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Application PEM fuel cells in virtual power plant

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In this article the laboratory stand for testing the cooperation of three energy sources has been presented. The aspects of the use of PEM cells in virtual power plant have been studied. The measurement results of parallel cooperation of the fuel cell with wind turbine and photovoltaic cell have been presented.

KEYWORDS: fuel cell, virtual power plant, distributed generation

1. Introduction

An important feature of the power system is the lack of storage capacity of electricity on an industrial scale. All the produced energy is immediately used. Power stations need to be prepared to cover the momentary load changes arising from a customer's life, his habits and work organisation. Electrical power system must be able to change the quantity and directions of transmitted energy. This is possible due to many connections that are provided by a network of power lines. The more complex the network is, the greater the chance of a reliable supply of energy to each recipient.

Different types of power plants carry out their production tasks covering the part of the current demand. There are basic power plants (modern thermal steam, nuclear, run-of-river and mid-merit power stations), peak power plants (older types thermal steam power plants and hydro storage power plants), peak power plants (pumped storage hydro power plants and power stations with gas turbines).

An increasing role in the electricity system plays distributed generation, especially wind and solar power plants. However, their disadvantage is the fact that they work only in favorable weather conditions. Therefore, they are not fully available and require launching and effective control of backup sources in real time, in the peaks of the demand and the ability to control power consumption in the valleys of electricity demand. A significant problem is also forecasting the production of electricity from distributed generation. Conducted analysis about the impact of distributed sources work on electrification system indicates that the occurrence of the diffuse sources in the system may adversely effect its work, in which case the impact largely depends on the saturation of the system by distributed sources. Due to this fact, consequently there are conducted parallel research on minimizing the adverse effects of diffuse sources on electrification system. In this context, a problem occures of how to use electricity storage which in the near future should effectively eliminate disadvantages of distributed generation in the electricity system. In connection with the integration of a number of small power sources, energy operators have more and more difficulty to balance power and in consequence variations in frequency. An effective technique for balancing multiple small sources gathered in a small area is to use the ability to combine them into one system. This allows you to treat them as a single large source. Groups of such condensed sources of distributed generation can be called a virtual power plant. A virtual power plant, therefore, combines on a particular area a variety of local sources of electricity (hydropower, wind power, photovoltaic, small gas turbines-steam-powered, generators driven by engines etc.) and energy storage (reservoirs, batteries) which are controlled remotely using a complex computer system. Virtual power station in order to fulfil its role in the electricity system, should fulfil the tasks associated with power and voltage control. As well as the system power plants, it should participate in the planning of energy demand. An important role in the creation of virtual power plants should play energy storage tanks, allowing electricity generation to adapt to daily changes of customers' demands. The unit capacity of generating equipment in virtual power plants using distributed sources of primary energy are not comparable with the powers of the large system power plants.

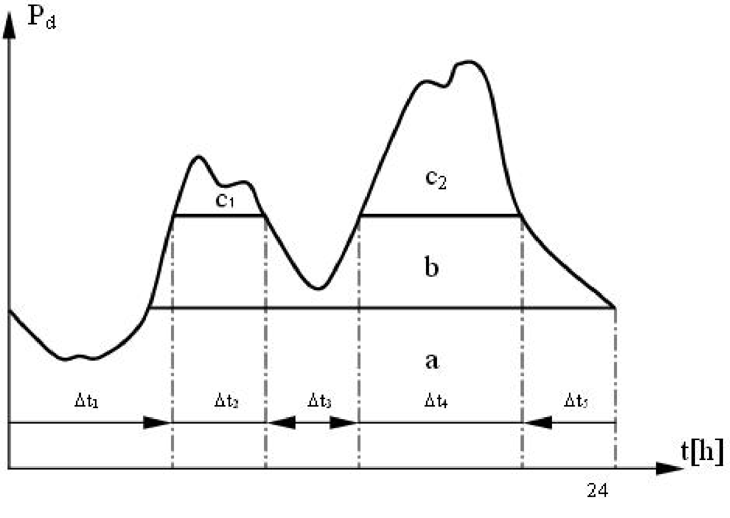

Fig. 1. The coverage of the daily load by power plants a –basic, b- mid-merit, c1+c2 - peak

In addition, the type of primary energy source of these devices, whose availability is determined mostly by weather conditions, puts these powerplants in the group of sources which must be reserved. They work only then when there are suitable conditions [2].

In case of increasing number of energy sources connected to the system of renewable sources of energy, such as wind and solar power plants, energy storage technologies will need to be introduced, based on conversion of electricity into another form, for example, chemical energy. You can use for this purpose e.g. a system consisting of the electrolyzer and a fuel cell.

Fuel cells are considered to be one of the most promising and forward-looking technologies to generate electricity and heat. They can be operated in a wide range of variation of electrical loads, maintaining their high efficiency of processing primary energy into useful.

The advantages of fuel cells include: high efficiency, very low greenhouse gas emission, low noise, modular construction, the ability to work with low loads, the ability to work reverse, very good possibilities of adjustment. The main disadvantage is the high cost of individual fuel cells whose electrodes must be covered with platinum so they can act as the production of electricity

2. PEM fuel cells - operation optimization and load change response

For the application of PEM fuel cells a virtual power plant of several fuel cells (and other types of power plants) is favorable for the operation due to two main reasons. PEM fuel cells are capable of bearing quick load shifts. However, a change in the supply of the reactant gases is slow. Load shifts may result in short timespans with over- or undersupply of the reactants and therefore reducing the lifetime of a fuel cell [3].

Generally, a fuel cell with modest load changes and constant operation parameters will have a higher lifetime, so one reason for virtual power plants is the possibility of splitting the load over several fuel cells so that each fuel cell can run at optimal operation parameters. The second reason is the distribution of the fuel cell plants will help to generate the energy locally where it is needed, which will reduce transfer losses. Moreover, the generated heat of the fuel cell systems can be used for district heating.

A virtual power plant has various other advantages [4, 5], nonetheless it requires a smart grid for communication between the subsystems and possibly a central power plant control (Fig. 2). The communication is important to synchronize the decentralized subsystems not only to deal with load change response, but also to transfer status and security information. The market price can also have an influence on the production of a virtual power plant. Additionally it is possible to include the information of weather forecasts or other grid operators to predict the generation of wind and solar so load changes can be prepared in advance. As fuel cells need time to start up this advantage is crucial for the operation management.

For the start process, fuel cell systems based on reformat gas require up to two hours to heat up the reformer. Systems based on pure hydrogen only require a view minutes to start up, but should not run on full load until the system temperature is stabilized at the nominal operation temperature (50-70°C for PEM fuel cells). The heat production of the stacks is enough to heat up the system and excess heat needs to be dissipated to keep the stack temperature stable.

Besides the reactant and thermal operation of a fuel cell system, the electrical operation is rather simple. A fuel cell behaves like a direct current source while the voltage is dependent on the load current and the quality of the fuel cell including aging. The cell voltage will depend on the operation conditions as well as temperature, humidity and pressure of the reactants has a direct influence on the cell voltage. The load current can be changed until the power output is at the required level. However, the virtual power plant approach allows dealing with small power differences of the decentralized systems without this requirement. Therefore, a single system can run at optimal load and stable current.

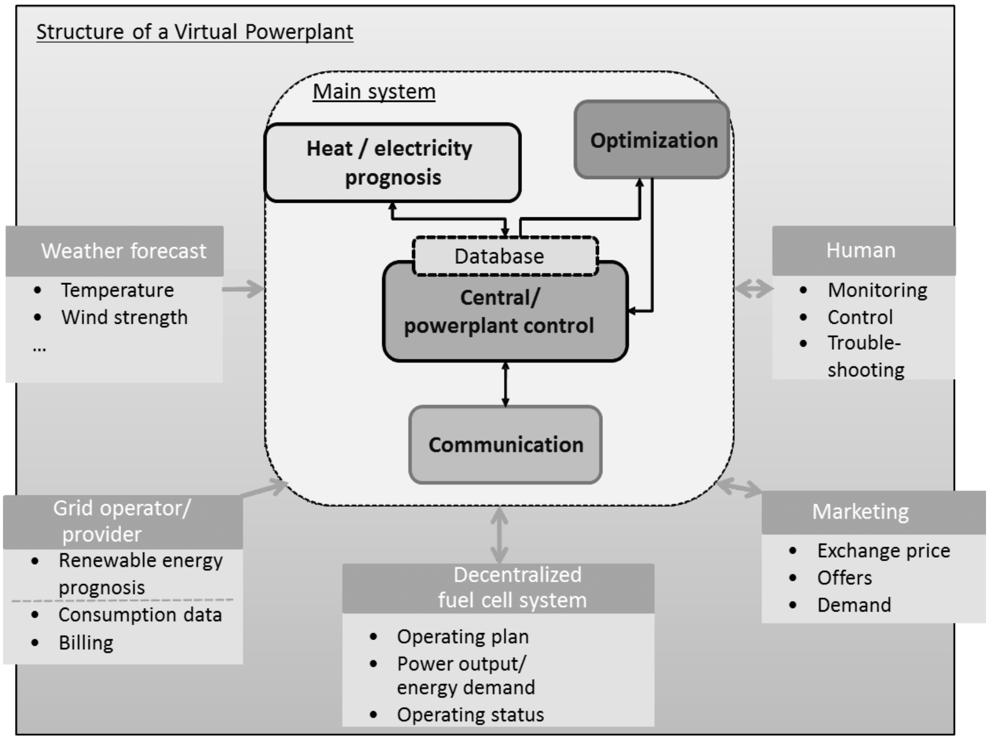

Fig. 2. Structure of a virtual power plant showing connections to external systems

3. Cooperation of PEM fuel cells with wind turbine and photovoltaic cells

The energy produced in the renewable sources should be used in the most efficient way, so only surplus of energy generated from wind and solar radiation should be stored, through the production of hydrogen in the process of electrolysis. The produced hydrogen is intended to power a fuel cell that generates electricity at the time when the customer needs it. Direct use of energy at the time when there are favorable weather conditions and there is a demand of the recipient, allows to minimize the losses related to the change of energy from one form to another [1]. The authors studied the impact of solar and wind conditions on the work of an electrolyzer. The research used a physical model in micro-scale consisting of three electricity-generating sources i.e. fuel cells, photovoltaic cells and wind power plant. Figure 3.1 shows a block diagram of the system which includes, wind turbine, photovoltaic cell, fuel cell and electrolyzer. There are two possibilities for energy flow. First option is feeding elecrolyzer with wind turbine and solar cells. Second option is parallel cooperation of fuel cell with both renewable energy sources. The first purpose of the test is to obtain information about the time of produce of specifc value of hydrogen by feeding electrolyzer with renewable energy sources. The second purpose of the test is to get information is fuell cell can work in parallel with chimeric energy sources as wind turbine or photovoltaic cell and cover momentary deficits of produced power.

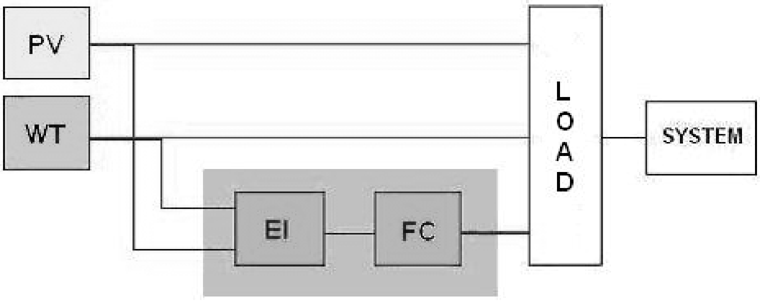

Fig. 3.1. A block diagram of the test system: El - elektrolyzer OP- fuel cells, PV – photovoltaic cell, EW – wind turbine

3.1. Wind turbine and photofoltaic cell feeds the electrolyzer

In Figure 3.2 a block diagram of the test system has been presented. The measurements were made at three operating points of the system. Operating points means points of intersection of the external characteristics of energy sources with the external characteristic of the electrolyzer. Electrolyzer was powered by wind power plant, for different values of wind speed running a turbine, forced by a fan with three states of work and solar for three different values of the intensity of the solar radiation. Figure 3.3 shows the external characteristics of the system components. Figure 3.4 presents the time of hydrogen production by electrolyzer powered by wind power plant, solar power plant and both of them at the same time.

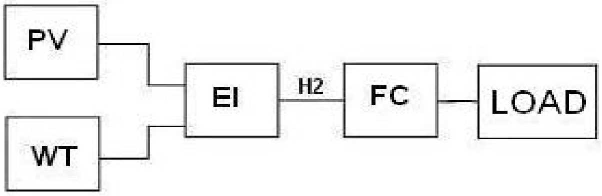

Fig. 3.2. Measuring system - block diagram: El - elektrolyzer OP- fuel cells, PV – photovoltaic cell, EW – wind turbine

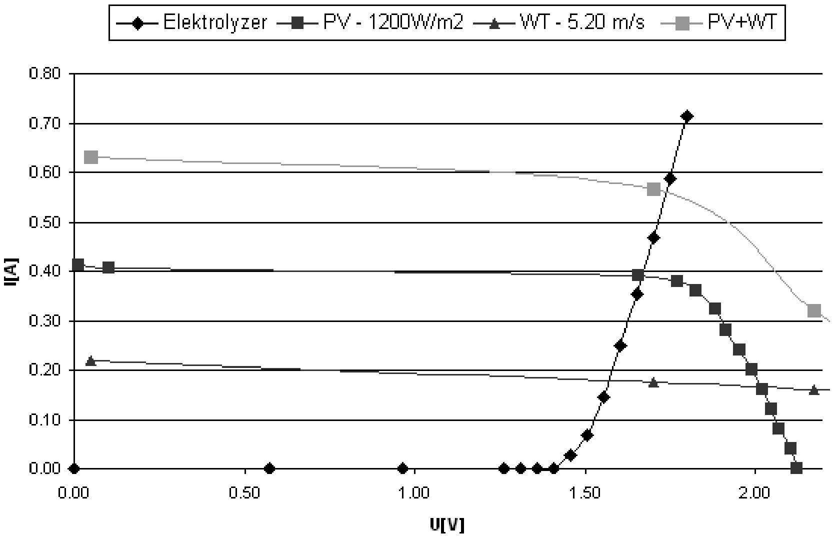

Fig. 3.3. External characteristics of the electrolyzer the wind turbine and photovoltaic cell

Figure 3.4 shows the results of measurements. According to the principle of conservation of energy, providing more of it in a shorter period of time to the electrolyzer allows for faster production of a given quantity of hydrogen, that is, the greater the strength of the wind and a higher value of the solar radiation intensity will be, the greater amount of energy will be stored for the period of the night.

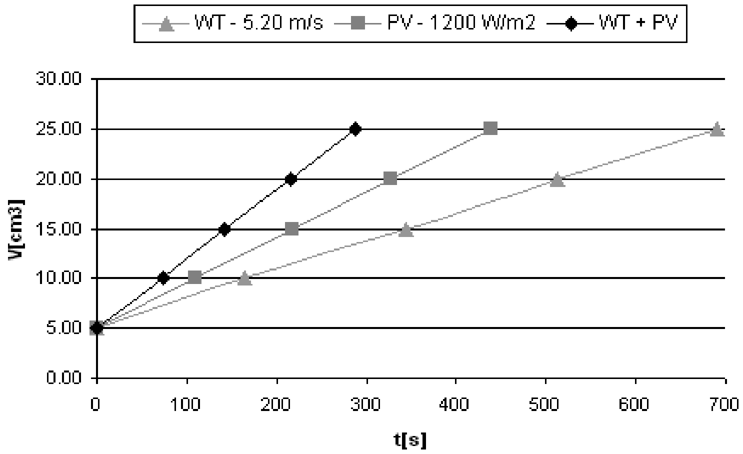

Fig. 3.4. The results of measurements

3.2. Fuel cell parallel cooperation with wind turbine and solar cell

In Figure 3.5 a block diagram of the test system has been presented.

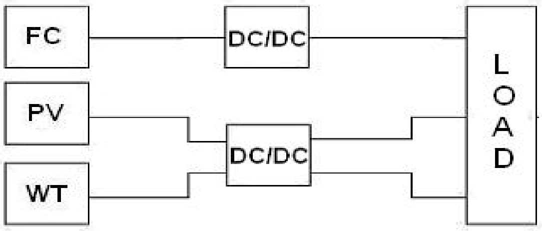

Fig. 3.5 Measuring system - block diagram

Voltage and current signals were registered using a multimeter. The DC/DC convertes were given a constant value of voltage which was 2.5 volts. Shunt resistors were used for the measurement of current signals. During the recording voltage and current signals, intensity of solar radiation and wind speed was changed. In Figure 3.6 the recorded signals have been presented.

Dark gray signal represents the current flowing from the fuel cell and light gray signal represents current flowing from wind turbina and photovoltaic cell. The sum of the currents is represented by the black signal. The initial operating point was established at the 0.2 ampere from renewable energy sources and 0.3 ampere from the fuel cell. After 10 seconds renewable energy sources were disabled and the current from the fuel cell with a value of 0.37 ampere has been generated. After the next 5 seconds, renewable sources restarted - the current value from the fuel cell went back to the earlier value, the system was stabilized and the current value of the load was again 0.5 ampere. After next 15 seconds the main light source was turned off. The value of current from photovoltaic cell has decreased to the minimum. The fuel cell changed the operating point and generated bigger current. Thanks to this the current value of the load was constant. After a while, the main light source has been switched on and off, then it was switched on and off again and then switched on. Thanks to the fuel cell the value of current of the load was 0.5 ampere. Wind turbine and photovoltaic cell were disabled at the end of the test. The fuel cell generated a maximum current and recording of the measured signals were completed.

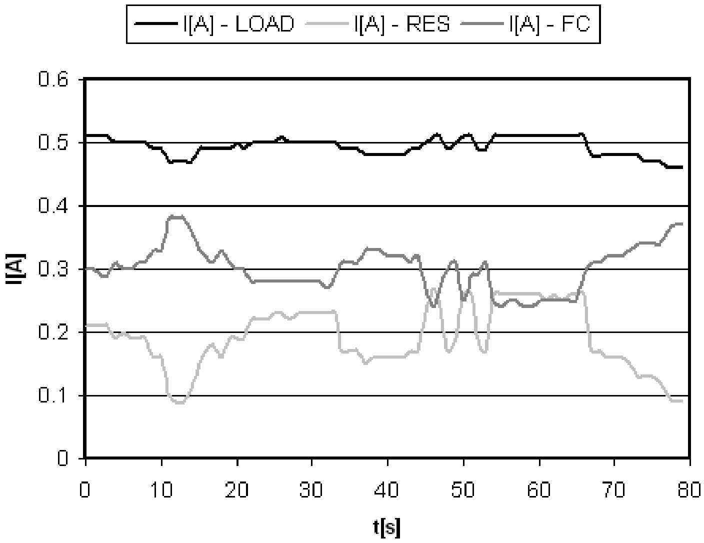

Fig. 3.6 The results of measurements - the current signals

The fuel cell can work in parallel with renewable energy sources and cover momentary deficits of produced power.

4. Conclusions

The tests performed let us draw the following conclusions:

- virtual power plants allow the combined operation of several fuel cell systems and other sources and will manage the load change response,
- providing more power to the electrolyzer will reduce the time production of a specific volume of hydrogen,
- the fuel cell can work in parallel with renewable energy sources and cover momentary deficits of produced power.

References

[1] R. Szczerbowski, B. Ceran, „Możliwości rozwoju i problemy techniczne małej generacji rozproszonej opartej na odnawialnych źródłach energii" Polityka Energetyczna, Tom 16, Zeszyt 3, 2013.

[2] R. Szczerbowski, Generacja rozproszona oraz sieci Smart Grid - wirtualne elektrownie. Polityka Energetyczna tom 14, z. 2. Wyd. Instytutu GSMiE PAN, Kraków, 2011, s. 391 - 404.

[3] Bernstein P. A., Heuer M., Wenske M., "Fuel Cell System as a Part of the Smart Grid" in Proc. Of POWERTECH 2013, Grenoble, France, 16-20 June 2013.

[4] Lombardi P., Stötzer M., Styczynski Z., Orths A., "Multi-criteria optimization of an energy storage system within a virtual power plant architecutre" in Proc. of IEEE PES General Meeting, 24-28 July 2011.

[5] Ruiz N., Cobelo I., Oyarzabal J., "A direct load control model for virtual power plant management" in IEEE Transactions on Power Systems, Volume 24, Issue 2, 2009, Pages 959-966.