Int. J. Electrochem. Sci., 13 **(2018)** 1822 – 1830, doi: 10.20964/2018.02.54

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Short Communication

A Hybrid Power Plant Based on Renewables and Electrochemical Energy Storage and Generation Systems for Decentralized Electricity Supply of the Northern Territories

A.S. Grigoriev[1], *V.V. Skorlygin*[1], *S.A. Grigoriev*[2,*], *D.A. Melnik*[1], *M.N. Filimonov*[1]

[1] National Research Centre "Kurchatov Institute", 1, Kurchatov sq., 123182 Moscow, Russian Federation
[2] National Research University "Moscow Power Engineering Institute", 14, Krasnokazarmennaya st., 111250 Moscow, Russian Federation
[*]E-mail: sergey.grigoriev@outlook.com

Received: 31 October 2017 / *Accepted:* 1 December 2017 / *Published:* 28 December 2017

The goal of this paper is to present hybrid power plant based on photovoltaic panels, wind turbine and electrochemical energy storage and generation systems for decentralized power supply of the customers located remotely in northern territories. It was shown that rechargeable electric batteries and low-temperature direct methanol fuel cells could be successfully used in extreme northern conditions instead of diesel generators. Methanol energy storage considerably surpasses accumulator batteries by its capacitance characteristics, being especially important during periods of prolonged absence of energy supply from sun and wind, *e.g.*, under the conditions of polar night and windless weather.

Keywords: hybrid energy system; decentralized power supply; electrochemical energy storage; direct methanol fuel cell; renewable energy sources

1. INTRODUCTION

Off-grid hybrid systems based on renewable energy sources (RESs) are currently of growing use for a number of applications. In particular, stand-alone power systems based on photovoltaic (PV) panels and wind turbines are used for power supply of maritime and river navigational lighthouses, aeronautical beacons, meteorological and hydrological stations, telecommunication equipment, and other remote facilities [1-12]. Due to an intermittent character of power supply from the RESs, reliable energy storage should be organized in order to cover the energy demand during dark time and windless weather. Within the framework of this article, the hybrid energy system based on PV panels, wind turbine and electrochemical systems (electric batteries and direct methanol fuel cells based on proton exchange membrane (PEM)) is reported.

It should be noted that pilot hybrid energy systems based on RESs, augmented with electrochemical energy storage and generation capability, are successfully implemented in a number of R&D projects [1-11]. In particular, a case study of the island located off the west coast of Scotland is covered in [6]. The merits of the adding electrochemical system were shown, however, the power plant includes the diesel generator and, hence, the system produces exhaust contaminating gases. The hybrid system reported in present paper does not include a diesel generator as an auxiliary power source used in [3-5, 12] and proves the environmental compatibility.

Another important feature of the power plant reported in this paper is its Arctic survival design that requires the use of a number of specific engineering and technological solutions as discussed below.

2. EXPERIMENTAL

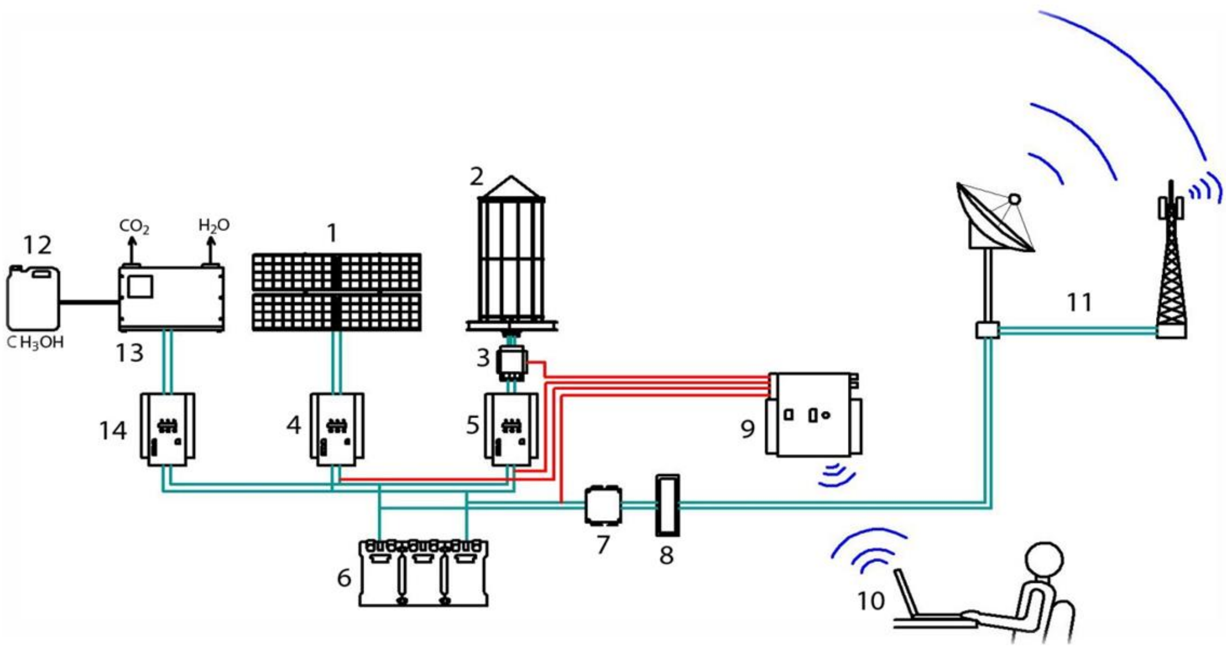


Figure 1. Block schematic diagram of a hybrid solar–wind–electrochemical power plant. 1. PV panels; 2. wind turbine; 3. rectifier; 4. controller of solar power; 5. controller of wind power; 6. rechargeable electric batteries; 7. DC/AC converter; 8. filter; 9. information and measuring system; 10. remote system operator; 11. consumer; 12. tank with methanol; 13. direct methanol PEM fuel cells system; 14. charge controller.

Creation of the hybrid power plant was carried out considering the following objective factors:

- rather low insolation level or even its total absence during polar night period;

- uneven distribution of power of a wind stream within a year and in some cases it rather low power potential;

- harsh Arctic environment, including cold temperatures.

Schematic diagram of the hybrid power plant based on RESs and electrochemical systems is shown on figure 1. Standard configuration of generating system with RESs of a power plant consists of:

- 16 solar PV panels of RZMP-130-T-M1 type (produced by Ryazan Metal Ceramics Instrumentation Plant, Russia) without tracking system with the maximum power output of 150 x16=2400 W;

- wind turbine of the vertical axis type (produced by OJSC “Istok”, Tver, Russia) with a rated electric power of 1100 W;

- electrochemical energy storage and generation system on the basis of electric batteries (92 pc with 1200 Amps*h overall capacity) and direct methanol PEM fuel cells (250 W rated electric power).

PV panels are mounted vertically and connected in series and in parallel for the integrated system (figure 2). The vertical position of PV panels is selected for their optimal productivity (the sun in polar latitudes is located low above the horizon), and to minimize the formation of snow cover on PV panels. Special “sea” modification of PV panels is used to allow their operation in the conditions of salty fog, panels have a protective back cover made of aluminum sheet for operation in severe weather conditions.

Vertical axis wind generator with a multi-blade rotor (figure 2) was selected for the optimum use of a wind flow. The benefits of the vertical axis design in comparison with wind generators with a horizontal axis of rotation are:

- low initial values of wind speed (starting from 3 m/s) to begin power generation;
- the capability to use wind from any azimuth without wind guidance system;
- no dangerous and destructive vibrations;
- safety for birds (the vertical axis wind generator is perceived by them as a single obstacle that they have to fly over);
- resistance to strong wind gusts (up to hurricane force wind) doesn't require windstorm protection.

Figure 2. Hybrid power plant on the test-site (left) and in the working area (right).

The electrochemical energy storage and generation system, and the control and management system (figure 3) are located in the container unit (yellow building in figure 2). Construction of a container unit provides access of a staff for inspection and service during the winter period taking into account the height of snow cover typical for this climatic zone. In order to avoid overheating of the equipment in summertime the container unit is supplied with automatic ventilating valves.

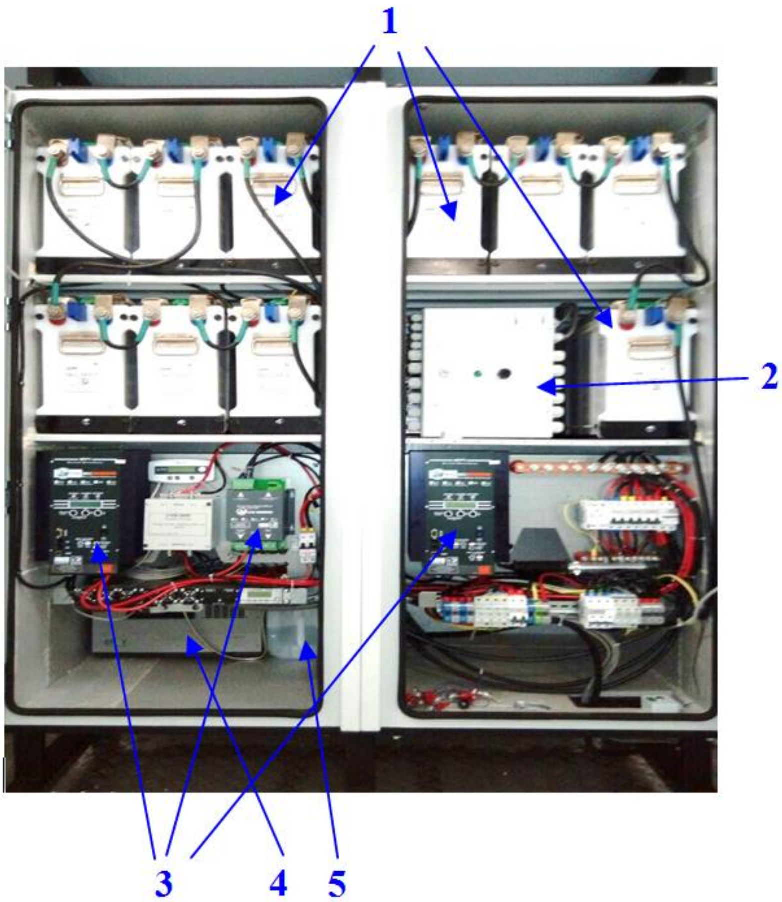


Figure 3. The electrochemical energy storage and generation system, and the control and management system. 1. rechargeable electric batteries; 2. information and measuring system; 3. controllers; 4. direct methanol PEM fuel cells system; 5. tank with methanol.

The electrochemical energy storage and generation system consists of 96 maintenance-free alkaline nickel-cadmium rechargeable accumulators of KGL300P type with a gas recombination (gas absorption) produced by JSC AIT Plant, Saratov, Russia. These accumulators do not require change and adjustment of level of an electrolyte during all service life, and are capable of performance restoration after deep discharges and long-term off-load cold conditions at a temperature of up to minus 50°C. Accumulators have buffer operation mode in the system. The life time of accumulators is 10 years. Overall capacity of accumulators is *ca.* 32 kW*h (1200 Amps*h x 27 V). Electrochemical energy storage and generation system also includes direct methanol PEM fuel cells system (figure 4) with rated power of 250 W. This system generates electric energy to charge accumulators.

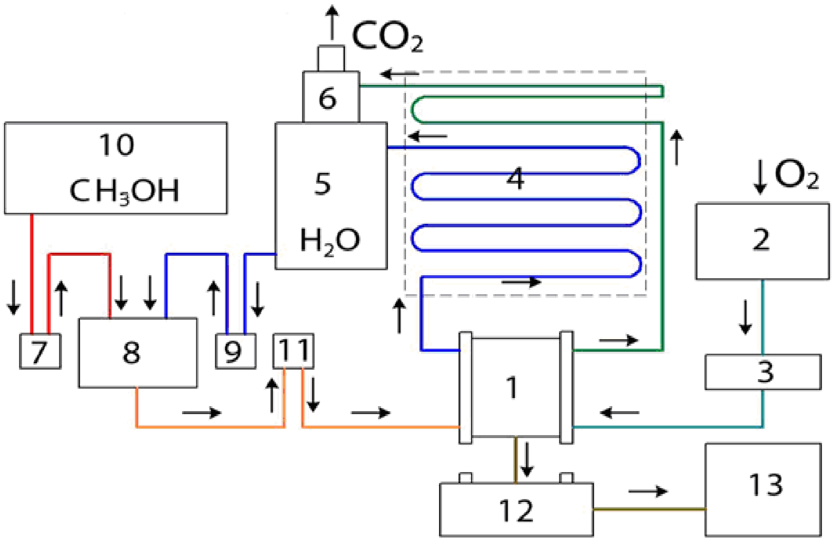


Figure 4. The schematic diagram of direct methanol fuel cells system. 1. direct methanol PEM fuel cells stack; 2. air pump; 3. air filter; 4. heat exchanger; 5. tank for water; 6. tank for an output of carbon dioxide; 7. pump for methanol; 8. tank for mixing of methanol and water; 9. pump for water; 10. tank with methanol; 11. pump for methanol-water mixture; 12. rechargeable battery; 13. consumer.

The control unit includes:

- ECO Energy MRRT.PRO solar and wind controllers of accumulator charge produced by LLC MicroART, Moscow;

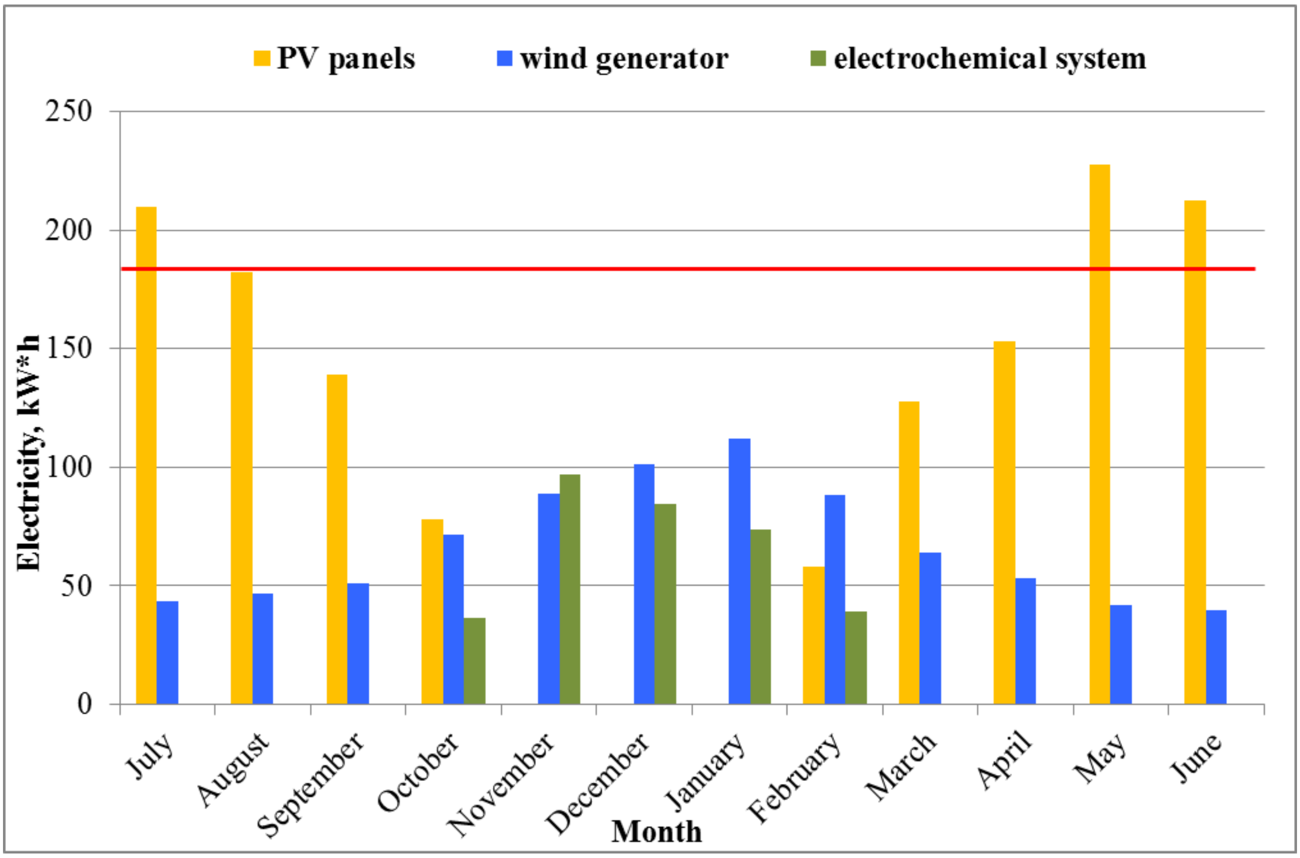
- software and hardware control and management system, including onboard computer produced by LLC Entels, Moscow.

3. RESULTS AND DISCUSSION

Developed power plant has been tested during one year on the facility located at Taimyr Peninsula. Time-base diagram of annual electricity output produced by the hybrid power plant is shown on figure 5. Power plant constantly supplies the customer located beyond Arctic Circle on the Taimyr Peninsula with 250 W of electric power (correspond to 180-186 kW*h per month, marked by red line on figure 5).

As it is possible to see from figure 5, within 5 months (October-February) the electric power input from RESs is insufficient for a supply of a customer with a power of 186 kW*h in a constant duty. Electric batteries and direct methanol fuel cells system were used to cover energy deficit during these months.

Figure 5 presents the timetable of electricity production different from one reported in [6]. In particular, according to [6], low level of power input from RESs took place mainly during 2 months (June, July). In our case, 2 autumn and 3 winter months require the operation of energy storage system. Feasibility study of hybrid system with hydrogen energy storage system for similar Arctic remote locations (Grimsey Island) has been provided in [12].



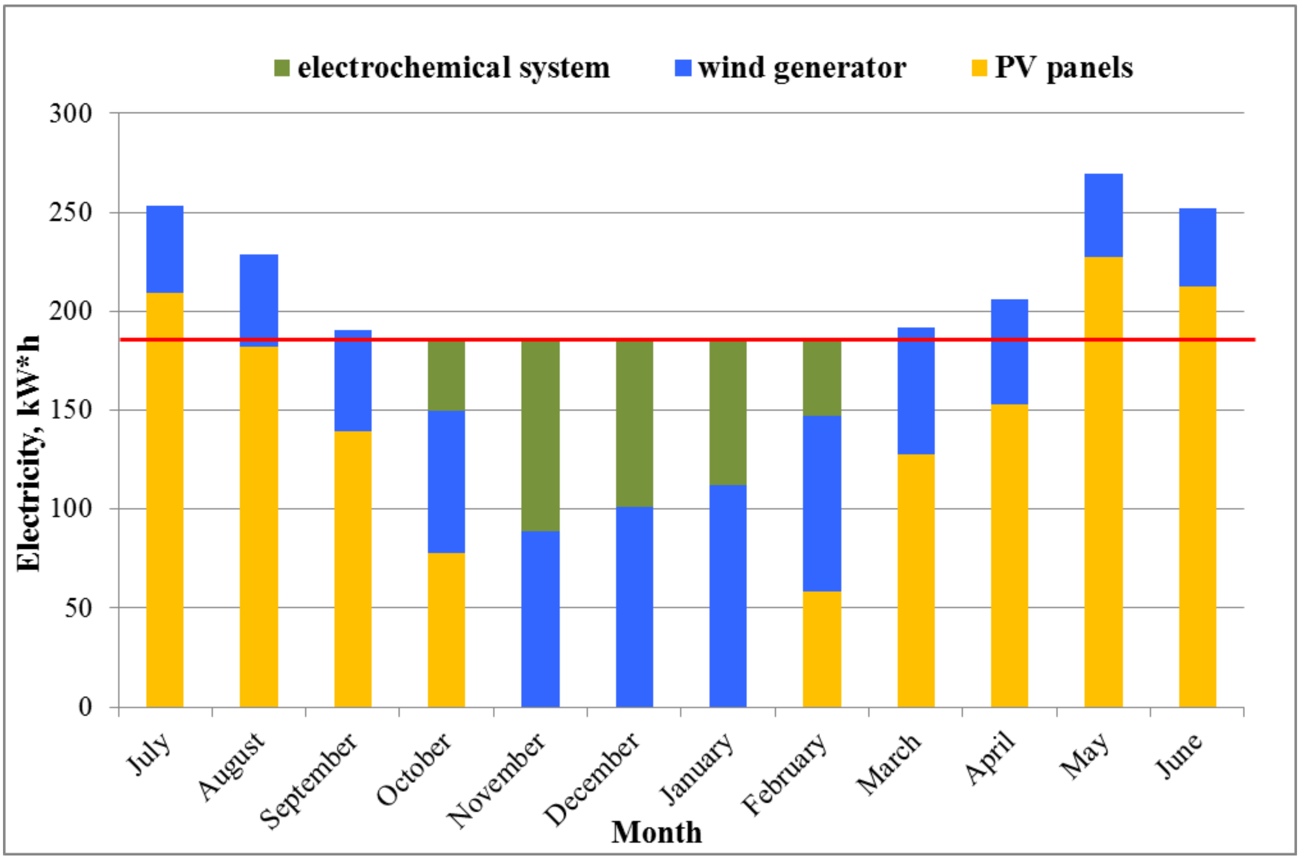


Figure 5. Time-base diagram of annual electricity output produced by the hybrid power plant located on the Taimyr Peninsula.

In our study, unlike consideration of scenarios, the concept of the power station on the basis of RESs with electrochemical accumulation of energy has been implemented in practice, and has successfully proved the working capacity.

Hybrid off-grid systems considered in [2] and [12] are intended for inhabited areas, and, hence, suppose periodic maintenance. In our case, power system is located away from populated areas, and designed for once-a-year fueling and maintenance. Our system is equipped with remote access allowing to anticipate any anomalous operation situations.

It was shown that the storage of energy in form of methanol considerably surpasses accumulator batteries by its capacitance characteristics, being especially important in the prolonged absence of energy supply from RESs, *e.g.*, under the conditions of polar night and windless weather. In particular, the power generation during the most critical period (November, December and January) has been provided mainly by wind turbine and direct methanol fuel cells (the charge of electric batteries is 32 kW*h that is less than 10% of monthly electricity demand). A fuel-to-electricity efficiency of fuel cells system is 22.3% (electric power output/LHV). Co-generated thermal power has been used for heating of the container unit during cold months [13]. During the year, the power plant used methanol fuel cells system within 45 days that corresponds to methanol consumption of 251 liters. It was decided not to use water electrolyzers for hydrogen production [14] and it subsequent use in fuel cell as used in [3, 13, 15]. From our opinion, it will demand frequent presence of the service personnel that will complicate the organization of operation for autonomous unattended system, in particular, during the winter period, as poor weather in off-road areas could make location site unreachable.

Significant advantage of applied fuel cell system is zero self-discharge. It is noteworthy that the specific cost of the fuel cell system decreases with increasing of energy storage capacity, since the accumulation of additional energy requires only additional volume for the tank with methanol. The advantage of fuel cells based power system over conventional electric accumulators by their mass-dimensional characteristics becomes especially essential for the creation of remote systems in hard-to-access regions to which equipment is delivered, *e.g.*, by helicopters or winter road. It is important to note that developed direct methanol fuel cell system allows omitting the use of diesel generators as supplementary energy sources [3-5, 12].

Use of essentially different primary power sources (sun, wind and methanol) considerably increases reliability of providing consumers with the electric power. Undoubted advantage of fuel cells as a part of power plants over the internal combustion engines is their significantly longer operation life, simplicity in operation and maintenance, and also lack of the noise and polluting emissions. Performance of the power plant could be adjustment according to customer's requirements and climatic conditions.

4. CONCLUSIONS

A hybrid power plant that utilize photovoltaic panels, wind turbine and electrochemical energy storage and generation systems for decentralized electricity supply of the remote customers located at northern territories has been developed and tested. It was shown that rechargeable electric batteries and direct methanol PEM fuel cells can be successfully implemented in extreme north conditions, and replace diesel generators. In particular, it has been confirmed that the application of electrochemical storage and generation system (electric batteries and fuel cells) with a corresponding methanol storage tank allows to store required amount of energy and to smooth the daily, monthly, and seasonal irregularity of energy supply from RESs. Some efficient technical solutions on the use of electrochemical systems in power engineering for energy generation and storage were proposed.

One of obvious advantages of use of fuel cells as a part of solar and wind power plants are opportunities for guaranteed cover of the lack of electric power at a long absence of sunlight and wind. An important advantage is that energy storage system in the form of methanol is easily scalable to increase the energy storage capacity by simple adding of new volumes of methanol storage tanks.

The developed power plant substantially decreases the role of negative factors that hinder the scaling of the off-grid power plants utilizing RESs. The power range of such power stations can meet the needs for electric power supply of small remote systems (such as, autonomous meteorological and hydrological stations, navigation systems, stations of a cellular and radio communication, sea and river beacons, transportation facilities, *etc*), and a number of more power-demanding customers. Developed power plant can be used in Polar Regions of the countries like Russia, Norway, Sweden, Finland, Denmark, Iceland, USA and Canada. Use of the developed power stations in northern latitudes will allow to create environmentally safe and effective network of the decentralized power supply facilities with continuous and stable power supply without use of traditional hydrocarbon fuels and radionuclides.

ACKNOWLEDGEMENT
Financial support from the Ministry of Education and Science of the Russian Federation within the framework of agreement on granting No 14.604.21.0164 from 26.09.2017 (unique project identifier RFMEFI60417X0164) is acknowledged.

References

1. P. Hou, P. Enevoldsen, J. Eichman, W. Hu, M.Z. Jacobson, Z. Chen, *J. Power Sources*, 359 (2017) 186.
2. P. García, J.P. Torreglosa, L.M. Fernández, F. Jurado, *J. Power Sources*, 265 (2014) 149.
3. C. Ziogou, D. Ipsakis, C. Elmasides, F. Stergiopoulos, S. Papadopoulou, P. Seferlis, S. Voutetakis, *J. Power Sources*, 196 (2011) 9488.
4. E.L.V. Eriksson, E.MacA. Gray, *Applied Energy*, 202 (2017) 348.
5. Y. Luo, Y. Shi, Y. Zheng, N. Cai, *J. Power Sources*, 340 (2017) 60.
6. N. Kennedy, C. Miao, Q. Wu, Y. Wang, J. JI, T. Roskilly, *Energy Procedia*, 105 (2017) 1388.
7. S. Tamalouzt, N. Benyahia, T. Rekioua, D. Rekioua, R. Abdessemed, *Int J Hydrogen Energ*, 41 (2016) 21006.
8. R. Loisel, L. Baranger, N. Chemouri, S. Spinu, S. Pardo, *Int J Hydrogen Energ*, 40 (2015) 6727.
9. B. Panahandeh, J. Bard, A. Outzourhit, D. Zejli, *Int J Hydrogen Energ*, 36 (2011) 4185.
10. G. Tzamalis, E.I. Zoulias, E. Stamatakis, O.-S. Parissis, E. Lois, *Int J Hydrogen Energ*, 38 (2013) 11646.

11. M. Yaqoot, P. Diwan, T.C. Kandpal, *Renewable and Sustainable Energy Reviews*, 58 (2016) 477.
12. D. Chade, T. Miklis, D. Dvorak, *Renewable Energy*, 76 (2015) 204.
13. S.A. Grigor'ev, A.S. Grigor'ev, N.V. Kuleshov, V.N. Fateev, and V.N. Kuleshov, *Thermal Engineering*, 62 (2015) 81.
14. S.A. Grigoriev, K.A. Dzhus, D.G. Bessarabov, P. Millet, *Int J Hydrogen Energ*, 39 (2014) 20440.
15. G. Doucet, C. Etiévant, C. Puyenchet, S. Grigoriev, P. Millet, *Int J Hydrogen Energ*, 34 (2009) 4983.