# Learning Resources in Sustainable Energy (SustEner)

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*Abstract*—**This paper present comprehensive learning resources developed for education in sustainable energy for professionals from industry, for teachers and also for students. Nine on-line learning modules are available within a modern learning portal. Each module is enriched by remote or virtual experiments that enable the learner to get some practical experience and better understanding of the presented theoretical concepts. Outlines of the learning modules with short description of the remote or virtual experiments are given.**

*Keywords— Lifelong education, sustainable energy, remote experiment, distance learning*

## I. Introduction

Online education resources have an enormous potential for improving not just a formal education but also the education of professionals from industry, education of educators and general public. In the field of the sustainable energy online education resources are due to their popularity and accessibility also an excellent opportunity for promotion of those technologies. However high-quality resources, which are comprehensive, interesting and motivating for the learner, are still lacking. The development and implementation of such resources in engineering is a big challenge since real processes and real devices/systems are addressed and some practical, hands-on experience is necessary to develop knowledge and understanding. Remote laboratories are frequently implemented for providing practical experience on distance allowing the user to operate devices via user interface over the web [1], [2], [3], [5] and [6]. The remote experiments are often combined with virtual experiments, respectively interactive animations or online simulations. The latter show operating principles by animations, allow the user to change some parameters and are very suitable for depicting invisible phenomena, dangerous processes or operation of expensive devices [4], [7]. However both remote and virtual experiments drastically increase the complexity and price of the e-learning materials, due to the deployment of special software and hardware and need of a booking system for remote experiments [5]. Current tendency is therefore to make the remote experiments more economic by using free software and stand-alone hardware [2].

In the field of the sustainable energy a number of ‘isolated’ remote experiments and online courses are available. For example a solar cell remote laboratory is described in [8] and a distance e-learning course on design and control of photovoltaic plants in [9]. However, from more comprehensive resources with complete online courses and remote/virtual experiments that present sustainable energy topics in more details, only very few are available. Some were developed within E-PRAGMATIC network (E-Learning and Practical Training of Mechatronics and Alternative Technologies in Industrial Community). Between 21 online training courses mostly oriented toward mechatronics, there are also courses from photovoltaic, energy efficient drives, electric vehicles and hybrid vehicles. They were prepared by EU educational institutions and are now available for the in-company training in the industry and for individual training of professionals [10]. Other good examples are the web based resources for photovoltaic professionals that are available at Pveducation.org [11]. Those resources are developed by researchers and photovoltaic experts and include theory, animations and simulations.

In this paper presented SustEner initiative (Teaching Energy for Sustainable World) addresses the lack of online education resources from sustainable energy by developing nine extensive learning courses with remote and virtual experiments [13]. The courses, developed by the researchers and educators from eight EU countries, are available on a single learning platform [14]. The platform offers all functionalities for successful supervised or individual distance learning. Therefore the SustEner education resources are at the moment one of the most advanced and rich online resources for education in the sustainable energy.

The paper is organized as follows. The section II describes the SustEner initiative and its background. In the Section III development of the learning resources is described. The section IV gives outline of the learning modules and available remote and virtual experiments. In the final section conclusions are drawn and future work is outlined.

## II. SustEner initiative

In the SustEner initiative eight universities and two secondary schools from seven European counties are directly included [13]. Further, contacts were established with some enterprises. The main goal of SustEner initiative is to bring sustainable energy knowledge directly from the education/research institutions to the following target groups:

- Electrical engineers in the industry who want to adapt to the continuous changes in technology by an active participation in lifelong education.
- Young engineers still profiling their specialisation, who wish to pursue their carrier in the sustainable energy field.

- Those who graduated originally in the electrical engineering but were not working in their profession for a longer time period, thus losing the contact with the latest development in the field.
- University professors and secondary school teachers who want to gain sustainable energy knowledge and then bring this knowledge also to their students and pupils by using web based education tools such as remote and virtual experiments.
- Disabled people, people living in distant geographical areas and everybody else who is having difficulties to attend regularly the courses that require their presence in specific place and at specific time.
- Small to middle enterprises that want to enhance their in-house training or introduce new training content, however they have not enough human resources and/or finances to develop their own learning courses for the employees.

The SustEner initiative is a part of the EU lifelong learning program Leonardo da Vinci [15].

## III. Development of learning resources

The development was done in few phases. In order to reach all mentioned target groups and fulfil their knowledge needs first the needs analysis was executed. Then the learning modules with virtual and remote experiments were realised. Finally, all learning resources were transferred to the learning portal, where they are available to the learners and visitors.

### *A. Needs analysis*

With the needs analysis the lifelong learning habits and concrete knowledge needs of the target groups were revealed. Necessary information was collected by executing an international e-survey. 140 responders from all target groups and participating EU countries have taken part in this survey.

It was found out that most of the responders already use online resources as a main source for their self-education. Further, more than 80 % believe that distance learning can be effective also in engineering, although only about 40 % have been already involved in organised distance training. Next, it was also found out that more than 90 % of the teachers use web resources in their classes.

The needs analysis also revealed the concrete knowledge needs of the target groups. Accordingly nine most interesting learning modules in five thematic areas were developed:

- Solar Energy: (1) Solar Electricity - From Solar cell to system; (2) Photovoltaic Systems - Optimization of operation and Combined Photovoltaic/Thermal System.
- Wind Energy: (1) Wind energy conversion and control
- Hybrid Vehicles: (1) Drivetrain and combined energy storage system for electric hybrid vehicle; (2) Power management techniques for hybrid electric cars.
- Electric Vehicles: (1) Power electronics for electric cars; (2) Solar Powered Electric Vehicles; (3) Power control and energy management in DC microgrids.
- Energy Saving: (1) Luminous efficacy of modern light sources.

The detailed results of needs analysis are available in [12].

### *B. Realisation of learning modules with virtual and remote experiments*

The learning modules were developed by the researchers and educators from participating universities, who have up-to-date professional knowledge and also rich education experience. Most of them have also participated in other lifelong learning projects and their expertise had an important influence on the development of the learning modules.

The learning modules provide the learners clear information about the module objective, content, required preliminary knowledge and average study time. Theoretical study material is given in the form of smaller learning atoms, which enable learning directly from the screen and usually include some graphical or interactive elements. Directly from the modules also remote and virtual experiments are accessible. The remote experiments are executed on the equipment which is placed in remote laboratories of the partners and connected to the learning modules via a booking system. The learners operate the experiments via user interfaces, observe the operation by video feedback and can usually also download experiment results for further analysis.

Most of the virtual experiments are realised in Java and can be at the same time, unlike the remote experiments, operated by many users. They are used in the cases where remote experiments cannot be realised because it is not possible to guarantee continuous safe operation of such device when operated on distance and showing some operation principles. In SustEner this is mostly the case with hybrid and electric drives.

### *C. SustEner learning portal*

All learning resources are available within the SustEner learning portal, Fig. 1. The portal is accessible at [14]. It is based on the eCampus learning management system, which is custom developed platform for education of adults [16]. All learning modules have a custom, graphically attractive design and are presented as a series of subchapters –learning atoms. Multimedia and interactive elements are directly integrated. The learning modules are transferred to the portal directly from the Word document; however they can be also created and edited directly on the portal.

The learning portal is connected to the Moodle based booking system for remote experiments [4]. In this way the learner can access remote experiments placed on different universities with the single user account, which is also valid for the access to the learning portal.

The learning portal has also all functionalities required for mentoring of completely distance courses such as:

- administration tools (user management, access policy management),
- communication tools (personal messages, forums, chat rooms),
- statistics tools (time and length of learning activities, results of test and similar),
- learning/teaching tools (virtual classrooms)


Fig. 1. SustEner learning portal.

Because of all those functionalities the portal can be directly applied also for supervised on-the-job training or distance training of individuals and students in regular education.

Very important is also that the learning portal allows the access from mobile devices, which makes the learning modules (unfortunately not also all remote and virtual experiments) accessible practically from anywhere.

## IV. Learning modules

The learning modules were selected according to the interest expressed by the target groups within the international needs analysis executed as described. In this section outlines of all available modules are given.

### *A. Solar Electricity - From Solar cell to system*

The learning module provides basic knowledge of solar electricity. Solar cells from modules to arrays are explored and problem of shading is explained. Different converters for a grid connection of the solar cell are described and the basic principle of maximum power point tracking is explained. An exercise for the solar park design is included. The practical part of the module is based on the remote experiment, where three different exercises are executed:

- Measurements of current-voltage (I-V) and power-voltage (P-V) characteristics of the PV module at three different illuminations.
- Measurements of the step Down (Buck) maximum power point tracking converter. The learner can study the relationship between the Duty Cycle of the gate signal and the electrical characteristics.
- User programs and tests hers/his own maximum power point tracking method. The user interface for this measurement is shown in Fig. 2.

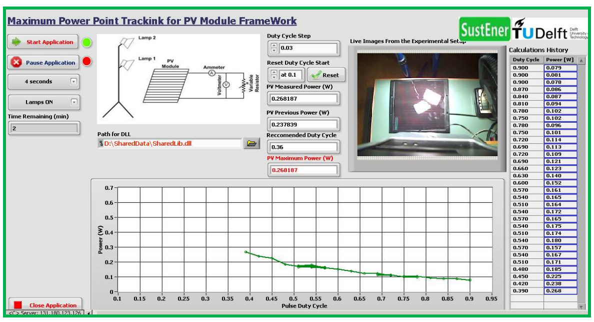


Fig. 2. User interface and video transmission for remote experiment from solar energy.

### *B. Photovoltaic Systems - Optimization of operation and Combined Photovoltaic and Thermal System*

The module presents basic principles of solar thermal systems. First the basics of photovoltaic systems are briefly described and then the possibilities of solar system using for water heating are reviewed and analysed. For the practical part a remote experiment is available, on which following exercises can be executed:

- Measuring of operational performance of the photovoltaic systems.
- Detecting and analysing defects on the photovoltaic panels.
- Measuring of operational parameters of the combined system (thermal and solar).

This module can be also taken as a continuation of the module ‘Solar Electricity - From Solar cell to system’ as it shows how to use the combination of solar and thermal systems.

### *C. Wind energy conversion and control*

In this module, the basic operating principles of a wind energy conversion system and its control are described. The focus is on the doubly-fed induction generator (DFIG) -turbine that is currently the most widely-used type for the grid-connected wind power generation. Firstly, individual elements of the DFIG system such as the aerodynamic rotor, induction machine, power electronic converters and the control are presented in separate chapters. Fig. 3. shows learning atom from the module, as the users can see it on the learning portal. Essential theoretical background is provided in every chapter and the operating principles are presented in the form of the interactive animated virtual experiments.

In the virtual experiments all the elements are integrated to demonstrate the general operation of the wind turbine system and how each one contributes to the wind energy conversion process. The user can adjust parameters and study their effect. The virtual experiment is implemented by using JAVA, and as such allows parallel use on a virtually unlimited number of computers.

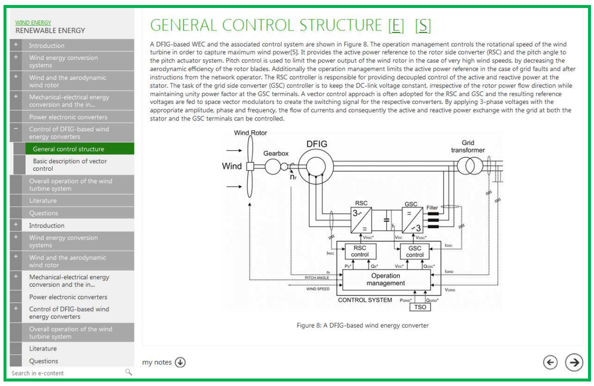


Fig. 3. User interface and video transmission for remote experiment from solar energy.

### *D. Drivetrain and combined energy storage system for electric hybrid vehicle*

The Hybrid Electric Vehicles (HEVs) belong to the green technologies that can significantly contribute to energy sustainability and decrease negative influence of personal transportation on the environment. In the module first the operating principle of a HEV's propulsion system is presented. Several drivetrain topologies, which are used in the modern hybrid drives, are described. Next two types of energy storage systems Li-ion batteries and supercapacitors, used in combined energy storage system, are addressed. The module describes the properties of both and also how to combine them for a more efficient HEV's energy storage system. Energy and power needs in HEV are analysed by using a detailed dynamic model of the vehicle, which takes into account different styles of driving, different environmental situation (temperature, wind), and different vehicles. As an example, the construction of an experimental hybrid drive, which has been designed in order to develop a drivetrain of a light utility vehicle, is presented.

Two comprehensive virtual experiments are available:

- Energy and power needs in HEV. User can interactively change different parameters/operating conditions such as the reference power (as defined by user), the driving route and vehicle's properties. Consequently, the power needs are calculated.
- Serial drive with combined energy storage. Operating of the serial HEV with the combined energy storage system (batteries and supercapacitor) can be studied. User can change a number of parameters and observe the power flow under specified (tuneable) driving conditions.

### *E. Power management techniques for hybrid electric cars*

The goal of the module is to show and compare the influence of the installed power of the combustion machine and the electric machine as well as the electrical storage capacity on the overall performance (acceleration rate, top speed, fuel consumption, etc.) of a hybrid car. Depending on the driving cycle the optimum level of hybridisation as well as the load sharing strategy and electric energy storage management for highest overall efficiency may thus be completely different. The focus of the module lies on the overall energy needed to drive a distance on specific standard driving cycles.

First classification of hybrid electric cars is provided. Different concepts of the hybrid drivetrain are described and compared. Then a basic description and comparison of different available internal combustion engines (with focus on the operating conditions and efficiency ranges) is given. Further, the operating principles of electric machines are explained, together with machine control, power electronics, and efficiency ranges. The most important and currently industrially applied electric energy storage components are described next. Then, the influence and possibilities of the internal combustion engine load sharing are analysed.

The interactive animation is provided. It shows that the peak efficiency is only one part of the achieved range of a vehicle as most of the energy is consumed at partial load operating states where the auxiliary power consumption of the vehicle may be even higher than that of the traction power.

### *F. Power electronics for electric cars*

In this module, the basic operating principles of electric vehicle, along with the vehicle components, are described. The stress is put on the elements on the vehicle drivetrain, consisting of the DC-DC converter, DC-AC converter, electric drive and Li-Ion battery as the power source. The essential theoretical background for each of those components is provided in separate chapters. A learning atom addressing power transistor drives is depicted in Fig. 4.

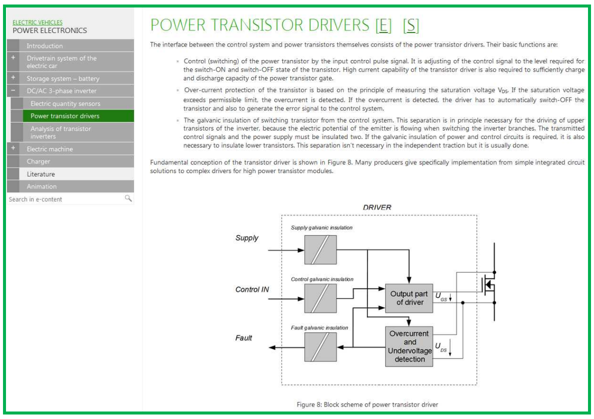


Fig. 4. Learning atom from ‚Power electronics for electric cars'.

### *G. Solar Powered Electric Vehicles*

The module addresses topic of solar powered electric cars. It is highly unlikely that the future hybrid or electric vehicles in mass production will be supplied exclusively by on-board solar cells; however a significant amount of the energy required by the hybrid or electric cars will be produced by renewable energy sources and collected by the vehicles off-board from grids or micro-grids. The module presents first a concept of electric vehicles with on/board PV panels and its elements: photovoltaic cell, DC/DC converter and energy storage system. Then a concept of local micro-grids and system architecture of charging stations with photovoltaic panels is described. Also utilisation of solar energy and wind energy for charging of fuel cells and charging stations is addressed.

Available virtual experiments address those topics:

- Economy of the electric vehicle with on-board solar panels.
- Energy consumption of the electric vehicle with on-board panels.
- Functioning principle of the solar powered charging station.

### *H. Power control and energy management in DC microgrids*

Nowadays, DC microgrids attract more and more attention because of their advantage in eliminating long transmission and distribution lines and their inherent capacity of easily integrating energy storage, alternative and renewable power sources.

In this module, a DC microgrid containing a fuel cell (FC), a battery tank (BAT), and a supercapacitor (SC) is studied. Three main architectures with their energy management strategies (EMSs) are detailed. The FC is the main source, and the BAT and the SC form the energy storage sources (ESSs) combined in three different ways. The emphasis is put on the control and the impact of the power architecture on the control strategy and its performances. A conventional linear control strategy is compared with a nonlinear control one based on the

Flatness-based Control Theory (FCT) for power flows and the Fuzzy Logic Control (FLC) for energy management.

A virtual experiment allows study of the transient and steady state behaviour of the system. Three operating modes (normal, over-load and regenerating mode) are considered with a given driving cycle. By executing those virtual experiments the learner can evaluate the impact of the energy management and the power control on the efficiency of the DC microgrid.

### *I. Luminous efficacy of modern light sources*

The applications of the energy-efficient, modern lighting technologies are becoming more important. In the case of a light source there are two dominant economical characteristics: lifetime and efficacy. In order to create an energy-effective lighting system, the logic choice for the used light sources are the LEDs. When examining the energy saving factor, the LED technology outperforms the classical lighting solutions in several aspects. However, from the technical point of view, this properties are the most difficult to perceive, as far as it is not possible to easily compare the produced light and the used energy. To do it, it is necessary to detect and measure the total luminous flux of the source and the total power input for the calculation of light efficiency. Since light sources are integrated into the electric network directly, the monitoring of the power input cannot be a problem.

The aim of this module is to acquire knowledge required to determine the luminous efficacy, and to make online measurements using an incandescent lamp and a LED light source.

The practical part of the module is based on the remote experiments. Within the experiments, a measurement to introduce the energy efficiency of LED sources, compared to the traditional ones and a comparative measurement between a modern LED and a classical incandescent lamp are executed. During this measurement the luminous flux and the power input of both sources could be measured at the same time interactively, and the energy saving advantages of the LEDs could be shown easily.

## V. CONCLUSION

Learning at a distance can significantly reduce the cost of education, expand access to education to the learners who cannot attend conventional education, and enable easier integration of learning activities in everyday life. Distance education technologies are rapidly evolving and therefore also engineering distance education is becoming a reality; namely remote and virtual experiments can at least partially replace real laboratory experience. The paper presented how the advanced distance education technology can be utilised to prepare comprehensive online education resources for non-traditional groups of learners, such as learners from industry and teachers.

All nine learning modules with remote or virtual experiments are available within the learning portal. The user accounts are created on the request.

Future work includes pilot testing of the developed resources and, accordingly, the adaptation of the modules. At the request of the enterprises further modules and distance training courses can be developed. Additional challenge could be also in making the developed resources even more accessible with the mobile devices such as tablets and smart phones. Those are already used a lot in everyday life and are finding their way also in the distance learning.

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