INTEGRATED POWER ELECTRONICS TEACHING METHOD

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Abstract

The few lessons on power electronics inside the electrical engineering curriculum are to be optimized for obtaining best educational results and also for attracting the necessary number of specialists who are the researchers of tomorrow. The proposed method combines in an integrated package a well-documented lecture on the basics, a self-learning program as a computer guided and computer aided seminar including computer simulation capability to build a bridge to the tutored laboratory practical covering the lecture topics and running parallel with the lectures. The lab practical shall be the final step enabling the students to do some own measurements while obtaining the required data and get practical experience. Having understood the basics and being able to base upon the just previously acquired knowledge is essential for the efficient learning process of every student, therefore a constant check on the knowledge progress of the student becomes necessary, not only during the laboratory practical.

Power Electronics Education

The expanding field of power electronics is lacking engineers who have studied this part of electrical engineering in detail. According to restrictions in teaching times the teaching methodology in power electronics engineering is to be optimized

- in its appearance in order to attract enough students who complete these courses for filling the gap in experienced engineers in industry and at the university, and
- for transferring the knowledge in the most efficient way to have engineers ready to work in the area of power electronics, in applications as well as in research and development, and
- in adapting the course contents according to the progress in science and technology in order to teach updated information.

Power Electronics Knowledge Levels

Power electronics is a field of wide importance to the engineering sciences and especially to Electrical Engineering. There is no doubt that an education program in power electronics has to be included in every technical sciences curriculum and is to be organized in a very efficient way. However, the intensity or depth in details will differ widely if the student studies mechanical engineering or electrical drive technology.

The following 4 levels of power electronics experts are proposed and should be distinguished:

- Level 1: Application and usage level
  Standard engineer (non-electrical or electrical), dealing with applications and usage of power electronics equipment up to a limited extent, and having the opportunity and necessity to contact a specialist in power electronics for solving a design task

- Level 2: Electrical system design level
  Electrical power engineer, dealing with systems design and therefore having to select the appropriate solution using power electronics, and who is operating the equipment, also as commissioning engineers for power electronics equipment
- Level 3: Power electronics production level
  Power electronics developing engineer, a specialist on power electronics, having the task to design standard and novel power electronics products ready for production
- Level 4: Power electronics research level
  Power electronics research engineer, being the scientific studies engineer and designer of new types of semiconductor power electronics devices or new operational principles and control systems

Level 1 has to be reached by every electrical engineer and preferable by all mechanical engineers, too, as the field of power electronics is very important for e.g. every type of drives. These engineers are responsible to operate systems with power electronics equipment.

Level 2 concerns the system selection level. Those engineers have to decide which type of ready-to-use system they should select with respect to cost and performance, and it will be their responsibility to maintain the system in operation and react on malfunctions, and to commission standard power electronics systems.

Level 3 is the developer of power electronics equipment and the problem solver in the case of critical malfunctions.

Level 4 is the researcher in a university research center or in company research department, and in this work this engineer is the prototype inventor, designer, production planner and commissioning engineer in one person.

Every engineer is submitted to life-long learning, therefore there should be a feasibility to teach the state of the art to experienced engineers in regular intervals. However, due to his/her affiliation and position in a company or industry a certain level will be reached. Only very few electrical engineers will be working in level 4, and all the higher levels require a thorough special learning procedure taking a prolonged amount of time.

Level 1 and Level 2 Power Electronics Education

Emphasis has to be laid primary on the level 1 and level 2 teaching method in order to establish a good basis even if there are a lot of students with different learning capabilities in the power electronics field. Being able to work in applying some knowledge requires a full understanding of the contents and the correlation and holding this knowledge alive and active over a long time, so retaining some "feeling" on the subject. The proposal for achieving this is

Hearing + Seeing + Experiencing in an Integrated Package

Teaching material on power electronics is available over international channels with books and even with worked out transparencies and notes for the teacher. But this alone seems to be not enough. The missing part is the integration of the theoretical knowledge transmission with information acquisition and comprehension and having the knowledge in a ready-to-use status, and the practical application by the student.

Subdividing Power Electronics into a Number of Chapters and Subtopics

The whole area of power electronics has a natural subdivision e.g. in semiconductor devices, line commutated circuits, circuits with turn-off-semiconductors, electromagnetic compatibility, converter control, power electronics applications and operation. Every chapter is composed of a number of subtopics. E.g. controlled line rectifiers in the B6 circuit are just one part of line commutated circuit inside power electronics. This shall be an example for the whole process.

Phases of the Integrated Teaching Package

Phase 1: Simplified idealized basics lecture

In the case of a B6 controlled rectifier it means to start to explain the circuit diagram with current paths and their change in an idealized environment, here e.g. (at first) commutating reactance near zero and DC smoothing reactor nearly infinite. Along with the circuit comes the idealized signal versus time diagram resulting in the well-known 120 degree current blocks at the line side and the ideal saw-tooth-like voltage at the DC side of the rectifier, prior to the smoothing reactor. Then the control angle is varied and the results are displayed. In a next step the ideal commutation is explained using in infinite smoothing reactor. This knowledge is given to students in a lecture by using transparencies or e.g. a PowerPoint presentation. In any case all displayed material should be distributed some time before the lecture to allow an individual preparation by the student for the (next) topic. Every circuit diagram or signal diagram has to be selected carefully and prepared to hold but the minimum necessary information but not more. It is essential to have small repeatable steps between the individual pages. The handouts have to be ready to accept some personal written notes of the student on the paper.

Teaching should be more than distributing paper and words. Every information can be kept for a longer time if the teaching activity is supported by actual hardware. Samples of semiconductors (thyristors, IGBTs, GTOs) and passive components (snubber capacitors, ferrite cores) and cooling material, but also control system units (current transducers, digital signal processor units) should be given to the students into their hands so they can obtain a “feeling” for these devices, the packages, the outline, the isolation, the weight – in total, for the whole field of power electronics. In the German language there exists the word “begreifen” which means both “understand” as well as “have it in your hand, touch it”. All of this should lead to a higher acceptance level of power electronics.

Phase 2: Computer guided and computer aided seminar

The computer is a versatile tool in education – the computer can be an excellent teacher without personal reflections if a student repeats a certain module several times until he/she passes this knowledge state check, and the computer still is as friendly and patient in repeating as it was for the first time. The level to be reached shall be the aim and not the time spent with it – slow learners need extended time, and the computer offers this time. A self learning program is to deepen the knowledge and perform very reliable tests without high personnel efforts and expenditures. Teaching personnel should help the student in the case of specific questions and should not be occupied by standard routine work. Thus this phase 2 is more like a seminar with computer guided program and teacher assisting each other in establishing the theoretical knowledge basis.

Phase 3: Computer simulation work

After having a basic idea the student shall have his own simulation experiment on a PC without a strict time schedule. A prepared circuit example allows a direct start in simulating the circuit and varying some parameters, e.g. in this line commutated B6 example the control angle, and the student has to look for the result. The simulation allows changing other parameters as e.g. the smoothing reactor, frequency, line voltage, and the students obtain at first the result (a DC current with a heavy AC component). Also the commutating reactor is set first to a quite low and later to a practical value, and the commutation related effects are clearly visible without understanding the correlation directly at the moment. In this phase, the student works alone on his/her computer, decides on the progress and learning speed and is guided through the program by a program book explaining the results which should be seen on the screen. An advisor is present in the case of problems or questions, but the advisor usually does not interfere with the guided computer course.

For computer simulations, a high number of commercial simulation programs is available. They are generally used for research and development and are somewhat oversized for teaching the basics in power electronics. These commercial packages require expensive computers with a high calculation power and may have the disadvantage of the price and/or the complicated usage (high amount of time necessary to learn how to use the program). So a group of students will have to share the (powerful) computer and this reduces the learning result. Otherwise, a very limited performance in some evaluation packages can be found. In the basic levels the operation of the program has to be self-explaining and self-understanding.

The mentioned disadvantages lead to the development of a special teaching tool. Emphasis has been laid on a self-understanding simple usage and using only few resources of the computer, and preparing the system especially for teaching purposes. Therefore inexpensive computers – and here a higher number of those is available - can be used and should result in one computer per student. Thus a self learning method can be implemented, the student himself defines the speed of progress in the contents based on his ability and readiness.

The simplicity of the program allows an easy translation into national languages. Screen shots of the program usage and computational results of the Russian version are displayed in fig. 1 to fig. 4.

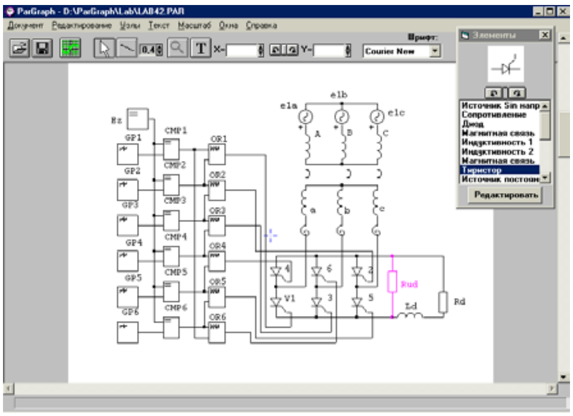

Fig. 1: Program ‘ParGraph’ – circuit modeling screen, power section and control part.

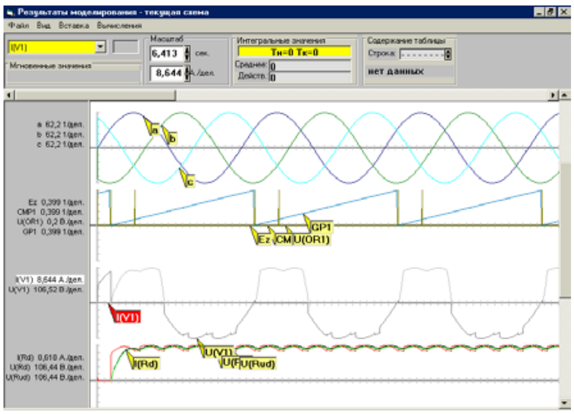

Fig. 2: Results of modeling, diagrams of voltage, control signals and currents versus time.

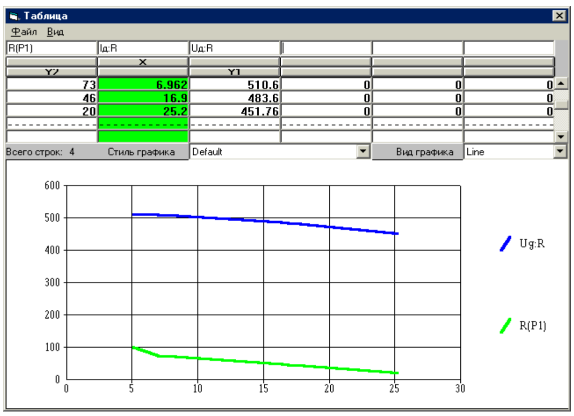

Fig. 3: Graphs of integral values (computational results)

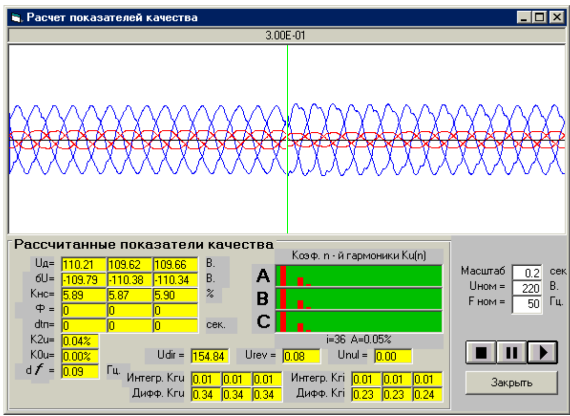

Fig. 4: Quality factor “measuring”, i.e. computation within the program.

With this simulation program, the circuit layout is repeated in setting up the circuit in the program (see fig. 1). Here also some specific converter control is included as the students see the realization of a control set for line commutated converters, this provides a logic understanding for the firing pulse generation and the time dependency of these pulses. The signal versus time diagrams (fig. 2) provides a connection to standard AC circuits which are already known by the students before, and in addition prepare the student for the measurement part, to know which type of signal and waveform is to expected. Inside the program, some numerical calculations which are very precise for the given parameters are carried out (fig. 3). These results are ready to be compared to the approximation calculations of the next phase 3. Today the behavior at the line is very important but not easy to calculate without appropriate means. The program automatically provides results of Fourier analysis computations in order to inform about this line behavior with respect to the fundamental frequency and the harmonics. It explains the quality factor and power factor relations in an easy to understand way, and again allows to modify parameters of the circuit in order to evaluate the results, e.g. the influence of the commutating reactance or the firing angle or the smoothing reactor on the harmonics of higher orders in the current.

Phase 4: Explaining practical effects and preparing for the lab practical

A number of practical effects can be calculated exactly or by a certain approximation. This is done in phase 4 in a lecture presentation. The results are compared with simulation results of phase 3, and the lecturer here is the tutor for explaining differences and reasons. Especially the limitations of some formulae are discussed, e.g. effects of the circuit commutated recovery time in a possible shoot-through of the inverter, some inverse currents related to practical semiconductor switches, non-ideal smoothing. At the end of this phase the students are prepared for a laboratory practical succeeding the lecture a short time afterwards, to know about the measurement procedure, some measurement problems and safety regulations (e.g. ground loops for standard oscilloscopes).

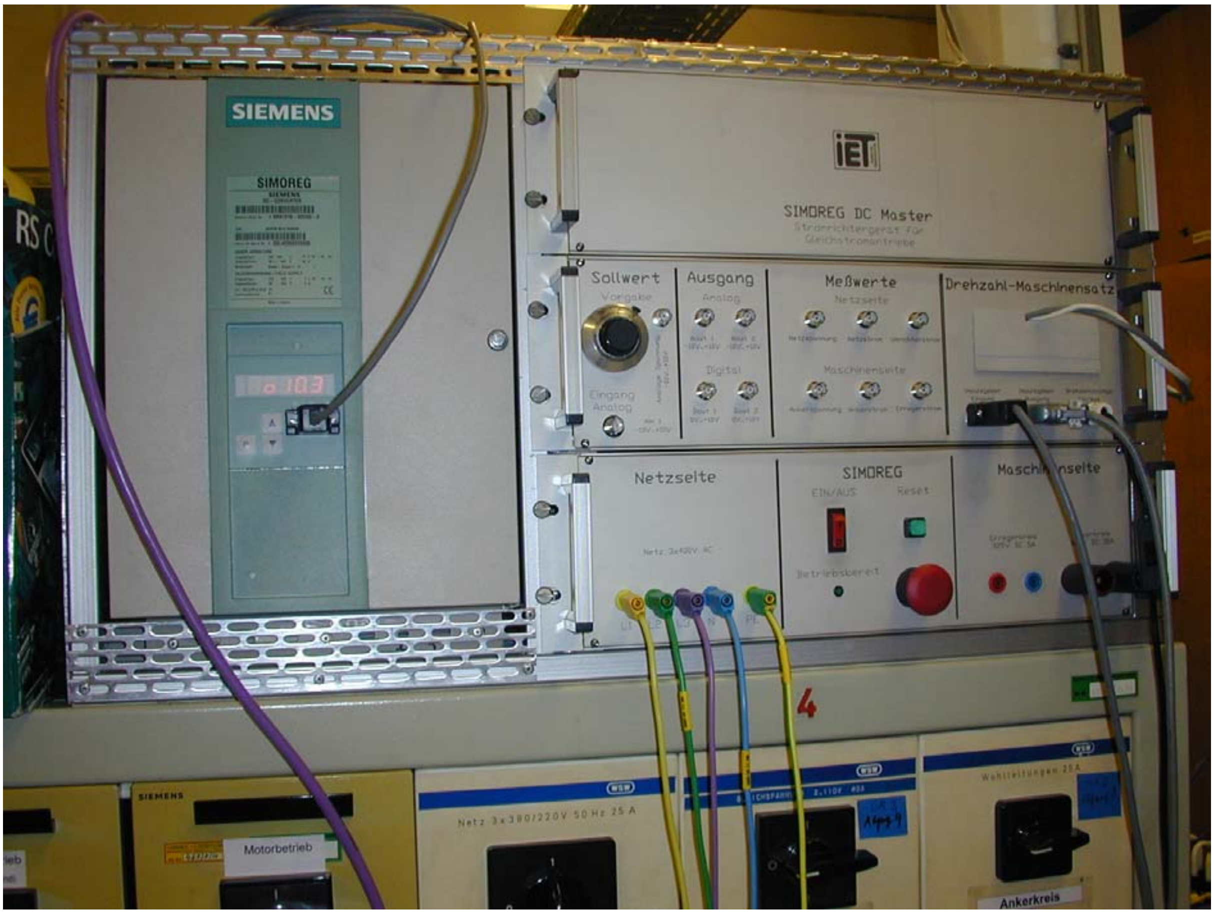

Fig. 5: Controlled rectifier device, industry standard, equipment for laboratory practical

Phase 5: Laboratory practical with measurements and computations

"Experiencing" as well as obtaining practical capabilities is the aim at the measurements and also acquiring a firm and long-lasting knowledge on the topic through this practical. Measurements on a real controlled rectifier (Fig. 5) enable the student to repeat the measurements as an engineer.

It appears to be necessary to use state-of-the-art equipment for both power electronics and measurement devices. Students should learn how to operate these devices they will have to work with after finishing their studies. The engineer has to be a problem solver and must not be the problem himself when for the first time he has to work on industry type equipment after finishing his studies. Therefore, the laboratory power electronics equipment is to be state of the art as well as prepared for a usage in teaching. This means that the industrial components are in an arrangement which allows a versatile usage still covering safety regulations and which offers extended measurement capabilities. Using this equipment implies running through the commissioning and parameterization of the device. In the course of teaching the students get practical information about the set-up procedure and internal operating philosophy of these units. Fig. 5 presents an example of a versatile AND safe laboratory equipment.

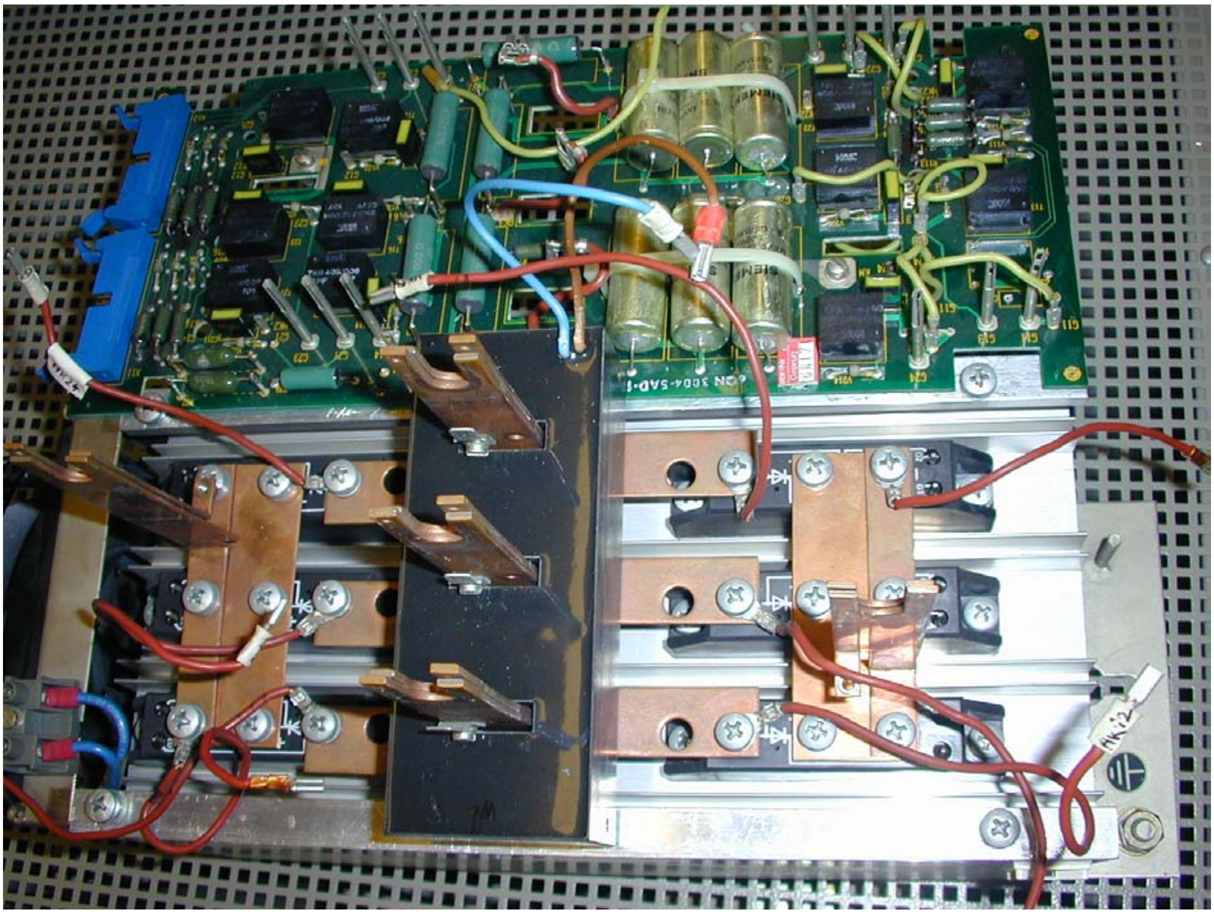

Fig. 6: Disassembled line commutated rectifier/inverter with measurement and firing pulse transformer circuits, for giving a "ready to touch" device

However, the main objective is to give the student an idea of a practical device, its design and operation. Therefore, one part of laboratory work consists of having a view on the power flow lines and control lines and the complete circuit layout. Fig. 6 shows a disassembled line commutated rectifier/inverter where the student can have their hands on it. This should assist widely in retaining the knowledge on this topic and enable the engineers to carry out some maintenance and repair. Only by investigation of the design some very important and critical power electronics properties can be understood and handled, e.g. electromagnetic compatibility. The "theoretical" knowledge of the students in Theoretical Electrical Engineering (including wave propagation, transmission) get a practical approach when the students see the amount of troublesome designs where every line becomes an antenna for radiating pulses, and electromagnetic noise is present everywhere. In this circumstances the high rate of electro-magnetic noise can be understood by the students, and their industry work or research jobs they have a good start when they have to solve practical problems in EMC.

Some tutors will be necessary to guide the students especially in safety regulations and finding out differences between simulation and actual measured values and the reasons or counter-measures for those. The measurements are done in groups, students form teams and every team member has a special responsibility. During the laboratory exercises the students acquire by "training on the job" team skills, too. The students have to write correct and complete measurement protocols. These protocols are discussed after correction in order not to repeat the previous errors. For this task experienced teachers are necessary.

Phase 5: Knowledge Settlement and Finalizing

This is a summary and a finalizing on the topic, and the aim is that the students have a clear overview on all the power electronics contents dealt with. The teacher (lecturer, tutor) is open for discussions, questions and explanations. In this phase especially the problems or failures of students during the previous phases are cared for, and measures are defined not to repeat the old problems.

Tests and Exams

In order to enable the class as a unity to proceed properly, tests are run during and at the end of each phase. Tests will be oral and by the computer. The final exam (fourth level) shall be a practical one for every student as an individual. Here a small presentation of results is introduced to check for the communication skills which are necessary in the practical work of every engineer.

Examination Levels

Examinations are done in four levels:

- **The first level -** formal quantitative estimation of number of correct answers to offered questions, characterizing an approximately general value of knowledge of the student about the specific subject. This test is done regularly during the lecture and the computer course and the laboratory.
- **The second level -** qualitative, requiring obligatory correct answers to predefined questions. These questions characterize the depth of understanding by the student to essences of the subjects. This test takes place at the end of phase 3.
- **The third level -** characterizing the practical and team co-operation abilities of each student as individual during the laboratory practical.
- **The fourth level** – ability to use the acquired knowledge in his/her own work, i.e. react on new situations in solving a measurement problem, defending measurement results; student is able to answer questions of increased difficulty, requiring the presence of creative abilities.

Summary

Power electronics is a complex field and requires a complex treatment in education. Good results can be expected in an integral approach combining lecture, computer guided and computer aided work and including a laboratory practical in parallel.

References

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