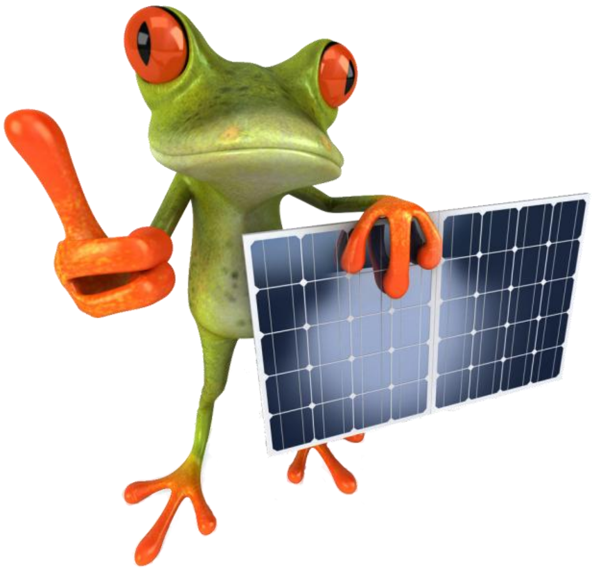
SUSTENER: TEACHING ENERGY FOR SUSTAINABLE WORLD



SustEner project (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 experiment. The courses, developed by the researchers and educators from seven EU countries, are available on a single learning platform (www.SustEner.eu) and free to access. All modules address specific local knowledge and skills needs of industrial partners and educational institutions. Provided contents and learning functionalities enable employees/trainees to acquire new professional skills and enhance their job performance. Bellow you can find list of modules and extended abstracts of each module.

List of Interactive Modules

- Solar Electricity - From Solar cell to system
- Photovoltaics - Optimization of Operation of Photovoltaic Systems Depending on Operating Conditions, Multivalent Heating Systems
- Renewable Energy – Wind energy conversion and control
- Drivetrain and combined energy storage system for electric hybrid vehicles
- Power management techniques for hybrid electric cars
- Power electronics for electric cars

- Solar Powered Electric Vehicles
- Power control and energy management in DC microgrids
- Luminous efficacy of modern light sources

Hereby the abstracts of the modules:

Solar Energy

Solar electricity - From solar cell to system

The module delivers basic knowledge of solar electricity. First solar module characteristics are analysed (and measured on distance laboratory). The solar cells from modules to arrays are explored and the problem of shading is explained. Different converters for grid connection of solar cells are proposed and the basic principle of maximum power point tracking is explained. An exercise for solar park design is included.

For obtaining some practical knowledge a distance laboratory which allows the measurement of a solar cell with three different illumination levels is available. Also power point tracking with the use of a buck converter is verified in the distance laboratory.

Photovoltaic Systems - Optimization of operation and Combined Photovoltaic/Thermal Systems

Over the past few years there have appeared a very dynamically growing number of installations of photovoltaic systems in the Czech Republic (CR). At the end of 2010 investors' requests to connect new renewable power sources in the CR, especially photovoltaic systems, exceeded the existing technical possibilities of electrical networks. This trend was mainly due to political and economic support for their construction and operation. With regard to legislative changes in the support of Renewable Energy Sources (RES), valid from January 2011, the number of installations of photovoltaic systems has decreased. Therefore the issue of effective operating characteristics of already installed photovoltaic systems gained in importance.

Such power source type is characterized by very rapid changes in energy production, since it depends not only on the day period, but also on the sky clouds coverage, power changes in tens of percent are possible to happen in the tens, sometimes even in fewer minutes. The photovoltaic cells installed on the single family houses and other civil constructions that have capacity within kW, the electricity network is affected very little, because part of the produce energy is spent directly in the production site. Problems can occur if a large number of small sources is connected to the network of 0.4 kV powered from a single 22/0.4 kV transformer, e.g. in the village. In full sunshine, this can lead to overflow of energy to a higher voltage level, if there is not a sufficient energy consumption of households from the network, which can incorrectly evaluate the high voltage protection line. Large photovoltaic power plants with capacities of MW have larger influence on electricity network, rapid changes in performance can result in voltage fluctuations at the connection point (usually high voltage).

The dynamic development of photovoltaic systems installations raised several important operational issues that need to be paid attention to:

- the possibility of effective managing the production and consumption of photovoltaic systems,
- elimination of discontinuity between production and consumption by using energy accumulation,
- optimization of the operating characteristics of photovoltaic systems,
- the possibility of detecting defects on the photovoltaic panels,
- definitions of terms for use of different types of panels under different operating conditions,
- operational performance of photovoltaic systems.

The basis for clarifying and solving the above described problems associated with the operation of photovoltaic systems is the detailed introduction and presentation of these issues to the students in technical colleges.

The aim of this training module is to create several "distant" laboratory tasks, where students will be able to verify the basic knowledge and to conduct further extending experiments focused to expand their knowledge.

Electric vehicles

Power electronics for electric cars

Power semiconductor inverter is the most important basic unit of discipline called “Power Electronic”. The power inverter is based on semiconductor switching devices operating only in switching area. Proper switching characteristic increase efficiency and reduce power dissipation in semiconductor devices. Power electronic deals with conversion of electric energy, more precisely it converses electric energy into electric energy of various qualities.

Moreover there are converters of others kinds of energy which are part of other technical disciplines:

- electro-mechanical converters (electric machines, etc.),
- electro-electric converters (transformers, etc.),
- mechanical-mechanic (transmissions, etc.),
- electro-chemical converters (accumulators, etc.),
- Thermo-electric converters (Thermocouples, etc.).

Power electronic has to little take other energy conversions into account because its field of interest partly involves technical disciplines where these energy converters are pretty common.

Especially semiconductor inverters and electro-mechanical and electrochemical converters are the basic units in the field of electric traction. These converters are connected in series in energy chain of the electric car drivetrain and semiconductor inverter it is not possible to design without information of the other converters. The following chapter will be focused on detailed description and design techniques of these various converters.

Solar powered electric vehicles

Solar energy, radiant light and heat from the sun, have been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar energy technologies including solar heating, solar photovoltaicsand solar architecture offer promising solutions to solving some of the current problems of power generation mankind now faces. Solar technologies are generally described as either passive or active solar utilization depending on the way solar energy is captured. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Due to the decreasing amount of fossil fuels alternative and renewable energy sources have been highlighted in last decades, especially photovoltaic (PV) power generation is getting one of the main renewable energy sources utilized. Global warming and energy policies have become a hot topic on international agenda in last years and developed countries are trying to reduce their greenhouse gas emissions. The European Union is committed to reducing the emission of greenhouse gases below 1990 levels and producing at least 20% of its energy consumption from renewable energy sources by 2020. One of the available alternative, green power generation technologies is the PV power generation. The only emissions associated with PV are those produced during the production of its components. During their lifetime, which is around 25 years, up-to-date PV panels can produce more energy than that used for their manufacturing. After their installation the PV systems generate electricity from solar irradiation without emitting any greenhouse gas. Low cost of long-term maintenance, simplicity made PV power systems comparable to other power generation systems. The recent development in car industry has resulted in partially or totally electric driven vehicles that will probably lead to high PV power generation in future. Here, some solutions applied in solar powered electric vehicles are introduced. Due to the advantageous features and its widely applicable technology the PV systems have bright future. The installation of PV power is increasing exponentially in the world and especially in EU.

Power control and energy management in DC microgrids

Nowadays, DC microgrids attract more and more attention because of their advantage on eliminating long transmission and distribution lines and their inherent capacity of easily integrating energy storage, alternative and renewable power sources. In addition, most of loads require DC power. Even ac machines are often supplied by a DC source when driven by a variable speed drive. The massive use of future Plug-in Hybrid Electric Vehicles (PHEVs) and Electric Vehicles (EVs) will require a more intensive use of DC microgrids in the vehicle on the one hand and in the charging spots on the other hand. This presents the interest of developing transportation systems with clean and renewable energy sources as a replacement for fossil-fuel vehicles. Furthermore, DC microgrids have the advantage of high energy efficiency.

In such systems, the fuel cell (FC) stack, battery bank (BAT), and supercapacitor (SC) bank are usually used as clean energy sources. The FCs and BATs are energy sources that directly convert the chemical energy reaction into the electrical energy. However, there are some well-known technical limitations to FCs: they have a low efficiency in a low load demand, a slow power transfer rate in transitory situations, and a high cost per watt. This case is the reason for which FCs are not used alone in transportation systems to satisfy the load demands, particularly during start-up and transient events. Furthermore, the association of an FC and an energy source leads to a reduction of the hydrogen consumption of the FC.

On the other hand, commercially available BATs present some drawbacks such as low life cycle, long recharging time, and low power densities, in spite of providing a significant high-energy density potential. In addition, the performance of the BAT may greatly be affected by high current discharges. In comparison with BATs and FCs, SCs present a higher power density but a lower energy density. Consequently, a combination of a primary energy source (PES; unidirectional energy source) such as an FC and one or more secondary energy sources (SESs; bidirectional energy sources) such as SCs and BATs, is usually used in EVs to satisfy the different energy requirements. In this combination, the PES and the SES are designed for the continuous and transient energy requirements, respectively. Therefore, the PES can be designed for the average energy and not for the peak of the energy demand.

In this module, a DC microgrid containing a FC, a BAT, and a SC is studied. Four 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 four different ways. The emphasis will be put on the control and the impact of the power architecture on the control strategy and its performances. A conventional linear control strategy will be 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 simulation program will be developed and detailed. Transient and steady state behaviors of the system will be studied by simulation. In addition, three operating modes (normal, over-load, and regenerating mode) will be considered. Interactive animations will be performed using the simulation program and a given driving cycle containing the above operating modes. These interactive simulations allow users evaluating the impact of the energy management and the power control on the efficiency of the DC microgrid.

Hybrid vehicles

Drivetrain and combined energy storage system for electric hybrid vehicles

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. The propulsion system of hybrid vehicle allows for a more efficient usage of fossils fuel, thus lowering the emission of greenhouse gases. HEVs are available as mass-market product; however, their performance can be further improved.

In hybrid drivetrain an Internal Combustion Engine (ICE) is combined with an electric motor. By combining the operation of electric motor and ICE, ICE can operate in the regime where its efficiency is the highest, which lowers fuel consumption. During the braking, electric motor works as a generator. In this way, the braking energy is recuperated and stored back into the electric energy storage systems.

In the module the operating principle of a HEV's propulsion system is presented first. Several drivetrain topologies, which are used in the modern hybrid drives, are described.HEVs use the energy that is stored in the form of a fossil fuel for ICE and electric energy in batteries for electric motor. Therefore, also the electric energy storage system for powering of the electric drive is necessary. This energy storage system can be composed only of the batteries; however, it can be also composed of more different energy storage systems, which are in different manners connected to the electric part of the drivetrain. The properties of the batteries at high power are a critical factor, as operating at the high power decreases battery capacitance and consequently battery lifetime. A combination of the batteries with supercapacitors can be used to tackle this problem. The learning module describes the properties of both batteries and supercapacitors and 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. The experimental drive is based on two propulsion motors, the ICE and the controlled AC PM electric motor. Mechanically they are connected in parallel, so that the torque provided by both motors is summed in the total propulsion torque. The total torque is then transmitted to the load unit (dynamometer) by the pulleys and toothed belt. As a load unit, an additional electric motor is used. With minor adaptations, also other drivetrain configurations can be easily realised.

A number of comprehensive virtual experiments are available:

- Dynamics, energy and power needs in HEV. The experiments which address dynamic model allow observing rolling resistance, gravitation force for certain driving condition. The user can interactively change different parameters/operating conditions such as reference power (as defined by user), driving route and vehicle's properties. Consequently, the power needs are calculated. User can also make a comprehensive analysis of the calculated data (statistics, measurement of specific part), which are provided also in graphical form for each of introduced experiments.
- Serial drive with combined energy storage. Operating of 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 driving conditions. User can also make a comprehensive analysis of the calculated data (statistics, measurement of specific part), which are provided also in graphical form.

Power management techniques for hybrid electric cars

In the hybrid electric cars the electric machine together with the internal combustion engine (ICE) generate the power needed for driving, see for example figure below. The main purpose of the electrical machine in parallel configuration is to keep the machine working near its optimum combustion efficiency. In a full electric car currently only the energy stored in the battery is available. In any configuration the goal is to use the energy available with the highest efficiency possible.

The electric machine has a peak efficiency of more than 90% Compared to less than 40% with modern internal combustion engines. However, these values may drop dramatically when operated only at partial load. In public discussion usually only the peak efficiency numbers are communicated sometimes leading to expectations that cannot be met in practical operation.

When driving at a speed of around 20km/h what corresponds to average speed of inner-city traffic, the necessary traction power is only a fraction of the installed power. As a result the efficiency of the drive train dramatically decreases and the power consumed by auxiliary systems of the vehicle like heating, air conditioning, power steering, audio or lighting may even be higher than that consumed for actually driving.

Depending on the driving cycle the optimum level of hybridization as well as load sharing strategy and electrical energy storage management for highest overall efficiency will thus maybe completely different.

The goal of the module presented here 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. The focus lies on the overall energy needed to drive a distance on specific standard driving cycles.

Wind energy

Renewable energy - Wind energy conversion and control

The extensive use of fossil fuels as energy source has caused a dramatic increase of pollution levels in the Earth's atmosphere. Especially CO2 emissions contribute to global warming, due to the greenhouse effect. The effects of global warming can be catastrophic for the environment and consequently for humanity. Global warming effects include: rise of sea-level and flooding of costal agricultural and residential areas, change in pattern and amount of precipitation, desertification of subtropical areas, increase in the intensity and frequency of extreme weather events. Clearly, in order to limit global warming, the use of polluting fossil fuels, such as coal, oil and natural gas, must be limited as much as possible and emission-free renewable energy sources must be used instead.

Another important fact that raises the need to replace conventional power generation with renewable energy sources, is that remaining stocks of fossil fuels decrease very fast. The amount of fossil fuels such available on Earth is limited. As the fossil fuel resources decrease, their price increases and their extraction from the ground becomes more difficult (e.g. at greater depth, offshore) expensive and environmentally harmful. This can also decrease the so-called 'energy security' of the countries who have limited or on access to fossil fuels, as they will depend more heavily on other countries to sell them and supply them with fossil fuels or energy. On the other hand, renewable energy sources are freely available almost everywhere, they don't produce greenhouse emissions and they availability is not expected to end any time soon! Furthermore, the demand energy consumption on a global level increases, mainly due to the increasing population and the development and industrialization of more counties e.g. China, India and Brazil. This increasing energy demand must be provided by developing and installing more 'clean' renewable energy technologies, if it is limit the environmental effects caused by power generation. For all these reasons, the global community has started moving towards a ‘decarbonized society’, where renewable energy sources will replace the conventional fossil fuels in the areas of transportation, heating/cooling and electricity production for residential and industrial use.

A wide range of technologies exist which convert freely available natural resources such as hydro, wind, solar, biomass, geothermal and waves into useful forms of energy. In the field of renewable energies, wind energy is the fastest growing technology with about 30% annual increase in installed capacity over the period 2004-2011 and with the largest total installed capacity (215 Gigawatts by 2011) after hydroelectric power. Installed wind turbines produced about 3.5% of the global electricity in in 2011 and this figure is expected to rise to 16% by 2030 under moderate scenarios [1]. In Europe, wind power generation is expected to contribute to EU’s 2020 targets for reduction of CO2 emissions by more than 30%. Over the last decades wind energy conversion technology has developed impressively and it is now proven both technically and commercially.

In this module, the basic operating principles of a wind energy converter (WEC) and its control will be described. The focus will be on a WEC with the doubly-fed induction generator (DFIG), that it is currently the most widely-used type for 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 will be presented in separate chapters. In the final experiment all the elements will be integrated to demonstrate the general operation of the wind turbine system and how each one contributes to the wind energy conversion process.

Essential theoretical background will be provided in every chapter and the operating principles will be presented in the form of interactive animated virtual experiments. In the experiments the user can adjust parameters and their effect can be studied through the interactive animations. In the experiments, which are realized as JAVA applets, the user can adjust parameters and their effect can be studied through the interactive animations.

Energy saving

Luminous efficacy of modern light sources

In the everyday life, lighting is one of the most energy-intensive human activities (Fig. 1). We use different light sources to illuminates our cities, buildings and homes, thus we use a lot of energy for this purpose. When there is no natural light source available, we need to create the visually comfortable environment.

The applications of energy-efficient, modern lighting technologies are becoming more important. Incandescent sources are still common light sources in the everyday use. This is because the light quality of these sources is excellent and the characterization of the illumination created by their light is well known and ordinary. However, from the economic point of view, the efficiency of this technology is insufficient. Because of their inefficiency, incandescent light bulbs are gradually being replaced in many applications by other types of electric lights such as modern LEDs (light-emitting diodes).

In the case of a light source, there are two dominant economical characteristics: lifetime and efficacy. Efficacy shows that how many lumens (visible light or luminous flux) can be produced with 1 W electric power - so it can directly characterize the rate of the energy saving.

Most of the incandescent sources are fails in both mentioned aspect of energy efficiency, so to minimize the wasteful effect of their use the European Union gradually banned traditional light bulbs (except halogen types!) from the end of 2011. In the first wave the 100W version was banned, then the 60W type was phased out and from the autumn of 2013 the ban on all remaining traditional types - including the 40W bulb - is being phased for „household lamps”.

When we want to create an energy-effective lighting system, the most modern choice for the used light sources are the LEDs. There are several cases and aspects, where some of the traditional lighting solutions are still better than the LED technology, but if we examine the energy saving factor, the LEDs outperforms nearly all of the competitors in several aspects. However, it must be noted, than from the technical point of view, this properties are the most difficult to perceive, as far as we cannot compare the produced light and the used energy easily. To do it, we need to detect and measure the total luminous flux of the source and the total power input for the calculation of light efficiency.

The aim of this module is to show the basic fundamentals of light science and light engineering and to help to understand the necessity of the change between nowadays most common light sources and the more energy efficient lighting solutions. To do so, the module helps to acquire knowledge required to determine the luminous efficacy, and it provides a comparative online measurement using an incandescent halogen lamp and a LED light source to investigate the differences between their efficiency. 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.