Empowering STEM Education at High Schools by a Talkative Power Based Learning Platform

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Abstract

This paper deals with an integration of STEM education and Project-Based Learning (PBL) by introducing a hybrid hardware/software-based learning platform covering eight learning units. PBL not only bridges the gap between theory and practice, but also focuses on improving students' soft skills, which is important as they prepare for further education or the job. The proposed STEM learning platform combines power electronics, digital communications, and informatics by using the novel Talkative Power Conversion (TPC) concept as a common framework, providing a multidisciplinary approach with relevance to society. Young people have a unique chance to learn fundamentals of these areas as well as acquiring practical skills by implementing these principles in hands-on experiments. The level of difficulty is adjustable so that the learning platform is suitable for both pupils at high school as well as university students. In this paper, the learning units are adapted to the abilities of pupils in their last two high school years, subsequently referred to as high school seniors.

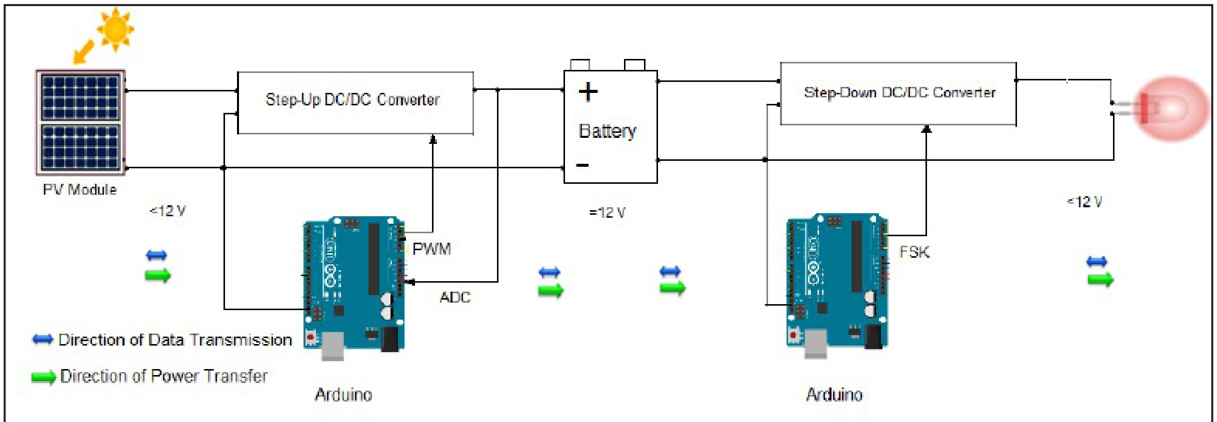

Figure 1. Block diagram of the proposed learning platform. Simultaneous information and power transfer is from left to right in the school project, but can be bidirectional in the general case.

Keywords
Electrical engineering education, Project-based learning, Soft skills, STEM, Talkative power conversion.

Introduction

The general complexity of STEM (Science, Technology, Engineering, and Mathematics) subjects, the need for continuous teachers training, and the ongoing efforts to stimulate high school seniors' interest pose a major challenge for the integration of STEM in education [Sawyer, 2005, Brown, 2012, Kokotsaki et al., 2016, Mohamad Hasim et al., 2022]. To address these challenges, Project-Based Learning (PBL) has emerged as a compelling alternative that successfully bridges the theoretical and practical gap in STEM education [Sadlo, 2014]. PBL allows high school seniors and university students to actively participate in real-world projects, improving their understanding of STEM principles and developing soft skills [Owens & Hite, 2022, Wan Husin et al., 2016]. PBL activities have been successfully applied in a variety of electrical engineering disciplines, such as robotics [Ma, 2021, Campos, 2023], sensor systems [Schneider et al., 2015, Martin, 2021], signal processing [Campos-Roca, 2021], digital systems [Ochoa et al., 2020], artificial intelligence [Macias-Guarasa et al., 2006], machine learning [Alam, 2022], power electronics [Hosseinzadeh & Hesamzadeh, 2012, Zhang et al., 2015], and solar energy [Martinez et al., 2010].

Communications engineering and power electronics have developed almost independently over the last century. Consequently, there is a need in education to adequately cover both electrical engineering disciplines and to explore symbioses. In this contribution, a multidisciplinary STEM learning platform is introduced that covers a wide range of issues relevant to society. The proposed learning platform is motivated by an innovative concept called Talkative Power Conversion (TPC) [He et al., 2020, Liserre et al., 2023, Wang et al., 2023] and combines STEM education with PBL. TPC enables a simultaneous transfer of energy and information. This functionality is useful in a wide range of applications, including data transfer in the electric grid of the future (called smart grid) and wireless power transfer (for charging of electric vehicles, household appliances, and medical implants). Regarding education, however, it is even more important that TPC offers a multidisciplinary framework suitable for STEM education and PBL. This explains why the proposed learning platform targets a wide range of electrical and information engineering disciplines. Lessons comprise (A) renewable energy generation, (B) electric energy storage, (C) electronic devices, (D) microcontroller-based software design, (E) power conversion, (F) control engineering, (G) digital communications principles, and (H) mixed hardware/software-based system design for joint information and power transfer. The Learning Units (LUs) take a comprehensive approach to STEM education by considering the complexity and interrelationships of real-world problems.

A block diagram of the proposed learning platform is depicted in Figure 1. A solar panel generates a time-varying DC output voltage, for instance 5-10 V. A step-up DC/DC converter transforms this input voltage to a fixed voltage, for example 12 V. The harvested energy is stored in a rechargeable battery module. A step-down DC/DC converter transforms the battery voltage to the load voltage, which is assumed to be less than 12 V. At the same time, a data sequence is transmitted from the step-down converter to the load via TPC. If an LED is used as the load, joint illumination and data transmission is possible, called Visible Light Communications (VLC) or Light Fidelity (Li-Fi) [Hoeher, 2019]. The innovative combination of simultaneous energy and data transfer without using additional auxiliary components provides flexibility and opens the door to novel applications. To strengthen learning success, the eight LUs are built on each other. They are presented next.

Methodology: Overview of the Learning Units

Each LU is dedicated to one special topic and consists of five parts: an anonymous pre-test (15 min), background information mediated by a teacher (45 min), hands-on experiments (120 min), review of learning goals (45 min), and an anonymous post-test (15 min). Among the aims of the LUs is to become acquainted with the topics (A)-(H) mentioned above. The LUs are appropriate for pupils in the last two years of high school.

LU-1: Renewable Energy Generation with Focus on Solar Power

Background information: Renewable energy refers to ecologically beneficial and sustainable alternatives to conventional fossil fuels [Nehrir et al., 2011, Olabi & Abdelkareem, 2022, Olabi et al., 2022]. These environmentally friendly energy sources like solar power [Yang et al., 2020], wind power [Olabi et al., 2023], hydro power [Moran et al., 2018], bio energy [Osman et al., 2021], geothermal energy [Anderson & Rezaie, 2019], and marine energy [Borthwick, 2016] help to minimize pollution and greenhouse gas emissions and are not exhaustible. LU-1 focuses on solar energy and photovoltaic (*PV*) modules. The fundamentals of *PV* modules, their pros and cons, and their applications will be explained. The students learn that solar modules are connected directly to the power grid via an inverter, so that the harvested energy can be used for any electrical device. Furthermore, basic electrical engineering concepts such as DC voltage V, current I, electric power $P = V \bullet I$, resistors R., and Ohms law $R = V/I$ prepare students for upcoming experiments.

Exp. 1.1 (Qualitative assessment of a *PV* module): The experiment begins with a qualitative assessment of a solar cell illuminated by sun light. First, a PV module is used to drive a load, like an LED or light bulb, a motor or a beeper. Then, the influence of the orientation of the PV module is discussed as well as external factors such as cloudy weather, trees, and wind. Students are motivated to talk to their parents about the feasibility of residential solar power systems, either in the form of plug-in ("balcony") systems or rooftop installations.

Exp. 1.2 (Open circuit voltage of a PV module): The next experiments delve into more details. Initially, the students are taught how to use a multimeter correctly. Afterwards, the open circuit voltage of a solar cell is measured with a multimeter. To enable repeatable measurements, an artificial light source in a darkened room is most suitable for this and the following experiments. The assessment starts without shadowing and a perpendicular orientation of the PV module towards the light source. Then, the influence of 25%, 50% and 75% masking of the photosensitive area is measured given a fixed light intensity. Subsequently, the influence of different light intensities on the voltage is evaluated. In the case that neither a dimmable light source nor a luxmeter is available, the distance between light source and *PV* module can be changed in equidistant steps. Then, the impact of distance on the voltage will be explored. Furthermore, the impact of the angle of incidence on the voltage will be discussed.

Exp. 1.3 (Short-circuit current of a *PV* module): Exp. 1.2 is to be repeated by measuring the short-circuit current with a multimeter. To speed-up time and for cognitive activation, Exp. 1.2 and Exp. 1.3 are performed by "voltage pupils" and "current pupils", respectively.

Exp. 1.4 (Impact of load resistance): In this optional experiment, the effects of load and irradiance on voltage, current, and harvested power are explored. For this purpose, various resistors will be connected to the *PV* module and the output voltage and current are recorded, whereby the irradiance is kept constant for each test. Then, the corresponding power at the Ohmic load is computed as $P = V^2/R$. Finally, the I vs. V graph (i.e. the voltage-current characteristic) as well as the P *vs.* V graph (i.e. the voltage-power characteristic) are plotted at different loads. The teacher explains how these graphs can be used to maximize the output power of the *PV* module under investigation [Yang et al., 2020].

LU-2: Energy Storage with Emphasis on Rechargeable Batteries

Background information: Energy storage is a critical challenge to close the gap between energy generation and consumption [Koohi-Fayegh & Rosen, 2020, Kularatna & Gunawardane, 2021]. There are many different energy storage systems available differing from their requirements and characteristics like charging time, storage capacity as well as response times. Whereas supercapacitors and capacitors store mainly electrical charges and can be used as intermediate short term storage, batteries can be used for hours or even months. In this manuscript the focus is mainly on using batteries as energy storage device. Rechargeable batteries transform chemical energy directly into electrical energy and vice versa [Buchmann, 2017]. Three main battery types are discussed. First, lead-acid batteries, which are well known from starter batteries in conventional cars, having a reasonable energy density. Second, Nickel-Metal Hydride (NiMH) batteries. They have a stable cycling, but suffer from severe self-discharge. Third, lithium-ion batteries, which exhibit a manifold higher energy density per mass as per volume being now the choice of battery storage for electronic devices. Nevertheless by using metallic lithium in these batteries, they exhibit high safety risks and environmental concerns. Despite electrochemical storage, energy can be stored chemically, including hydrogen and oxygen produced from renewable sources, and green hydrogen synthesis using electrolysis. Alternatively, energy can be stored mechanically, e.g. in hydropower dams or flywheels. In general, it is important to match the demands with the individual characteristics of the storage devices [Koohi-Fayegh & Rosen, 2020, Kularatna & Gunawardane, 2021].

Exp. 2.1 (Charge and discharge curves of a rechargeable battery): The goal of this experiment is to explore the behavior of rechargeable batteries by monitoring the voltage and currents in order to understand the connection between the charging and discharging time as well as the lifetime of electronic devices. The students learn the relationship between the measured currents and the resulting charges flowing. As these relationships are more intuitive in graphical form, students will plot the charge as well as discharge curves over time. Learners are divided "charging pupils" and "discharging pupils" for cognitive activation. In LU-2, rechargeable coin cells are utilized. A resistor is used in order to speed-up the discharging, while charging is done by a standard battery charger. Complete discharging is to be avoided.

Exp. 2.2 (Estimation of internal battery resistance): The open-circuit battery voltage V_{bat} divided by the initial short-circuit current determines the internal resistance of a battery. As students are not permitted to short-circuit a battery, a low-impedance power resistor should be used instead. This external resistor, together with the internal resistance of the battery, essentially forms a voltage divider. Hence, the internal resistance of the battery can be calculated according to $R_{int} = R\,(V_{bat}/V_R - 1)$, where V_R is the voltage across the external resistor immediately after connecting it to the battery. Students determine and compare the internal resistance of a charged and an empty battery by measuring V_{bat} and V_R with a multimeter. They are encouraged to think about the question whether the internal resistance is an indicator for battery aging or not.

LU-3: Electronic Components and Basic Circuits

Background information: In LU-3, essential electronic components and basic circuits are studied [Horowitz et al., 1989]. In LU-1, resistors and Ohm's law have already been investigated. Based on this knowledge, series and parallel concatenations of resistors are explained. The corresponding formulas are derived, and possible applications are pointed out. Then, transistors used as electronic switches are briefly introduced. A transistor has three pins, two of which correspond to those of a mechanical switch. If the third pin is activated, the switch closes, otherwise it is open. Next, Light Emitting Diodes (LEDs) are explained. LEDs emit light when connected to a voltage source. As opposed to a light bulb, however, the current flows in one direction only. Afterwards, capacitors are studied. A capacitor stores energy in an electric field between metal plates, like a small battery. The main parameter is the capacitance C. Finally, inductors are introduced.

An inductor is a coil that generates a magnetic field and therefore serves as an energy source. The main parameter is the inductance L. When a capacitor and an inductor are connected in series or in parallel, their energy is exchanged back-and-forth between these two components. The frequency of this exchange is called resonant frequency, and can be computed as $f_r = 1/(2\pi\sqrt{LC})$ [Horowitz et al., 1989]. An analogy to this are oscillations in spring-mass systems, with which many students are familiar.

Exp. 3.1 (Resistors in series and parallel): In this experiment, two resistors (combined in series or in parallel) are connected via a mechanical switch to a DC power supply. Students get used to breadboards and explore the relation between voltage, current, and overall resistance.

Exp. 3.2 (Using a transistor as a switch): Afterwards, the mechanical switch is replaced by a transistor. The switching mechanism is activated by connecting the third pin to a voltage source. When replacing the resistors by an LED, the switching mechanism becomes even more intuitive to the learners.

Exp. 3.3 (Energy storage with a capacitor): Next, students connect a capacitor with high capacitance in parallel to the PV module introduced in Exp. 1. As a load, either an LED, light bulb, motor, buzzer or multimeter can be used. The effect of energy storage is discussed for time-varying irradiance levels, which can be simulated by masking or tilting for instance.

Exp. 3.4 (Charging and discharging of a capacitor): Finally, a capacitor is charged and discharged via a resistor. The voltage across the capacitor is plotted as a function of time. Students are encouraged to think about a recognizable commonality between a capacitor and a battery.

LU-4: Microcontrollers and Associated Software

Background information: In this LU, students explore the world of microcontrollers, with emphasis on the Arduino platform, which is well-known in education. The Arduino family consists of microcontroller boards including programmable I/O devices and an Integrated Development Environment (IDE) software tool for writing C-like programs known as sketches [Monk, 2023]. Any Arduino program consists of two parts: setup() and loop(). The setup() function is called once in order to configure the I/O interface, while the loop() function is run continuously to perform the execution part. A key concept regarding digital I/O interfacing is Pulse Width Modulation (PWM). PWM is a periodic square-wave signal, see Figure 2. It can be delivered at any digital output pin of an Arduino board. A crucial parameter of PWM is the duty cycle D, $0 < D < 1$, which is defined as the ratio of the "ON" time to the "ON plus OFF" period of the PWM signal.

Exp. 4.1 (Slow PWM): First, students learn to configure a digital output pin and to generate a PWM signal

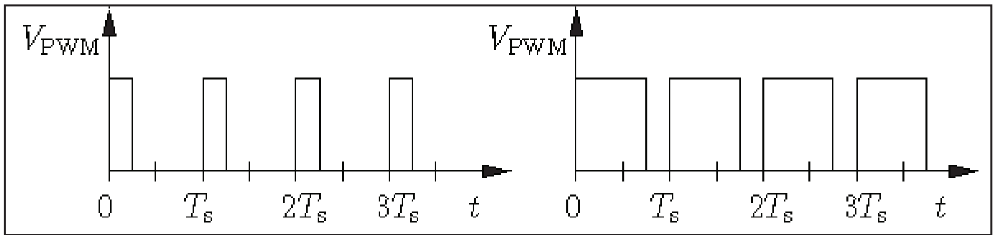

Figure 2. Pulse width modulation with duty cycle D = 0.25 (left) and D = 0.75 (right).

with period of several seconds by using the delay() command. If an LED is connected to this output pin, it blinks slowly.

Exp. 4.2 (Fast PWM): The students are then taught how to use an oscilloscope. Next, students substitute the delay() command by the delayMicroseconds() command. This way, a fast PWM waveform can be generated, for example with frequency $f_s = 50$ kHz, to avoid flicker or to control a power converter. Furthermore, students learn to adjust the duty cycle D and to see the effect on an oscilloscope. Adjusting the duty cycle is a common method for LED dimming and power converter control.

LU-5: Power Conversion

Background information: Renewable energy sources are anticipated to play a significant role in the smart grid, the energy infrastructure of the future. Most renewable energy sources supply variable amounts of energy over time, in contrast to bulk power facilities (like coal and nuclear power plants). Low-loss power converters are able to transform a fluctuating input voltage into a constant output voltage, or vice versa. A step-down DC/DC converter delivers an average output voltage $V_{out} = D{\bullet}V_{in}$, which is smaller than a given input voltage V_{in} [Kazimierczuk, 2015], where D is the duty cycle of a PWM signal introduced in LU-4. A block diagram of a popular power converter, known as buck converter, is depicted in Figure 3. The converter consists two parts: electrical switches and a filter. The two switches, S1 and S2, are connected to a microcontroller or a similar processor. They are switched "ON" and "OFF" alternately, i.e. if S1 is "ON" S2 must be "OFF" and vice versa to avoid a short-circuit. Accordingly, the voltage along S2 is either equal to the input voltage V_{in}, or zero. In Figure 3, this voltage is denoted as VPWM. Let the "ON plus OFF" period be denoted as T_s. The inverse, $f_s = 1/T_s$, is called switching frequency. The two switches (and components for their control) can be replaced by an integrated circuit to reduce the number of components and simplify the interfacing to the microcontroller. Afterwards, the mean value of VPWM is determined by a low-pass filter. The arrangement shown in Figure 3 illustrates a suitable LC lowpass filter with inductor L and capacitor C. It has the resonant frequency f_r introduced in LU-3. Signals components with frequencies below f_r are passing the filter, while signal components with frequencies above f_r are strongly attenuated by the filter. It can be proven by the students that the mean value of the PWM signal is equal to $D{\bullet}Vin$. Therefore, the filtered output voltage Vout consists of the DC voltage $D{\bullet}Vin$ plus a small superimposed ripple voltage. The ripple voltage can be reduced by increasing the ratio f_s / f_r. Note that f_s is determined by the microcontroller (i.e. by software), while f_r is determined by the product $L{\bullet}C$ (i.e. by hardware). From a power electronics point of view the desired signal is the DC voltage. From a communications point of view, however, the ripple is important as it represents the data sequence. Ripple modulation will be explored in LU-7 and LU-8. The following experiments are carried out for a step-down converter with a fixed resonant frequency $f_r = 5$ kHz. The switching frequency is assumed to be $f_s = 50$ kHz in the remainder unless mentioned otherwise.

For the sake of completeness, it should be mentioned that also step-up DC/DC converters exist. As the name implies, these are able to convert a smaller DC voltage into a larger DC voltage [Kazimierczuk, 2015]. A step-up DC/DC converter is used in the learning platform to connect the solar module to the battery. For didactic reasons, however, we do not provide any details at school level.

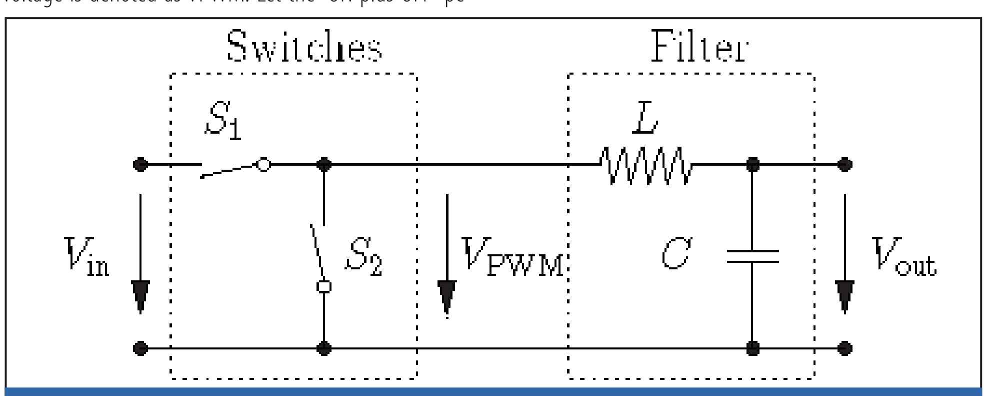

Figure 3. Block diagram of a step-down DC/DC converter.

Exp. 5.1 (Output voltage as a function of the input voltage): Initially, students implement a step-down DC/DC converter on a breadboard. Given a constant PWM duty cycle, students afterwards measure and plot V_{out} versus various values of V_{in}.

Exp. 5.2 (Output voltage as a function of the duty cycle): Given a fixed input voltage, students then measure and draw Vout versus different values of D.

Exp. 5.3 (Ripple voltage as a function of f_s / f_r): Given a fixed input voltage and a constant duty cycle, students finally plot the ripple voltage versus the ratio between f_s and f_r by changing the switching frequency f_s. Students are encouraged to think about the impact of a ripple voltage on power lines.

LU-6: Voltage Control

Background information: The energy harvested by a PV module depends on environmental conditions, see LU-1, and hence is time-varying. Among our goals is to use a PV module for battery charging. This task requires an adjustable charging voltage or current. Consequently, a power converter with integrated control unit needs to be inserted between PV module and battery, see Figure 1. This LU focuses on basic control concepts and shows how to use an Arduino to build a closed-loop voltage control circuit.

Control theory distinguishes between open-loop and closed-loop control [Doyle et al., 2013]. The difference can be explained, for example, by temperature control in the passenger area of a car. In the simplest case, the air ventilation is adjusted mechanically without feedback. External distortions like sunlight cause temperature variations. In air conditioning systems, on the other hand, the ventilation is adjusted automatically based on the difference between a preset temperature and the actually measured temperature. In closed-loop control, external distortions are compensated.

Figure 4 illustrates a block diagram of an Arduino-based control loop for regulation of the voltage delivered by a PV module. The control tasks are handled by the Arduino board that performs the switching of the step-up DC/DC power converter, see Figure 1. The input voltage of the power converter is delivered by the PV module, while its output voltage is charging the battery. The output voltage of the power converter is connected to an analog input pin of the Arduino board, and transformed into the digital domain by an Analog-to-Digital Converter (ADC). We use a build-in 10-bit ADC of the Arduino board to convert each sample of the analog voltage to an integer number between 0 and 1023. The measured integer number is scaled (as described below) and afterwards subtracted off from a targeted reference value, for example the nominal battery voltage. The difference is the error signal. If the measured voltage is larger (smaller) than the reference voltage, the error signal is negative (positive). The error signal should be averaged, otherwise undesired oscillating may happen. The sign (and eventually also the magnitude) of the smoothed error signal is used to adjust the duty cycle of the PWM switching signal. If the smoothed error signal is positive (negative), the duty cycle is increased (decreased). The corrected PWM signal is finally delivered to the power converter via a digital output pin. This closes the feedback loop. Most Arduino boards are based on 5 V technology. Then, the scaling factor is 5/1024, because for example 2.5 V corresponds to the integer number 512. If the voltage at an input pin exceeds 5 V, a voltage divider is necessary to avoid damage. In Figure 4, a 10:1 voltage divider is depicted. The voltage divider must be taken into account when scaling the measured voltage.

Exp. 6.1 (Arduino-based voltage measurement): In the first experiment, the Arduino is used to measure a DC input voltage of less than 5 V in order to avoid a voltage divider. A DC voltage source will be attached to an analog input pin. A constant voltage of 2.5 V is assumed first. The integer number obtained by analog-to-digital conversion must be multiplied by 5/1024 to represent the input voltage. The calculated voltage is displayed via the IDE software and compared with the voltage of the DC source.

Exp. 6.2 (Error signal and averaging): In the second experiment, an error signal is computed. First, Exp. 6.1 will be repeated with a time-varying DC voltage between 1 V and 4 V. Afterwards, the measured voltage is compared with a target value, for example 2.5 V. Then, the moving average of the error signal is computed in software. Finally, the error signal as well as the smoothed error signal are displayed via the IDE software for different DC input voltages.

Exp. 6.3 (Arduino-based voltage control): The final step is to integrate the control loop into a step-down DC/DC converter according to LU-5 using and extending the concepts learned in Exp. 6.1 and Exp. 6.2. The input of the power converter is connected to the PV module, which serves as a variable DC voltage source. To avoid damage, a voltage divider is necessary. Through a software-based adjustment of the duty cycle, the Arduino controls the output voltage of the power converter to adapt it to a targeted reference value. For didactic reasons, we never implement a step-up DC/DC converter and do not want to charge batteries in LU-6.

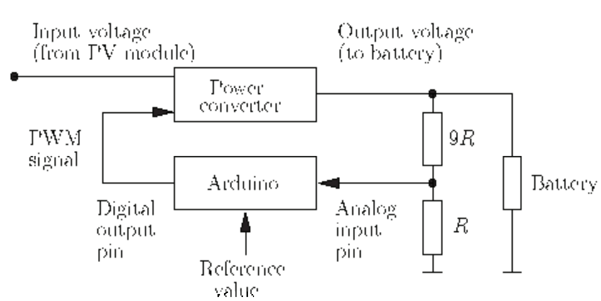

Figure 4. Arduino-based control loop for regulation of the voltage delivered by a PV module.

LU-7: Digital Data Transmission

Background information: The aim of digital communication is to send data bits delivered by an information source via a noisy channel [Proakis, 2008]. The transmitter converts the bit into an appropriate waveform. In its most general form, a transmitter can be divided into a source encoder (for data compression), an encryption unit (for data security), a channel encoder (for reliable data transmission), and a modulator. The task of the receiver is to recover the original bit sequence. Digital communication is extensively utilized in the Internet, in wireless communication, in fiber optics, and in power line communication, among other applications.

Within the scope of the proposed TPC-based learning platform, digital modulation is necessary to modify the PWM signal that is controlling switched-mode power converters. Therefore, of special interest are two-level modulation schemes. An examples is Frequency Shift Keying (FSK), see Figure 5. In binary FSK, two different frequencies are utilized, for instance employing a single pulse for a logical "0" and two short pulses within the symbol duration T_s for a logical "1". If the length of the two short pulses is half of the length of the single pulse, the average pulse duration is maintained. In Figure 5, symbol duration and switching period are assumed to be the same in order to maximize the data rate. FSK and other simple PWM-type modulation schemes are discussed with the students. All PWM-type modulation schemes have in common that they deterministically affect the ripple voltage at the output of a DC/DC power converter. A key objective is to maintain a constant duty cycle to ensure a constant average DC output voltage.

Exp. 7.1 (Data modulation using the Arduino): First, students implement binary FSK modulation on the Arduino assuming a data sequence with alternating "0"s and "1"s. The modulated signal can be visualized

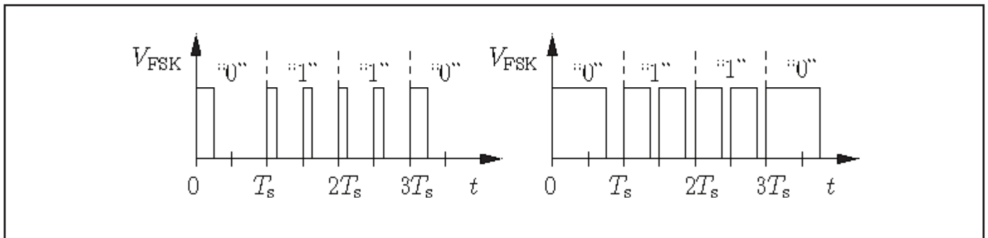

Figure 5. Digital modulation scheme with duty cycle D = 0.25 (left) and D = 0.75 (right).

by connecting an oscilloscope to a digital output pin.

Exp. 7.2 (Data transmission via the step-down converter): Afterwards, the output pin of the Arduino drives a step-down DC/DC converter. Students monitor and evaluate the power converter's output signal. Finally, the data sequence is replaced by ten consecutive "0"s followed by ten "1"s, and the previous tasks are repeated and results are compared.

LU-8: Talkative Power Conversion Learning Platform

Background information: A microgrid is a local power grid that is either connected to the main grid or is autonomous. Microgrids are expected to play an important role in the development of smart grids, in which renewable power generators, loads and storage modules are interconnected [Bevrani et al., 2017]. In order to meet the challenges of variable energy sources and changing user requirements, future power grids will need more flexibility compared to the outdated electric grid of the 20th century.

One innovative smart grid solution is the implementation of talkative power converters. This approach enables simultaneous transmission of power and information via the same medium, for instance the same wire, by integrating data packets into the switching signal of a power converter. In the specific case in Figure 3, S1 and S2 are not switched periodically, but data-dependent. For example, an FSK-modulated switching signal according to LU-7 may be used. Consequently, the ripple voltage which superimposes the DC output voltage is data-dependent. This process is called ripple modulation. With a suitable receiver, the data can be recovered from the ripple voltage.

Exp. 8 (Simultaneous charging the battery and joint data transmission and illumination): In this final experiment, the mixed hardware/software learning platform is implemented and evaluated by the students. A prototype of learning platform, which is based on the block diagram in Figure 1, is shown in Figure 6. The power source is assumed to be a PV module (studied in LU-1), which provides a DC voltage of less than 12 V. A step-up DC/DC converter (briefly introduced in LU-5) connects the PV module to a 12 V battery. A fully-functional step-up DC/DC converter is made available to the students, including a control loop (studied in LU-6) implemented on an Arduino microcontroller (presented in LU-4). A step-down DC/DC converter (according to LU-5) is to be implemented on a breadboard to connect a high-power LED to the battery. The duty cycle of the step-down converter is set by a second Arduino to the nominal voltage of the LED (introduced in LU-3). The LED is used for simultaneous illumination and data transfer, i.e. for Li-Fi. The brightness of the LED is determined by the DC output voltage of the step-down converter, while the ripple voltage that superimposes the DC voltage carries the information according to the TPC concept. A short deterministic data sequence that is transmitted periodically is sufficient to illustrate the essential mode of operation. FSK modulation (studied in LU-7) is to be implemented on the second Arduino. The students can visualize the superimposed ripple at the output of the step-down converter using an oscilloscope. Data detection can be performed by a photodetector connected to another channel of the same oscilloscope. After verification that the setup works properly, the 12 V battery (discussed in LU-2) can be connected to both power converters to be charged by the PV module and discharged by the LED.

Exploring Pedagogical Dimensions

The program consists of the eight LUs just presented. Before the first session (LU-1), a preliminary empirical investigation known as "piloting" is done to assess high school seniors' knowledge with and attitudes toward electrical engineering and information technology. The piloting process comprises asking general questions. These questions aim to gather the students' thoughts and experiences with electrical engineering and information technologies. Students are asked where they come into contact with electrical engineering in their everyday lives, whether they have ever considered a career in electrical engineering or related fields, and whether they find the subject interesting. The questions also delve into students' interests in STEM subjects, their understanding of the distinctions between information engineering and computer sciences, and their understanding of practical applications in electrical and information engineering. Furthermore, the questions aim to assess students' perspectives of electrical engineers' everyday tasks and responsibilities. After the last session (LU-8), the same questions are reviewed to monitor changes and to improve the program.

Each LU includes pre-testing, background information, hands-on experiments, a questionand- answer section, and post-testing. (i) The pre-test consists of an anonymous questionnaire tailored to the goals of the daily LU. (ii) Following that, in a conventional classroom setting, a teacher gives background information while encouraging interaction and mixed by audio/visual supplementary contents. (iii) Then, students work in small groups in a lab environment to execute the presented project-based experiments. Hands-on teams promote practical learning and soft skills. This requires careful selection of the electric devices and measurement equipment in order to avoid damage, but also instructions by the teacher. (iv) Afterwards, the learning goals of the LU are reviewed in a ques-

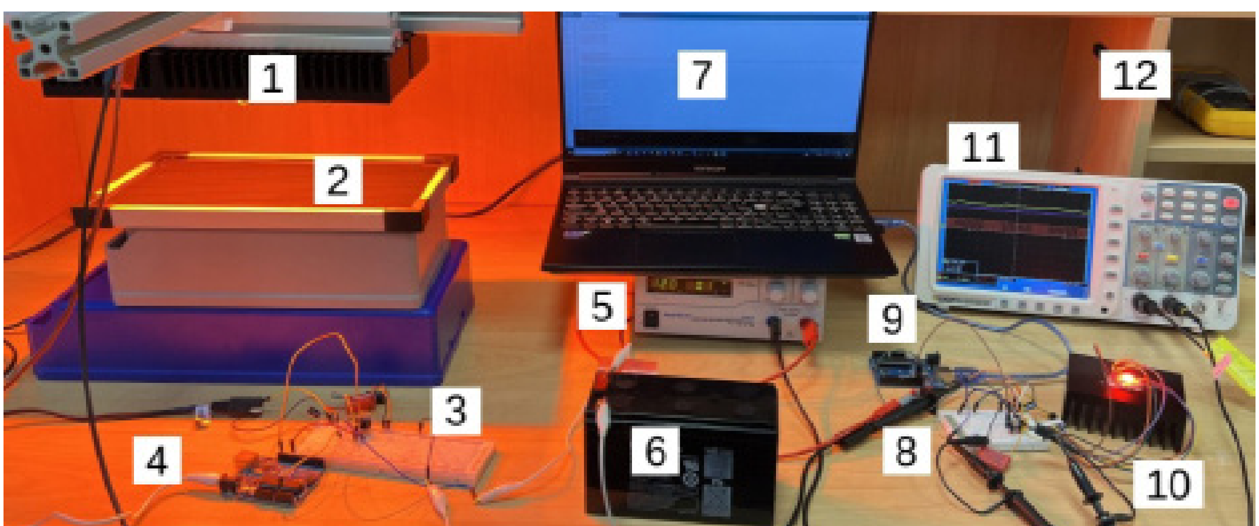

Figure 6. Prototype of the proposed TPC learning platform. (1) Light source, (2) PV module, 3) step-up converter, (4) Arduino, (5) DC voltage source, (6) battery, (7) IDE software, (8) step-down converter, (9) Arduino, (10) LED, (11) oscilloscope, (12) multimeter.

tion and answer session, where all teams participate. (v) Finally, the questionnaire of the pre-test is presented again as a post-test to examine learning progress and students' viewpoints. The post-test not only examines students' understanding of daily learning goals, but is also suitable to measure the efficacy of the entire session.

Electrical engineering is often not easy for students to understand since it depends on abstract models, making it difficult to comprehend experimental phenomena in comparison to other topics. To solve this, our program mixes experiments from many electrical engineering fields and related topics in order to foster interest and knowledge transfer while also encouraging students to pursue jobs in the field. Piloting allows to assess students' past knowledge and interests and to modify the curriculum appropriately. Empirical test data is statistically examined using SPSS software [Jacob et al., 2011], which includes classifying open-ended replies, descriptive statistics, exploratory factor analysis, and correlation analysis. The proposed learning platform is planned to be offered in form of a pilot study by the Leibniz Institute for Science and Mathematics Education [IPN, 2024] to improve STEM education and provide opportunities for teachers training and public participation in science and technology. The program shall be offered in schools after the pilot phase.

Conclusions

In the field of STEM education, there is a need for action to bridge the knowledge gap between communication engineering and power engineering. This gap is closed in this paper by a talkative-power-based learning platform to explore the synergies between these domains. Today's students' preference for software and apps has reduced their experience with basic hardware circuits and electric devices. To address this observation, the proposed learning platform covers a wide range of important topics, including renewable energy generation and storage, power electronic devices, microcontrollers, power conversion, control engineering, digital communications, and hardware/software-based system design. Moreover, while much research focuses on understanding students' perceptions of electrical circuits, there remains an opportunity to leverage these perceptions and apply them to new areas of research and experimentation in electrical and information engineering. This project aims to combine hands-on experiments with students' perceptions and analyze the results to enhance the understanding of high school seniors in the field of electrical engineering and related disciplines. This learning platform, with its project-based learning experiments, may provide high school seniors with broader insights, allowing them to contribute to the electrical and information engineering field in the future as a new generation of electrical engineering professionals. The level of difficulty of background information and experiments reported in this paper is matched to pupils in their last two years at high school, but the complexity is customizable to bachelor and master students as well.

So far we have not been able to offer the learning units for K12 education. However, we have completed all necessary tests. We are confident that the experiments can be reproduced by pupils as well as students and that the proposed learning platform will be a success from a pedagogical point of view. A follow-up contribution that includes a statistical analysis is planned.

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