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The Tajikistan Project: Energy for Education

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Abstract: This paper presents the main results of a project aimed at developing educational materials (lectures, laboratory exercises, and e-learning materials) in the field of renewable and hydrogen energy for the students of the Tajik Technical University. Special emphasis was placed on the exchange of knowledge and experience with respect to scientific achievement and education in renewable energy and energy storage technologies. The design and construction of a special educational installation of off-grid distributed power systems designed for the practice of exercises is described. An autonomous solar lamp system powered by PV solar panels is described in operation under in-field conditions. The laboratory setup consisted of 150W photovoltaic solar panels, an accumulator-type battery, an electronic charge monitoring system, and a Raspberry Pi microcomputer, enabling the real-time monitoring of PV system parameters (measurement of the voltage, current, and power generated by PV panels) as well as the archiving of data transmitted via the internet to the SQL database.

1 The energy sector in Tajikistan

Tajikistan is a mountainous country; over 93% of its area is covered by mountains, in particular the Pamir range. Tajikistan is bordered by Afghanistan to the south, China to the east, and Kyrgyzstan and Uzbekistan to the north and west, respectively. The country is inhabited by over 8.4 million people, with an area of about 143,000 km^2 and a resulting population density of about 50 people per m^2. Water resources in Tajikistan are significant. The potential for annual energy production is estimated at 527 billion kilowatt hours (kWh); in terms of technical potential, this figure is approximately 317 billion kWh, or 60%, per year. This places Tajikistan in eighth place overall in the world, as well as second in electricity per capita and first in hydropower potential [1–3].

The specific nature of the terrain causes many infrastructural problems. Many villages, especially in the Pamir area, are cut off from access to electricity and even water. Another problem is inequality between the country's regions: the economically developed north has difficulty extending the electric grid to the poorly-developed south, where the best conditions prevail for the construction of large hydroelectric power plants capable of meeting the entire

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country's demand for energy. Especially in southern Tajikistan, numerous rivers, well suited, as a rule, for the construction of small and medium hydropower plants, are characterised by marked declines in flow rates during the summer months. At present, 95% of the country's electricity is obtained from large hydropower plants. Due to the freezing of rivers in the winter months, energy production drops drastically during the time when demand is the highest. This strongly affects the country's economy. According to estimates, 1 of 7 people have very limited access to electricity, or none.

Tajikistan produced 17.3 GWh of electricity in 2017. Consumption by particular sectors is shown in Fig. 1.

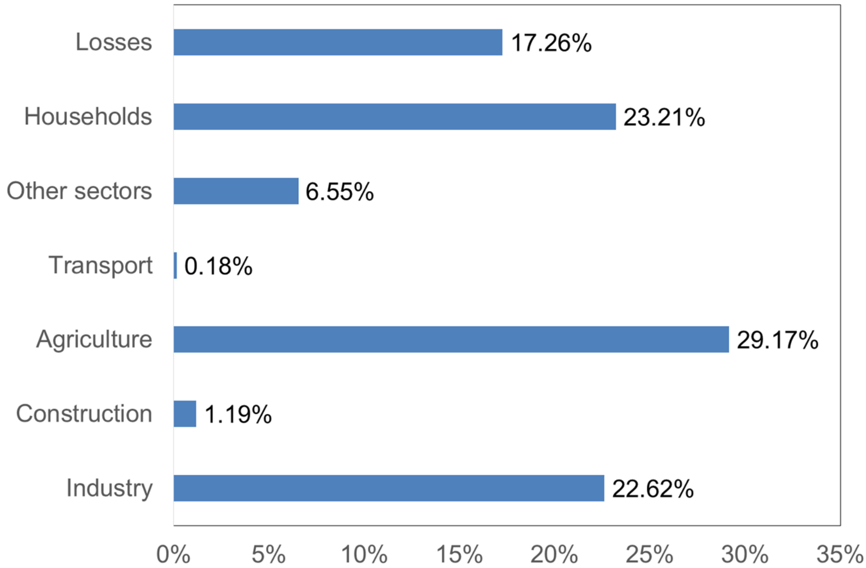

Fig. 1. Participation in electricity consumption by sectors in 2017 [4]

The largest hydroelectric plant currently in operation is the Nurek 3,000-MW hydropower plant, with maximum power equal to 60% of the installed capacity of the whole country. Due to changes in river flow rates and energy demand, only 53–68%, on average, of the installed capacity is used. The greatest problems arise during the winter months, during which the maximum energy supply is estimated at 2,250 MW, which covers only 47% of the demand. This is a particularly serious problem for small hydro plants that are not equipped with reservoirs capable of storing water; as a result, their ability to produce energy drops by 75%. In winter, the energy supply gap is 24%, which is equivalent to economic losses estimated at $200 million [5]. Air pollution resulting from burning low-quality wood and coal to heat households or cook meals represents an immediate threat to the lives and health of residents. Residents of rural areas choose biomass as fuel, partly due to the price of electricity, which, despite being among the lowest in Central Asia (US 1.9 cents/kWh) [6], nonetheless represents between 10 to 24% [6] of monthly income for 70% of the country's population. This is not improved by either the poor state of the infrastructure, which causes high energy losses, or very energy-intensive aluminium production by one of the largest Tajik companies, TALCO. One potential solution to these problems is represented by the government's efforts in Tajikistan to improve existing power plants and build new ones. The most important project is the construction of the Rogun hydropower plant, with a planned capacity of 3,600 MW, which would satisfy domestic demand as well as enabling energy exports to other countries. What is more, Rogun, like Nurek, will be used not only to produce energy but also to store water for irrigation. It should be noted that the construction of such a large power plant is a geopolitical project that affects the local and international community as well as the natural environment. The government of Uzbekistan, which borders on Tajikistan and is located downstream of the rivers flowing through the country, is concerned that the construction of the dam will cause further drying of the Aral Sea; this will exacerbate problems in the region, leading to drought which, in turn, may cause losses estimated at $600 million per year [7]. Irrespective of these problems, the first turbine is expected to be activated in November 2018. Another area for development in Tajikistan is a solution promoted by the United Nations, emphasising the use of renewable energy sources and improvement of energy efficiency, according to which priority should be given to small hydropower plants and solar energy, both thermal and photovoltaic [8]. The latter form is capable of constituting the basis of this programme, by virtue of such factors as a high rate of solar exposure and the proximity of China, a solar technology leader, thanks to which cheap, high-quality devices can be provided. Therefore, we decided to introduce students to the field of renewable energy. In the project we followed this idea, starting with the promotion of Sustainable Development Goals – primarily three: affordable and clean energy, quality education, and partnerships for the goals.

2 Renewable energy in Poland

In 2017, the generation capacity of the Public Power System (PPS) in Poland equalled 43.5 GW, with an average annual demand of 22.9 GW and a maximum demand of 26.2 GW. In 2017, the annual generation of PPS electricity amounted to 170.1 TWh, most of which was derived from the combustion of fossil fuels – coal-fired power plants (50%), lignite-fired power plants (30%), and gas-fired power plants (6%) – due to Poland's possession of substantial coal reserves. The remaining 14% was derived from renewable energy sources (RES), the main sources being wind farms (7%), biofuels and waste (6%), and water turbine plants (1%). In Poland, wind farms (5.8 GW) predominate in terms of RES generation capacity, followed by water turbine plants (1 GW), biomass sources (0.9 GW), biogas plants (0.2 GW), and solar cells (0.2 GW) [9-12].

The share of RES in electricity generation, which is growing consistently every year, is expected in 2020 to reach the target of 15% of RES set for Poland with regard to the fulfilment of its European Union obligations resulting from the directive of the European Parliament and the Council of 23 April 2009 (2009/28/EC) aimed at reducing CO_2 emissions. In the generation of RES electricity, the dominant share is currently held by large wind farms characterised by increasingly large turbines with capacities of several MW, which, due to their size and prevailing wind conditions, are being planned with increasing frequency for installation at sea (offshore). The capacities of such renewable sources as water, biogas, and biomass have been maintained virtually unchanged for years. As a result of a new law on renewable energy sources and a significant price decrease in the photovoltaic market, a dynamic increase in electricity generation from solar energy is being observed (a 110-fold increase in the amount of electricity generated by PV since 2012). The dynamic growth of PV systems is possible due to the aforementioned new law, which introduced the concept of prosumers, owners of PV micro systems with capacities of up to 10 kW who generate energy from renewable sources for their own use. These are on-grid installations with capacities of up to 10 kW, working in tandem with the power system, which serves them as a form of energy storage, such that, when prosumers are low on electricity, they can recover up to 80% from the power grid free of charge for each 1 kWh of electricity sent to the grid. This has resulted in the increased popularity of new domestic photovoltaic micro power plants and their installation on a large scale in Poland [9-13].

3 Electricity storage in hydrogen

Electricity storage is not only an important element of the market approach to balancing the demand for and supply of electricity while ensuring the reliability of the latter. As an element of the so-called 'smart grid', it is also an important component supplementing a distributed network of renewable energy sources, which is subject to unstable operation due to changing weather conditions. Electricity can also be stored in the form of chemical energy of fuel. This technology takes electricity from renewable sources or energy production surpluses and uses it to produce hydrogen by electrolysis. This process takes place mainly in polymeric or alkaline electrolytic cells. The high-purity hydrogen obtained by means of this technology can subsequently be used as a raw material for power-to-gas or power-to-liquid synthesis, or for the production of electricity. Currently, many countries, both in the EU and worldwide, are emphasising the development of their hydrogen economy, which encompasses three concepts: hydrogen production, storage, and use in the fuel and energy sector [14,15].

It is worth mentioning that hydrogen, as an energy carrier, is still seeking social acceptance. Undoubtedly, the main reason for this is its bad reputation in the past. The *Hindenburg* disaster still inclines people to doubt that hydrogen can be an ecological and safe fuel or a reliable energy carrier. Despite the zeppelin's careful construction and the extensive experience of the Germans in the use of hydrogen, in May 1937, while the ship was being moored at an airport in Lakehurst, NJ, USA, a fire broke out, most likely caused by a discharge between the airship sheathing and the mooring tower. Thirteen passengers and 22 crew members were killed [16]. After many years of research, it was found that the cause of the crash was not hydrogen but an unfortunate coincidence related to the construction of the airship.

Another spectacular example of a hydrogen-related disaster was the explosion of the *Challenger* space shuttle in 1986. The cause of the accident was damage to the sealing ring in the booster engine, and a sequence of subsequent events leading to the ignition of the external fuel tank and the destruction of the shuttle. Although the cause of the crash was a failure of an engine component, the image of the fuel explosion remained in the public consciousness [17].

The hydrogen-related accidents described above distort the public perception, according to which it is a dangerous fuel. The question now is whether it is more dangerous than other fuels already in widespread use, and whether we as a society should change the way we think about hydrogen. It should be emphasised that the use of currently popular fuels such as natural gas, gasoline, diesel oil, or coal also poses hazards.

The implementation of renewable energy technology in connection with hydrogen technologies requires action at various levels to create not only a hydrogen infrastructure similar to those existing for liquid fuels, but also an integrated energy development system encompassing, along with safety improvements, research and development, and hydrogen use safety, the development of specialised teaching materials for university students and engineering staff and for primary and secondary school students alike [18].

This challenge was taken up in the Tajik project. This paper presents the main results of a project aimed at developing educational materials (lectures, laboratory exercises, and e-learning materials) in the field of renewable and hydrogen energy for students at the Tajik Technical University.

4 Online monitoring of a solar-powered LED lamp system

To promote the acquisition of practical skills in the field of renewable energy, a 'solar lamp' test stand was built, consisting of a LED lamp powered by a battery which could be recharged with electricity generated by photovoltaic panels. Fig. 2 presents an electrical diagram of the LED lamp system, powered by electricity generated by photovoltaic panels, with a monitoring system.

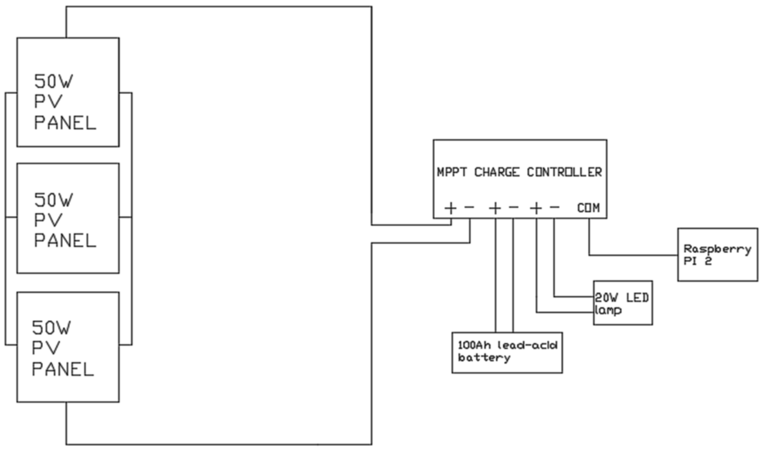

Fig 2. Electrical diagram of an online monitoring system for an LED lamp powered by solar energy from a photovoltaic panel

Table 1 presents the main devices necessary to construct this LED lamp system.

Table 1. List of components of an online monitoring system for an LED lamp powered by solar energy from a photovoltaic panel

Device	**Technical description/model**	**Quantity**
Photovoltaic panel	4SUN-FLEX-M 50W	3 pcs
Charge controller	EPSolar Tracer 2210A (MPPT)	1 pc
Lamp	LED 20W IP65	1 pc
Battery	100-Ah 'REACTOR' 1000 lead-acid	1 pc
Microcomputer	Raspberry PI 2B	1 pc

Table 2. Electrical parameters of the three photovoltaic panels (4SUN-FLEX-M 50W) connected in parallel

Optimal power [P_{max}]	145.8 W
Working voltage [V_{mp}]	18 V
Working current [I_{mp}]	8.1 A
Short-circuit current [I_{sc}]	8.7 A
Open-circuit voltage [Voc]	20 V

Table 2 presents the electrical parameters of the three 4SUN-FLEX-M 50W photovoltaic panels used to construct the investigated setup.

As can be seen in Fig. 2, the LED lamp was powered by a battery via an EPSolar Tracer 2210A (MPPT) charge controller, which controlled recharging of the battery from the photovoltaic panels. Thanks to the RS-485 communication port in the controller, it was possible to design an online monitoring system based on the Raspberry PI 2B microcomputer, which was selected on the basis of its sufficient computing power, small size, and energy requirements (so-called auxiliaries).

The current and voltage values of the photovoltaic panels measured by the charge controller were sent via the RS-485 communication port to the Raspberry PI microcomputer. Then, processed data was sent every minute via the Internet to the MySQL database located on the AGH University of Science and Technology server. There, the data was acquired, monitored, and presented on a website.

5 Hydrogen from the electrolyser powered by photovoltaic panels

Another important stage was the education of students in the field of hydrogen technology. The construction of a research station consisting of a Kyocera 80-W photovoltaic panel and an E107 electrolytic cell (H-TEC, Germany) was a satisfactory solution. The versatility of this set enabled work to be carried out in both natural and artificial lighting.

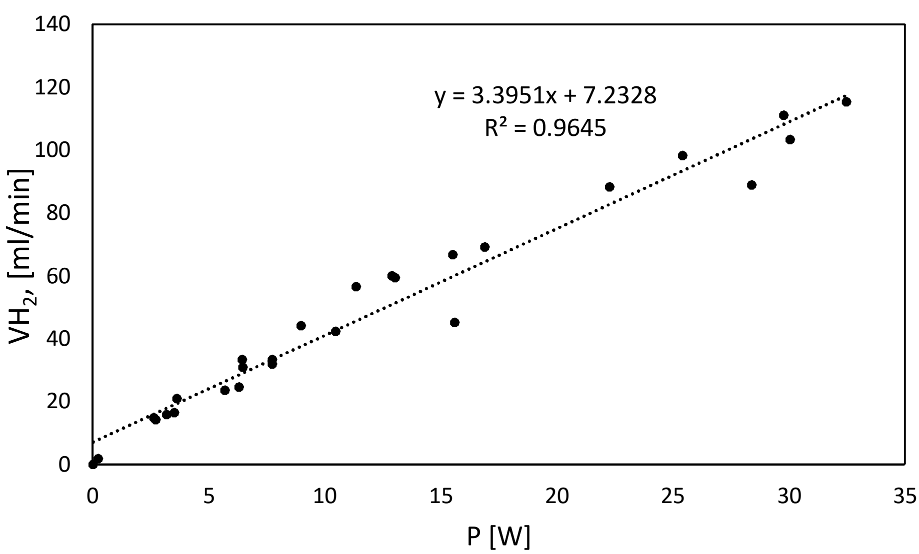

Fig. 3. Dependence of variation in the amount of hydrogen produced by the electrolyser from power supplied from the photovoltaic panel

Fig. 3 presents the dependence of variation in the amount of hydrogen produced by the electrolyser from power supplied from the photovoltaic panel. The same figure shows that the amount of hydrogen produced increases linearly with the amount of supplied electrical power (P).

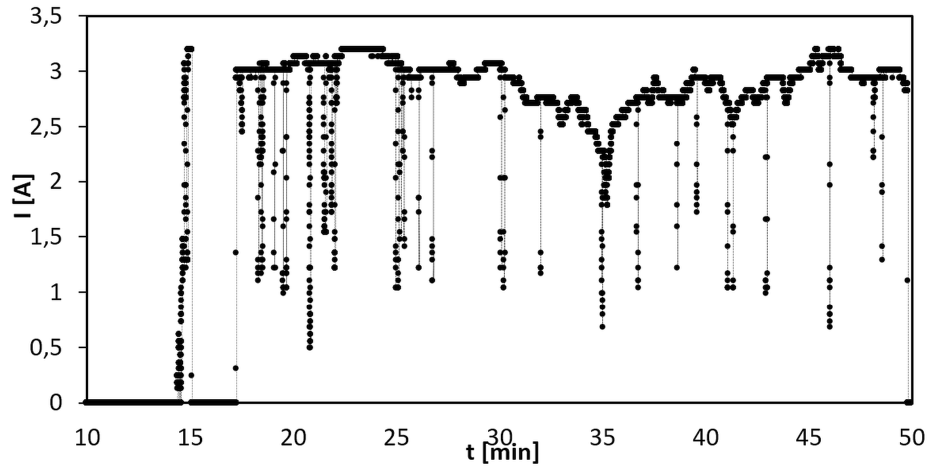

Fig. 4. Dependence of variation in the intensity of the electrolysis current (I) generated by the photovoltaic panel under natural lighting conditions

Fig. 4. presents the dependence of variation in the intensity of the electrolysis current (I) generated by the photovoltaic panel under natural lighting conditions. The changes observed in the intensity of the current (I) generated by the photovoltaic panel are the result of changes in atmospheric conditions, mainly exposure to sunlight, during the experiment. Fig. 3. shows how variations in exposure to sunlight adversely affect the production of electrical power, which in turn directly affects the limited efficiency of the electrolytic cell. The experiments presented in Fig. 3. and Fig. 4. indicate the necessity to install either electrical power equipment to stabilise the electrolytic cell or a buffer energy source in the form of a battery and a supercapacitor cell, making it possible to safely intensify and stabilise the production of hydrogen from the electrolytic cell. Despite fluctuations, the average current was around 2 A; it was possible to produce 5.7 Ndm^3 H_2 of hydrogen despite partially cloudy conditions.

6 Conclusion

The Tajikistan project was a unique initiative of co-operation between universities in Poland and Tajikistan. The most important educational goal of the project was achieved. Tajik students shared knowledge about renewable energy sources with their younger colleagues and then taught other students and children from schools in Dushanbe and other cities. Undoubtedly the educational setups used in the projects played a very important role during classes and enabled students and pupils to acquire practical skills. This project unquestionably facilitated scientific co-operation between the AGH University of Science and Technology and the Tajik Technical University in new areas of science, not only those related to renewable energy. In today's world, the international exchange of knowledge and experience serves as a basis for development – above all, sustainable development.

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