the help of a manual pump. The boiler is further more fitted with a safety relief valve. The resulting steam is lead through stainless steal piping via an adjustable valve. The valve can be controlled with the help of a taco-meter and a small electrical step-motor. When the steam engine is powered up, it may deliver a few watts at around 1000 rpm or wind up to between 2-3000 rpm in idle/no load. The three phase generator (Graupner 7709 Compact 9.6V) is of the type that is used to generate electric power to small remote controlled aeroplanes. The generator is designed to run at up to 18000 rpm. It is therefore not designed to offer an optimal energy conversion at 1000 rpm. The three phase generator is connected to three ring transformers making it up for a three phase transformer. Since the 3 transformers are not connected, the students can play around with different connections (Y and Δ) between the generator and the transformer. In this step the voltage of about a few volts are transformed up to 12Vac. The 12Vac is converted into dc with a power electronic converter that the students have to build themselves. Also the power electronics that determines when the power should be stored in a battery/capacitor or if it is to be released in a load is built by the students.

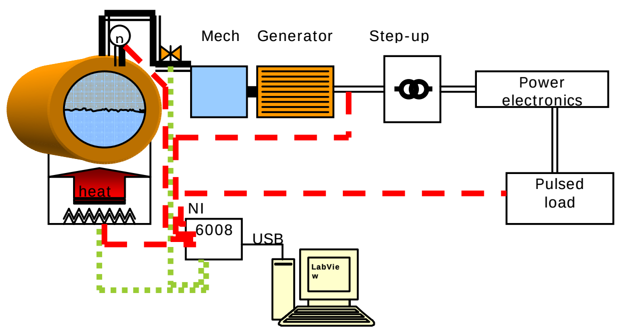

Figure 2 Sketch of the system including the data logging and control.

The heat input controlled by the solid state relay as well as the steam valve controlling the steam pressure reaching the cylinders can be controlled from a National Instrument (NI) I/O box (NI6008/6009). A sketch of the system including the data collection and control path is shown in figure 2. The box displays both analogue and digital I/O ports. Some of the output/control signal needs to be boosted with a TTL circuit because the NI6008 is powered only by a USB computer connection which does not provide enough power for controlling a relay. Further, the NI6008 function as a data acquisition card (DAQ) on which it is possible to sample the tachometer to determine the valve position, to sample the rpm for determining the generator frequency as well as the voltage in different places of the electric circuit. The students are introduced to the software LabVIEW which is dedicated for engineering measurement and control. In this graphical environment and through the NI6008 box they are able to collect the relevant data, analyse the data and implement simple direct control as well as PI and PID control.

DISCUSSION AND CONCLUSION

The response from the students has been positive about the concept and the whole idea of using a steam engine. It often reminded them about the young days when playing with a similar toy, but also gives back the feeling of a real engineer, capable of handling technical challenges of many kinds. Several groups have been inspired to improve the system that they started out with. One group attempted to determine the water level in the boiler by optical means and pattern recognition. Another group combined a LEGO MINDSTORM with the manual water pump to be able to automate also the water replenishing to the boiler. Many groups developed an extensive graphical interface showing the system outline, the system parameters and at the same time allowing for dynamic parameter change as well as system control.

The prefabricated steam engine based system has two major advantages compared to starting from scratch; potentially it reminds the student of joyful memories of the past, further it is appealing because it generates immediate action, even when the students have not yet any control over the system or deep understanding of the system. It may be somewhat different from other Design-built projects but it was judged necessary in this particular course. Given the nominal work load of 10 ECTS credits it was judged risky to set out on building an electric energy system from scratch. The need for the lectures and exercises is thus justified by the advanced level of starting.

The resources in terms of supervisor time, work shop hours and cost of components is significant but may be justified in the large number of students attending and staying with the course (50+) and the priority on the agenda that the Design-built projects have received.

The degree of success with this Design-built project is an integral of the student feed back on course and supervisors as well as the fraction of students that eventually are credited the course.

REFERENCES

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[2] http://www.cdio.org/framework-benefits/cdio-syllabus.

[3] DTU Course handbook (on DTU homepage)

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