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Experimental solar-based charging station for electric vehicles

Streszczenie. *Od kilku lat istnieje realna potrzeba tworzenia platformy badawczo-dydaktycznej dla technologii źródeł energii odnawialnej. Nowy innowacyjny temat został podzielony na kilka podzadań realizowanych przez zespoły składające się ze studentów z różnych krajów. Jedno z podzadań i sposób jego realizacji jest opisany w niniejszym artykule. Podzadanie dotyczy zarządzania pracą stacji ładowania samochodów o napędzie elektrycznym. Podstawowym źródłem energii dla tej stacji są panele fotowoltaiczne. Praca dotyczy zarządzanie procesem ładowania/ rozładowania poszczególnych elementów stacji za pomocą klasycznego regulatora ładowania. Układem regulacji jest specjalnie opracowany dla potrzeb tej pracy przekształtnik regulowany za pomocą mikrokontrolera PIC. Wymiana danych między stacją ładowania, pojazdem elektrycznym oraz jednostką nadzorczą odbywa się za pomocą sieci bezprzewodowej. Wstępne wyniki badań są przestawione w tym artykule. (Eksperymentalna stacja ładowania samochodów elektrycznych oparta o źródła fotowoltaiczne)*

***Abstract**. For a few years the need of research completion on renewable energy allows the installation of several student projects at the University. A group of co-operating foreign students working together within the framework of a technically innovative subject has been created through the international relations activity of the University. The subject is as follow: an Experimental Solar-Based Charging Station for Electric Vehicles is designed. The objective of this device is to recharge a stationary battery from solar panels through a classical charge controller. This takes place via a converter regulated by a PIC micro controller, which was especially developed for this application. The exchange of data between the station, the vehicle and the supervision systems takes place through a networking system using zigbee modules. The preliminary results of this project are presented in this paper.*

Słowa kluczowe: projekty studenckie, ogniwa fotowoltaiczne, mikrokontrolery, gokarty elektryczne, współpraca międzynarodowa, ładowanie akumulatorów, magazynowanie energii.
Keywords: students' projects, photovoltaic energy, microcontroller, electrical go-kart, international collaboration, elevator chopper, batteries charge, energy storage.

Introduction

For a few years, teaching and research about renewable energies have started to take an important place in the electrical engineering education. This very popular subject gave rise to a few projects at the Institut Universitaire de Technologie (I.U.T). This school of engineering situated in the northern region of France belongs to the University of Artois. About thousand students are enrolled in 6 technical and scientific departments related to the secondary sector.

This paper concerns a few projects conducted at the Electrical Engineering Department of the I.U.T. During the second year of undergraduate studies, students can select one among of the following specialties - Automatics and Systems or Electrical Engineering and Renewable Energies. These specialities are related to a defined number of teaching hours, and an augmented volume of hours is assigned to modules related to the selected speciality. A renewable energies module is included in the studies aiming to get the Diplôme Universitaire de Technologie (D.U.T) in Electrical Engineering - level L2.

Practical training is essential at the I.U.T, around half of the total volume of hours is assigned to laboratory exercises. The Electrical Engineering Department owns several teaching laboratories equipped with very up to date hardware. The laboratory rooms are equipped with real electrical systems, in which different projects and designed systems are run. Teaching through project is a priority on which a higher and higher emphasis is laid [1 - 2].

Except the development of students' practical skills through practical teaching, the I.U.T of Béthune is also involved in a very intensive international cooperation spread out over 20 UE countries, Eastern and Central Europe, North and South America and North Africa. Thanks to this network our students can spend a part of their university course in industrial utilities or universities out of France. This can be achieved through such international exchange programs like Erasmus for Europe. Reciprocally we receive foreign students which will to spend a mobility period at the I.U.T of Béthune in order to complete either teaching modules or a last year project. They can later validate this period of studies through the ECTS system.

The project presented in this paper has been mainly realised by students having been at a mobility exchange at the I.U.T of Béthune. These exchanges took place within the framework of an international collaboration on renewable energies. The supervision of the project was performed by the authors of this paper.

The international collaboration

A few invited professors who where in Béthune in 2006 May, have decided to establish an international collaboration within the framework of the renewable areas. The main objective is to run appropriate projects through student enrolment (internship program or short period of studies) and capitalisation of scientific results of run research. The main assumptions of the project are as follows - the projects are organised in such a way that all participants will be remotely in touch through Internet. Projects are carried out in common. Modern information exchange tools like Internet forums will be installed for current information exchange. The collaboration has been given the acronym I.C.E.E. (International Collaboration in Engineering Education). Each participating institution should conduct a common project on a given subject under the supervision of a local teacher or researcher [3 - 4].

A power system which could be decomposed in a few subsystems is one possible technical application of the project. The system is a production and management unit of an agricultural utility using different types of renewable energies. Fig. 1 depicts a general view of the system considered

Within the framework of sustainable development several manners are used for electric energy production and storage: photovoltaic panels, wind turbine and hydraulic turbine. Energy loads are also considered as a part of this power system. Water pumpage automatic system is a part of the energy management system. Unused energy is stored in a battery storage system and will be sold later on after having set up an appropriate connection to the power distribution system.

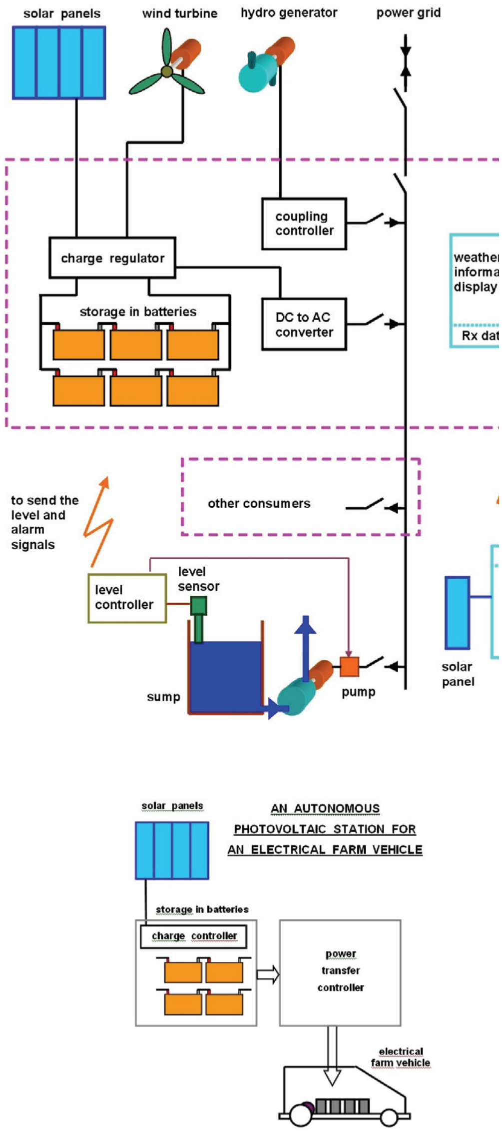

Fig. 1. General view of the electricity production and management system of an agricultural utility

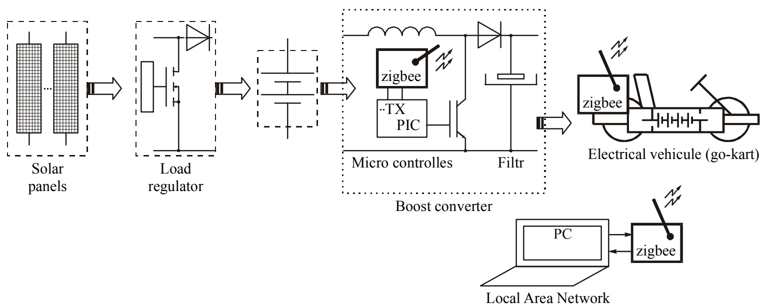

Fig. 2. Charging station principle

The proposed system is open and can be modified according to partner needs. One of the partners has for example proposed a conception of meteorological station with a radio frequency based data transfer system. At the beginning six institutions have participated in the collaboration. The respective coordinators of these institutions are as follows:

- L'I.U.T de Béthune, Université d'Artois, France, Dr Patrick Favier
- The Pennsylvania State University, Altoona College, U.S.A, Pr Sohail Anwar
- Kando Kalman Faculty, Budapest, Hungary, Dr Lorant Nagy
- D.I.T., Dublin, Ireland, Paul Tobin, Dr JohnMac Grory
- W. U. T., Warsaw, Poland, Pr Désiré Rasolomampionona
- Cluj Napoca University, Cluj, Romania, Pr Virgil Maier

Each partner has to select a subsystem to be worked on and propose a subject to be solved by a group of students at their own laboratory or research unit. The repartition of tasks among the different partners was quite easy and all parts of the global application were discussed. Béthune was in charge of the photovoltaic installation, Altoona took the pumpage system, Budapest the battery storage control system, Dublin was in charge of the meteorological station. Warsaw has worked on a hybrid system with photovoltaic panels and a fuel cell. Cluj worked on the selection and automation of the photovoltaic installation.

The realisation of the projects took place at different periods according to the academic calendar, the needs and the availability of the staff of each university. The different tasks are performed in form of practical exercises performed during training periods, projects under supervision, training periods abroad. A special Website [5] was designed by Patrick Favier in order to give information to the whole community about the performed progress task realisation. This primary Website is hosted by the Université d'Artois. A mirror of the Website is hosted at the Warsaw University of Technology, Institute of Electric Power Systems [6]. This site contains information about the international partnership, includes a few technical information and allows publishing students' project reports. This aspect is very valuable from the student point of view because it rewards their personal commitment in the project. They are proud to show what they are really able to do.

The organisation and the mode of project conduction have been set up during autumn meeting with international partners held in Béthune in 2008. It has been decided that the projects will be continued during the academic year 2008/2009 and that the main subject renewable energies will remain the same. The collaboration has been extended to a few other partners and a way of communication of groups of students between one another is sought for.

In October 2008 a annual meeting of all international partners was organised in Béthune. The cooperation has been presented and a workshop in Electrical Engineering was held in order to dare invite other possible partners to participate in the cooperation.

During this academic year all partners have started new projects or continued current ones. An internet forum has been set up in order to facilitate the information exchange between students. Students from different countries are subscribed.

The first part of this paper will be dedicated to the description of the solar-based charging station and the progress of the project. Then the ZigBee module-based communication part will be presented.

The technical project and its progress

The functional diagram of the solar-based station for electric vehicle charging is depicted in. The station is composed of solar panels charging a group of 24V batteries called station batteries. Batteries are charged through a controller of classical solar charger. The BOOST step-up converter, controlled by a PIC controller is the main part of the system. This converter has two functions: regulation of the current and measurement of different quantities. Then the micro-controller sends the measured values to a ZigBee module which forwards the data to the vehicle batteries the voltage of which is 48V.

This project has started by the design of an electrical go-kart, the supply voltage of which is 48V. Electronic boards have been designed and built by 2nd year students of the I.U.T. as a final project in 2006. Although the go-kart design has nothing common with an agricultural activity as it was said before, the obtained electrical vehicle has been used in order to implement the charger and the ZigBee communication module between the charging station, the electrical vehicle and a LAN network.

The output converter

The implementation of the solar-based charging station started in 2008, is a feasibility study of the converter presented on Fig. 2. A study and development of a prototype was carried out by two second year students of the Electrical Engineering Department - speciality Electrical Engineering and Renewable Energies. This project ended in 2009 by the building of a converter model operating in open loop current control.

A student from the University of Resita (Romania) has spent 3 months of internship within the Erasmus mobility framework. He was finishing a bachelor course this year (2010). This student has worked on the design and the implementation of the IGBT control electronic board, a board for measuring instantaneous and average values of charging current and voltage. If their values exceed a defined threshold, Hall Effect sensors are activated and lead to the galvanic isolation between the control and the power unit. A wiring of electronic control and protection can be considered after running the above-mentioned boards.

A Polish student from Warsaw University of Technology continued the job of the Romanian student in February, 2009. He was in charge of the conception and implementation of the ZigBee communication modules for data exchange and also the supervision station by Web Services. He also implemented the telemetry part.
This task is presented in details in the next section.

From middle-April to middle-June two Morocco students have joined the team in order to complete their bachelor course in Electronics and Computer Science. One of them was in charge of the microcontroller programming for the charging station and the vehicle battery control and the information exchange with the external environment. The second student works on the improvement of the energy efficiency of the converter. He is in charge of the comparative analysis of simulation and experience results. He also works on the software which manages the start/stop operation modes of the system and the temperature control.

These tests permit at first to validate the feasibility of such charger. More details with experimental recordings are available from [7]. Indeed, we observe that the efficiency is quite fair and is about 83%, but the more the power is the lower the efficiency drops. This last result seems logic knowing that the most important losses are caused by Joule effect. Probably this efficiency could be improved by a more judicious design of the charger elements.

This experimental study shows that a slow charging at low current rates is recommended for the sake of battery longevity. Anyway it allows also to perform a fast charging (at high current rates), which could be the case if a faster reuse of the electric vehicle is indispensable.

The input charge regulator

The station is not connected to the grid, the batteries are charged from the photovoltaic (PV) panels. The transfer of the energy is controlled through a charge regulator. The principle function of this electronic device is to avoid the overcharge of the station's batteries. The Fig 3 shows the structure of our shunt regulator.

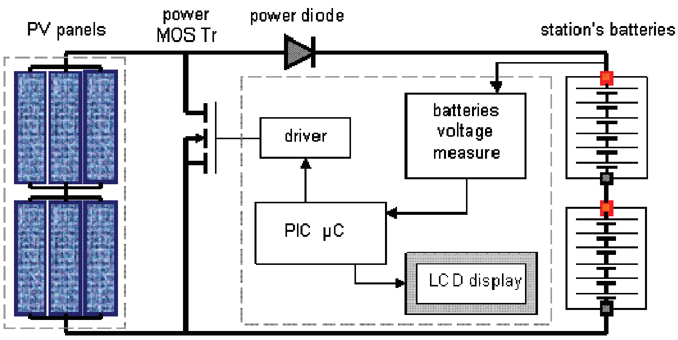

Fig. 3. Structure of the charge regulator

A PIC microcontroller (µC) (16F877) is the digital unit to control a power MOS transistor. The batteries voltage V_{bat} is measured and adapted to the 0,+5V level of an analogical input of the µC. The µC compares this voltage V_{bat} with different programmed threshold voltages.

The rated voltage of the station's batteries is 24V. When V_{bat} is under 26.6V the batteries are not well charged, the µC locked the power transistor, and the current from the PV panels goes to the batteries for charging. A special IC driver controls the gate of the MOS transistor. This circuit TLP250 converts the 0+5V digital signal from a µC output to a 0+15V V_{GS} gate voltage. A diode allows the transfer of the energy from the PV panels towards the batteries and locks the reverse conduction when the PV panels are not under the sunshine.

When the batteries are almost charged, the V_{bat} voltage increases up to 26.6V. From this threshold, the transistor is periodically switched on to reduce the average current to the batteries. When the transistor is conducting, the PV current is derived to the shunt circuit through the transistor. This switching functioning allows finishing progressively the charge. When the V_{bat} voltage increases up to 28V, the batteries are fully charged. The µC keeps the transistor conducting continuously to stop the current in the batteries. An LCD display shows a few information concerning the functioning: batteries voltage, working state, and so on.

To test our prototype, we used six PV panels type FEE 14-12 from the factory Free Energy. The characteristics of one panel are: output power 12Wp, 0.75A at 16V, amorphous silicon. The panels are connected in two groups in series, each group is composed of three panels in parallel. This PV generator is able to output 72Wp, 2.25A at 32V under the standard conditions. The station's accumulator is constituted with two acid-lead batteries of 12V, 55Ah each. The series connection gives a 24V, 55Ah accumulator. The charge duration is depending of the sun irradiation conditions: location, panels' orientation, period during the year and weather conditions.

The charge duration is long because of the low power of our PV generator. It needs several days for full charge. We connected only six PV panels, just to test our prototype.

To reduce the charge duration, it is possible to increase the power of the system. The maximum power of the PV field we are allowed to connect is limited by the semiconductors of the electronic regulator. The used transistor is a power MOS type STE53NA50 with a continuous maximum current equals to 53A, the power diode is a BYT30 with a maximum forward current equals to 30A. Put a bigger station's battery allows to store more energy.

This regulator has been designed and implemented by two French students during the 2009-2010 academic year. They worked on this project during their second year of the I.U.T curriculum speciality electro-energetic and renewable energies. The final realisation is shown on the picture Fig 4. We can see the power part at the top. The left terminals are connected to the PV panels, the right terminals to the stations' batteries. The electronic board takes place in the central position with the μC. The LCD display is at the right bottom with switches to control the functioning.

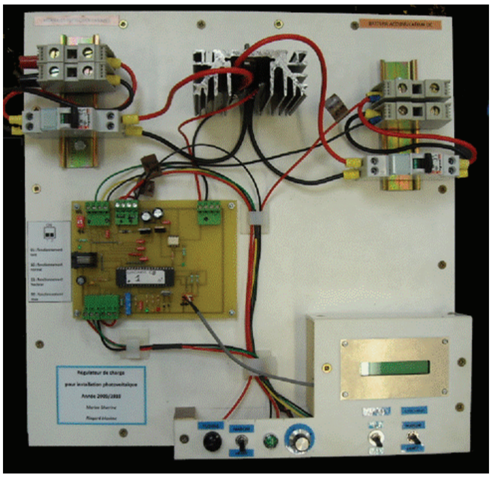

Fig. 4. Picture of the charge regulator prototype

The students dealt with the different tasks such as realization of the mechanical frame, assembling and connection of the electrical components, designing of the electronic board. They wrote and debugged the programming of the μC under C language. More details are available on the ICEE web site by logging to the student's report [5] [6].

The Zigbee communication

The second section of this paper presents the results of the WUT student's research during the internship at I.U.T. As it was said previously, his task consisted of implementing the communication path during the different element of the Zigbee technology-based communication path.

The communication part of this project is composed of two subparts closely linked. The first subpart is aimed to develop a local area network (LAN), the role of which is to manage the communication between the electrical go-kart, the charging station and a master server, in order to supervise and control the charging station. The go-kart being itself mobile, the only possible communication way is a wireless solution. The technology which has been selected is the ZigBee detailed in the next paragraphs.

The second subpart of the communication is aimed to develop a Web server, the role of which is to store the parameters collected from the charging station and send through the LAN network. This allows communicating with the server through a secure link from an Internet-connected computer, which supervises and controls such parameters of the charging system like the charger operation, go-cart batteries or the charging station itself.

ZigBee is an LP-WPAN (Low Power – Wireless Personal Area Network), the characteristics of which are as follows:

- Low data transmission rate (max. 250 kbits/s) but strong enough for the project because of the low quantity of data exchanged.
- An operation range from a few meters to a few hundreds meters, compliant to the French and European standard concerning radio frequency transmission (max 3 dBm),
- A very low power standby mode (100 μW). ZigBee can have a power supply for months using only simple batteries.

The ZigBee project has started in 1998, but the final standard IEEE 802.15.4, describing all the specificities of the project has been eventually issued in 2003, May [8]. The main information contained in the ZigBee standard concerns the definition of physical and communication layer.

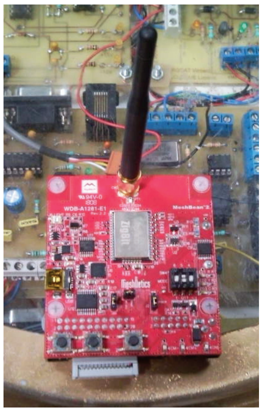

Fig. 5. The ZigBee module

The ZigBee modules are used for the communication of autonomous embedded systems like sensors, actuators, command and control. The ZigBee modules are related to these sensors. More and more ZigBee applications are used in the industry because of the high demand for intelligent and low-cost communication systems which will increase the productivity. Wireless networks of sensors like IWSN, (Industrial Wireless Sensor Network) give a lot of advantages compared to traditional industrial control system based on wiring. Some studies are carried out in order to test the possibilities of Wi-Fi control systems for home facility management [9].

A network composed of three ZigBee modules arranged in a star topology is proposed in this project. The modules « go-kart » and « station » are connected to the module « server » also called « coordinator ». All sent messages are relayed through the coordinator and the direct communications between all other modules themselves are blocked. Because of the importance of the coordinator's role its energy consumption is much higher, hence the "server" is power-supplied continuously through one of its USB ports. Fig. 5 presents the example of ZigBee module installed on the go-kart.

The other part of the communication system consists of design and building of a Web Server, on which the supervision of the charging station and the go-kart will take place and the exchanged information will pass through and forwarded to the connected users. The main supervision tasks are as follows: supervising the proper operation of the charging station with the battery level – the go-kart batteries must not be too much overcharged or discharged. The charging station and the go-kart send regularly, each 5 seconds information through the ZigBee modules. This information are stored in the computer. A history of the parameters like the charging station voltage for the last 24h, on-line graphs of such parameters like temperature measured at different locations are available for immediate visualisation. Also information about error history and possible malfunctions during the energy transfer (i.e. current control error) between the "station" and the "go-kart" are available. In case of any issue the application should give the user the possibility of disconnecting the charging station or starting a new charging process of the go-kart batteries.

Having in consideration the above-mentioned measuring possibilities, it has been decided to study the remote measurement of speed and current during the go-kart's operation. This telemetry was performed by using the two inputs ADC1 and ADC2 of the ZigBee modules. The obtained analogical signals are transformed to digital ones. Ten measurements are performed at the input ADC1 each half a second, and then next ten measurements at the input ADC2. Afterwards a portable PC is connected to the ZigBee module and a simple program is run in a loop mode. This program receives the data and computes the average value for each channel (speed and current). The obtained results can be visualised using graphical software, if they are needed for further processing. The only problem for this operation is that the application which performs the charging station supervision and the remote measurement application (telemetry) can not operate simultaneously. An example of the obtained graphs is presented on Fig. 6, current (red curve) and speed (green curve) are recorded.

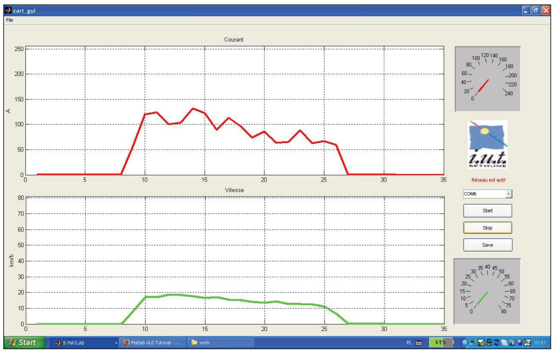

Fig. 6. Telemetry measurements

The obtained results have shown the feasibility of the project as a complex whole. Moreover external tests have demonstrated that the remote measuring coverage is about 50 meters.

After having finished the feasibility tests, two South African students of the University of Potchefstroom have continued the project during an internship which took place at the I.U.T. The aim of this internship was to continue and improve the design and implementation of the LAN network, which will give access to the go-kart and the charging station data. Also both of them have worked out a communication platform between the microcontrollers and the ZigBee modules. Thanks to this LAN network the communication was more efficient because the number of data exchanged (voltage, current, temperature, and so on…) has been increased.

All those projects are very closely related one another. Moreover they have evaluated according to the proposals of students and teaching staff. Mutual communication, project progress, reciprocal assistance between students, supervision shared by the staff are the necessary conditions for the project achievement.

Conclusions

A prototype of charging station for electrical vehicle has been studied and implemented by the staff and the students at I.U.T Béthune. The efficiency of the station is satisfying. Charging and discharging control functions are integrated in the charging system. Also Wi-Fi communication between the different modules with a supervision function included was studied and implemented. The system can be easily adapted to different voltage levels. The converter can be improved from the point of view of energy efficiency. Real application will need an exact calculation of the photovoltaic panel number, the battery capacity and the electronic components calibration according to the expected power and the utilisation ratio of the charging station itself. Two cases can be considered, when the photovoltaic station is either installed in an isolated area or connected to the power distribution system.

The proposed test bench is entirely innovative from the electrical engineering teaching point of view. Students from different countries having studied in different educational systems, and having different levels of knowledge work together using the same method on the same project. The modern aspect of the common project for the application of renewable energies was very attractive for all students integrated in this international collaboration. This technical project gathers different domains of Electrical Engineering – some electronics, sensors, automatics, regulation and control, renewable energies, information technology, microcontrollers, web page creation. The implemented prototype will be used as a knowledge platform for conducting lab exercises for the future students in power system course. Knowing that such subjects like technology transfer and industry cooperation are very well-known at the I.U.T this policy will lead the institute a little farther towards the sustainable environmental development.

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