A hydrogen technology as buffer for stabilization of wind power generation

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Abstract
Quality of supply and reliability requirements should be guaranteed when using wind power. Energy storage systems are being considered for continuous electricity generation with the lack of adequate winds. The surplus wind generated electricity can be used for hydrogen generation and storage - a hydrogen buffer. This hydrogen could be used in fuel cells to compensate wind generator output during lack of energy. Also, pure water and heat generated in fuel cells can be used in the processes.

Keywords
Wind power, water electrolysis, hydrogen, fuel cell, hydrogen buffer

Introduction
Sustainability and efficient use of energy resources is an urgent issue of today. The reasons are not only in the growth of demand and production, but also in the present level of resource exploitation leading to exhaustion of energy resources and related environmental impacts. A sustainable use of energy requires applications and methods that could increase efficiency. This is especially important in converter applications.

An extensive penetration of renewable sources is a global growing trend. Wind power appears to be one of the most perspective and widespread among alternative energy sources [1, 2]. European growth figures are displayed in Table 1 [3].

Table 1. Wind power use in European countries

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<tr>
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<tbody>
<tr>
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<td>Italy</td>
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<td>2123</td>
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<tr>
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<tr>
<td>Sweden</td>
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<td>Estonia</td>
<td>33</td>
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<td>59</td>
<td>78</td>
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</table>

Use of renewable energy and storage proposes prospects of significant decrease in fossil fuel extraction and accompanying environmental pollution threats [2].

Estonia has a long coastal line and islands, which is a larger part in the Baltic region where the total annual energy production can reach 37 million kWh. New local wind power stations are being developed in compliance with the requirements of the EU and the latest converter technologies.

Unforecastable winds make it difficult to plan production (Fig. 1), complicating parallel operation with other power plants intended for compensating the instability of wind production. Due to unforecastable wind and difficulty in forecasting periods of excess energy as well as lack of energy occur.

Fig. 1. An example of unforecast energy production by Estonian wind farms

Traditional storage methods of excessive energy described in [4] allow to store the energy. First of all, the flywheels and supercapacitors have higher power, whereas electrochemical batteries impose high energy performances but raise some environmental issues and have disadvantages regarding peak power. For this reason, a new idea has emerged to conserve the wind power surpluses in the form of chemical energy such as hydrogen or metals.

The universality of hydrogen implies that it can replace other fuels for stationary generating units for power generation in various industries. Having all the advantages of fossil fuels, hydrogen is free of harmful emissions when used with dosed amount of oxygen thus, reducing the greenhouse effect [1].

Excess of electrical and thermal energy in its various forms, in combination with unlimited supplies of pure water and air, using a variety of technological processes (thermochemical, electrochemical) could lead to application of hydrogen technology.
1 Renewable energy system with a hydrogen buffer

The typical configuration of a wind farm connected to the transmission grid is formed by a set of wind generators electrically connected through a medium voltage network, sharing one single infrastructure for access and control. The topology of the wind turbine WinWind WWD3 is shown in Fig. 2 [5, 6].

Fig. 2 The topology of wind the turbine WinWind WWD3

Converters of wind turbines ensure grid friendly and controllable power. The connection to the electric power transmission grid is ensured via corresponding transformers sized according to the rated power of the plant. A block diagram of the hydrogen buffer system for the stabilization of wind power generation site is presented in Fig. 3 [4].

Fig. 3 Block diagram of the hydrogen buffer
1 – synchronous generator, 2 – primary converter,
3 – secondary converter,
4 – transformer for grid connection,
5 – power supply of electrolyzer,
6 – fuel-cell system with a converter

So hydrogen buffer system consists of the following main components:
1. conversion of excess energy
2. storage
3. conversion of fuel into electrical and heat energy

1.1 Conversion of excess energy

The hydrogen generation system is connected to the internal grid. In order to store electrical energy, the system produces hydrogen from water electrolysis [7] using electricity from the wind generator. Since the electrolyzer needs a DC current, the first stage in the hydrogen generator is a power electronics converter to supply it. Water is supplied at constant pressure to ensure the necessary input flow.

Current technology [8]:
1. state-of-the-art alkaline electrolyzer, efficiency: 60-70%
2. operating temperature: up to 80°C
3. operating pressure: 1 atm - 25 atm
4. cost: ~$1000/kW - $2500/kW

Future Technology: increase capacity, efficiency and reduce cost:
1. system efficiency should reach 70-80% by advanced electrolyzer technology
2. cost of industrial size electrolyzer (MW level) should be reduced to $300/kW - $500/kW (COH at $2/kg)
3. integration with renewables (wind, PV, geothermal, etc.)

1.2 Current technology of hydrogen storage

Current technologies of hydrogen storage are [8]:
- compression processes:
  - high energy consumption: losses 15-30%
  - high capital cost for large quantity storage: $1000 - 2000/kW
  - pressure: to 200-350 bar
- Liquefaction processes are:
  - high energy consumption: losses 40-50%
  - high capital cost: $1500 - 2500/kW
- compressed Storage
- liquid Storage
- Advanced storage technologies are:
  - low pressure: “solid state” - metal hydrides, chemical hydrides
  - large capacity: underground tankage
  - low cost: storage material systems design, compression and liquefaction processes.

1.3 Conversion into electrical energy

In recent years fuel cell generation systems have seen increased attention due to their high efficiency, low aggression to the environment, no moving parts and superior reliability and durability.

When a power generation system requires a universal energy resource, hydrogen should be converted into electrical energy using a fuel cell system and a power electronic converter connected to the grid. The fuel cell takes the hydrogen from the tanks and oxygen from air to generate electricity, plus water and heat as by-products. The electrical energy is produced in the DC form. Thus, a power converter is required to change the DC voltage level required by the grid.
The system includes an electronic control block with all the necessary circuits to take the decision for the activation of one of the two main systems: using an electrolyzer, taking into account fuel demand requirements.

2 Operating principles of a fuel cell

Operation of the hydrogen fuel cells known since the 1800s is simple. It is based on the reaction between hydrogen and oxygen to produce water and heat, as shown in Fig. 4. Since this reaction should be controlled, it is necessary to use an electrolyte that ionizes hydrogen creating ions $\text{H}^+$ and electrons. The oxygen reacts with the electrons taken from the electrode and the ions $\text{H}^+$ to form water $[9, 10]$.

The proton exchange membrane fuel cell (PEMFC) consists of porous carbon electrodes bound to a thin sulphonated polymer membrane. The anode, cathode, and net cell reactions of the PEMFC can be expressed as $[9]$:

\[
\begin{align*}
\text{H}_2 & \rightarrow 2\text{H}^+ + 2e^- \quad - \text{anode reaction} \quad (1) \\
\frac{1}{2} \text{O}_2 + 2\text{H}^+ + 2e^- & \rightarrow \text{H}_2\text{O} \quad - \text{cathode reaction} \quad (2) \\
\text{H}_2 + \frac{1}{2} \text{O}_2 & \rightarrow \text{H}_2\text{O} \quad - \text{net cell reaction} \quad (3)
\end{align*}
\]

where the mobile ion is $\text{H}^+$.

Fig. 4. Operating principles of a fuel cell

Common characteristics of a FC $[11]$ are shown in Table 2.

In general, the main characteristics of a fuel cell that a system designer has to overcome are:

1. Low output voltage, theoretically, the maximal value of a single cell voltage of a fuel cell is 1.23 V that it is never reached even at no load. Therefore, a fuel cell is always an assembly of elementary cells that constitute a stack (Fig.5).

2. Large voltage variation. Fuel cell power or current must be kept within an interval (rated value, minimum value or zero). At the rated current, the voltage of an elementary cell is about 0.6-0.7 V $[12]$.

3. Slow dynamic response. Fuel cells also have a long start-up time due to the delay caused by electrochemical reactions.

4. Low efficiency with high ripple current. Fuel cell ripple current must be kept lower than around 5% of the rated value to ensure minor impact on the fuel cell conditions.

A fuel cell as a source of energy has advantages and disadvantages $[13]$, as shown in Table 3.

Due to the electrochemical reaction, a fuel cell has low voltage and high current. However, the fuel cell stack with high output voltage is difficult to fabricate and it may fail when any single cell is inactive. In addition, the output voltage is easily varied with respect to the load variations. Unlike batteries fuel cells can have a fairly constant output voltage with respective control, the fuel cell has a unique V-I characteristic and a wide voltage change range as shown in Fig. 5 $[14]$.

Fig. 5. Typical fuel cell polarization curve

Fuel cells can be used in mobile and stationary applications. In addition, low operation temperature is desirable for vehicle applications and rapid operation capability, whereas cogeneration capabilities are desirable for the stationary applications for improved overall efficiency ($< 60\%$). Using the heat produced by a fuel cell, the efficiency exceeds 85%.

Over the past ten years, numerous studies of fuel cells in high power applications have been conducted. Today the required fuel cell power is in the range of 1 kW to 2 MW $[15]$:

1. 1 - 2 kW for unmanned aircraft and 40-700 kW for manned aircraft
2. 50 - 100 kW for urban cars
3. 100 - 200 kW for buses and light trams
4. 600 kW - 1 MW for tram substations and locomotives (e.g. four motors of 160 kW peak are installed on a tram. The total power installed is 800 kW)
5. 480 kW - 2 MW for distributed generation systems for parallel connection to the electrical grid.

Due to high power of the wind generator explained in $[2]$ it is reasonable to implement phosphoric acid fuel cells (PAFC). High power with the highest possible conversion to electrical energy in PAFC, which uses a molten phosphoric acid ($\text{H}_3\text{PO}_4$) as the electrolyte, is shown in Table 2.
Table 2. Common characteristics of fuel cell

<table>
<thead>
<tr>
<th>Type of Fuel Cell</th>
<th>Electrolyte</th>
<th>Qualified Power (W)</th>
<th>Working Temperature (°C)</th>
<th>Electrical efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton exchange membrane fuel cell</td>
<td>Polymer membrane (ionomer) (e.g., Nafion or Polybenzimidazole fiber)</td>
<td>100 W to 500 kW</td>
<td>(Nafion)50–120 (PBI)125–220</td>
<td>Cell: 50–70% System: 30–50%</td>
</tr>
<tr>
<td>Alkaline fuel cell</td>
<td>Aqueous alkaline solution (e.g., potassium hydroxide)</td>
<td>10 kW to 100 kW</td>
<td>under 80</td>
<td>Cell: 60–70% System: 62%</td>
</tr>
<tr>
<td>Molten carbonate fuel cell</td>
<td>Molten alkaline carbonate (e.g., sodium bicarbonate NaHCO₃)</td>
<td>100 MW</td>
<td>600-650</td>
<td>Cell: 55% System: 47%</td>
</tr>
<tr>
<td>Phosphoric acid fuel cell</td>
<td>Molten phosphoric acid (H₃PO₄)</td>
<td>up to 10 MW</td>
<td>150-200</td>
<td>Cell: 55% System: 40% Co-Gen: 90%</td>
</tr>
<tr>
<td>RFC - Redox</td>
<td>Liquid electrolytes with redox shuttle &amp; polymer membrane (Ionomer)</td>
<td>1 kW to 10 MW</td>
<td></td>
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</tr>
<tr>
<td>Tubular solid oxide fuel cell (TSOFC)</td>
<td>O²⁻-conducting ceramic oxide (e.g., zirconium dioxide, ZrO₂)</td>
<td>up to 100 MW</td>
<td>850-1100</td>
<td>Cell: 60–65% System: 55–60%</td>
</tr>
<tr>
<td>Planar Solid oxide fuel cell</td>
<td>O²⁻-conducting ceramic oxide (e.g., zirconium dioxide, ZrO₂, La₂XO₄ₓ, X= Ni, Co, Cu.)</td>
<td>up to 100 MW</td>
<td>850-1100</td>
<td>Cell: 60–65% System: 55–60%</td>
</tr>
</tbody>
</table>

Table 3. Advantages and disadvantages of fuel cell

<table>
<thead>
<tr>
<th>Type of Fuel Cell</th>
<th>Application</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton Exchange Membrane</td>
<td>Cars, buses, portable power supplies, medium to large-scale stationary power generation.</td>
<td>Compact design; relatively long operating life; adapted by major automakers; offers quick start-up, low temperature operation, operates at 50% efficiency.</td>
<td>High manufacturing costs, needs pure hydrogen; heavy auxiliary equipment and complex heat and water management.</td>
<td>Most widely developed; experimental production.</td>
</tr>
<tr>
<td>Alkaline</td>
<td>Space (NASA), terrestrial transport (German submarines).</td>
<td>Low manufacturing and operation costs; does not need heavy compressor, fast cathode kinetics.</td>
<td>Large size; needs pure hydrogen and oxygen; use of corrosive liquid electrolyte.</td>
<td>First generation technology; gains interest due to low operating cost.</td>
</tr>
<tr>
<td>Molten Carbonate</td>
<td>Large-scale power generation.</td>
<td>Highly efficient; utilizes heat for co-generation.</td>
<td>Electrolyte instability; limited service life.</td>
<td>Well developed; semi-commercial.</td>
</tr>
<tr>
<td>Phosphoric Acid</td>
<td>Medium to large-scale power generation.</td>
<td>Commercially available; lenient to fuels; heat for co-generation.</td>
<td>Low efficiency, limited service life, expensive catalyst.</td>
<td>Mature but faces competition from PEM.</td>
</tr>
<tr>
<td>Solid Oxide</td>
<td>Medium to large-scale power generation.</td>
<td>High efficiency, lenient to fuels, takes natural gas directly, no reformer needed. Operates at 60% efficiency; co-generation.</td>
<td>High operating temp; exotic metals, high manufacturing costs, oxidation issues; low specific power.</td>
<td>Least developed. Breakthroughs in cell material and stack design sets off new research.</td>
</tr>
<tr>
<td>Direct Methanol (DMFC)</td>
<td>Suitable for portable, mobile and stationary applications.</td>
<td>Compact stack structure, slow load response, operates at 20% efficiency.</td>
<td>Complex stack structure, slow load response, operates at 20% efficiency.</td>
<td>Laboratory prototypes.</td>
</tr>
</tbody>
</table>
3 Interaction of hydrogen buffer components with a wind farm

Interaction of the hydrogen buffer system is based on an internal low-voltage grid to which a wind generator is connected through power electronic control and a transformer. The hydrogen generation system is also connected to this grid. In order to store electrical energy, the system produces hydrogen from water electrolysis using electricity from the wind generator.

Interaction of the main components of the hydrogen buffer system can be divided into the following stages:

1. conversion of excess energy - wind generator - electrolyzer
2. conversion of chemical energy into electrical energy - fuel cell - grid

3.1 Excess energy conversion via a wind generator and an electrolyzer

An electrolyzer is a device that uses DC current, depending on the electrolyzer type, voltage levels applied to it range from several volts up to 300 V DC.

The converter used in the wind turbine (WinWind WWD3), Fig. 2, is the AC/DC/AC type with the intermediate DC-bus. The value of the DC voltage level determined by the generator voltage is between 575…690 V, which is higher than the electrolyzer voltage level. Thus it is necessary to use an interface converter. More feasible interconnection of the wind farm and the electrolyzer is possible in several types of connections which are presented in [4].

3.2 Chemical energy conversion into electrical energy

The authors propose some interconnections of the wind mill to the parallel balancing fuel cell-based generation system:

1. Connection of the fuel cell to the AC grid of the wind generator. An example of the connection to the wind turbine topology WinWind WWD3 is shown in Fig. 2. The rated output voltage of the synchronous generator is 690 V, DC-bus voltage is 930 V and AC output voltage of the wind generator frequency converter is 690 V. In this case the fuel cell is connected to the AC voltage with rated value of 690 V via a suitable converter. For this reason the fuel cell requires an additional interface converter (6) presented in Fig. 6.

2. Connection of the fuel cell to the DC-bus of the wind mill frequency converter. The proposed solution (Fig. 7) enables the interconnection of the fuel cell to the intermediate DC-bus (930 V) of the wind mill. This solution requires an additional interface DC/DC converter (6) used to interconnect the voltage of the DC-bus and the fuel cell.

Thus, special attention must here be paid to the minimization of current ripple caused by the operation of the interface converter (6). In addition, proper filters must be used on the input of the interface converter.

![Fig. 6. Generalized block diagram of a fuel cell connection to the AC grid.](image)

1 – synchronous generator, 2 – rectifier, 3 – inverter, 4 – voltage matching transformer, 6 - interface converter

![Fig. 7. Generalized block diagram of fuel cell connection to the DC-bus of the wind turbine frequency converter.](image)

1 – synchronous generator, 2 – rectifier, 3 – inverter, 4 – voltage matching transformer, 6 - interface converter

3. Connection of the fuel cell to the distributed grid. To connect the fuel cell to the distributed grid (10…24 kV) an additional interface DC/AC converter (6) and a transformer (7) presented in Fig. 8 are required.

![Fig. 8. Generalized block diagram of a fuel cell connection to an AC distributed grid](image)

1 – synchronous generator, 2 – rectifier, 3 – inverter, 4 – voltage matching transformer, 6 - interface converter

Considering all the explained topologies for connecting the fuel cell, it is clear that there are two viable circuit topologies which can be implemented. Because of implementation complexity the connection of the fuel cell to the distributed grid seems more difficult since it requires synchronization of phases and frequency, thus the converter system is made more complex.
3.3 Interfacing circuits

Because of low output voltage of the fuel cell a problem arises of how to achieve a required operating voltage level. For this reason power conditioning is an enabling technology that is necessary to convert the DC voltage generated by the fuel cell into a usable DC or AC voltage.

Various power conversion blocks such as DC/DC converters and DC/AC inverters are employed in fuel cell power conditioning systems. A DC/DC converter is responsible for drawing power from the fuel cell and at the same time it should not introduce any negative current into the fuel cell. A DC/AC is essential to provide the DC to the useful AC power at the frequency of 60 Hz or 50 Hz [16].

The choice of a converter circuit topology depends on several parameters:

- power
- input voltage
- output voltage
- input current
- output current
- requirements to output voltage quality
- requirements to input and output current ripple

As was pointed out before, there exist two main possibilities to connect a fuel cell so that these connections can be divided into several groups [16]:

1. Connection of a fuel cell to an AC grid:
   a) using a power conditioning unit with a line frequency transformer
   b) using a power conditioning unit with a high frequency isolation transformer
   c) using fewer power conversion stages in series

2. Connection of a fuel cell to the DC-bus of a wind turbine frequency converter
   a) Connection of a fuel cell to an AC grid using a power conditioning unit with a line frequency transformer. Low output voltage of a fuel cell is converted to a regulated DC output by means of a simple DC/DC boost converter. The output of the DC/DC converter is then employed to generate high output voltage. The main limitation of this system is the low voltage of the entire power conditioning unit, which results in higher current and lower overall efficiency. Another disadvantage is the presence of a line frequency isolation transformer, which is large in size and weight [16]. This circuit topology is shown in Fig. 9.
   b) Connection of a fuel cell to an AC grid using a power conditioning unit with a high frequency isolation transformer. In this design the high frequency isolation transformer is eliminated by employing an additional DC/DC conversion stage. The DC/DC conversion stage includes a high frequency isolation transformer. The fuel cell and the first DC/DC converter are rated for steady state conditions. The second DC/DC converter, along with the DC/AC inverter, is rated for steady state and transient conditions (Fig. 10). This approach suffers from three power conversion stages in the power flow path, which contributes to reduced efficiency [16].

   ![Fig. 10. Connection of a fuel cell to an AC grid using a power conditioning unit with a high frequency isolation transformer](image)

   c) Connection of a fuel cell to an AC grid using a power conditioning unit with fewer power conversion stages in series. In this approach, a push-pull type boost converter employing a high-frequency isolation transformer is used. The DC/DC converter output is connected to two half-bridge dual voltage DC/AC inverters to obtain an AC output (Fig. 11). The fuel cell and the push-pull DC/DC converter are rated to supply steady state load, while the DC/AC inverter stage is rated to supply the steady state load [16].

   ![Fig. 11. Connection of a fuel cell to an AC grid using a power conditioning unit with fewer power conversion stages in series](image)

2. Connection of a fuel cell to the DC-bus of a wind mill frequency converter. A fuel cell interconnection with the high-voltage load is possible. Generally, a fuel cell is used as a power source with the low output voltage. To supply the high-voltage DC-bus it is necessary to boost the relatively low output voltage of the fuel cell to a certain operating voltage level. Moreover, for the safety reasons the isolation transformer should be used for decoupling the low-voltage input and the high-voltage output sides of the converter. Thus, the step-up isolated DC/DC converter topology should be used in the presented application. This circuit topology is shown in Fig. 12.

   ![Fig. 12. Connection of a fuel cell to the DC-bus of a wind turbine frequency converter](image)
Thus, having considered all connection possibilities of a fuel cell to a wind farm and all interfacing circuit diagrams presented earlier, it is clear that a DC/DC converter with a step-up isolation transformer connected to the DC-bus of a wind mill frequency converter is more perspective solution, because it requires few components and does not require synchronization of phases and frequency. Moreover this topology is reliable and simple.

The final block diagram of the electrically connected hydrogen buffer system with a wind generator is shown in Fig. 13.

Fig. 13. Generalized block diagram of an electrically connected hydrogen buffer system
1 – synchronous generator, 2 – rectifier, 3 – inverter, 4 – voltage matching transformer, 5 – electrolyzed power supply, 6 – interface converter for a fuel cell, 7 – control of power supply

4 Other methods of stabilization wind power generation

Power balance depends strictly on the system configuration and it derives from energy balance and can be realized with other technical solutions:
1. reversible fuel cell
2. fuel cell/gas turbine hybrid power system
3. hydrogen-fed power generation plant

4.1 Reversible fuel cell
For stand-alone systems, energy storage devices are essential to store electricity for use when the wind is absent. Wind energy systems have a fluctuating power output due to the variability of the wind speed with the power output varying by the cube of the speed. Integrating an appropriate energy storage system in conjunction with a wind generator removes the fluctuations and can maximize the reliability of power to the loads [17]. The bi-directional flow energy allows using vanadium redox flow battery to provide the necessary power to maintain a constant load voltage.

Vanadium redox flow battery (VRB) is an electrochemical cell divided into two compartments, positive and negative tanks containing an electrolyte, and a pump and piping for circulating the electrolyte from the tanks to the cell. This system does not include dangerous gas storage such as hydrogen.

The active material for both the positive and negative electrodes of the VRB is vanadium ions that are dissolved in the sulfuric acid and serve as metal ions whose valence number changes. Fig. 14 shows the operating modes of the VRB [18].

Fig. 14. Operating modes of the vanadium redox flow battery

VRB use a controlled pump to induce the flow, which improves battery performance and efficiency. In a VRB battery, the total energy storage of the system depends on the state of charge (SOC) and the amount of active chemicals in the system. The total power available is related to the electrode area within the cell stacks.

Configuration of the stand-alone wind energy system with the VRB energy storage is shown in Fig. 15.

Fig. 15. Configuration of the stand-alone wind energy system with the VRB energy storage
1 – generator, 2 – rectifier, 3 – inverter, 4 – voltage matching transformer, 6 - interface converter

A VRB system has a high speed response and is not aged by frequent charging and discharging. The efficiency of the battery increases when the charge/discharge period becomes shorter. In addition, the VRB has short duration overload capacity and a long service life. Thus, this relatively new electrochemical technology seems well suited for enhancing the utilization of renewable energy.

4.2 Fuel cell/gas turbine hybrid power system

The hybrid power system in this study is a combination of a gas turbine (GT) generator and a solid oxide fuel cell (SOFC) stack. Several significant advantages of SOFC lead us to consider it as a part of the hybrid power system. First, an SOFC operates at high temperatures. Also, the energy conversion efficiency of an SOFC stack can reach up to 60%, and its overall efficiency, when used in combined heat and power (CHP) applications as an integrated SOFC combustion turbine system, can even reach up to 70% [19] Fig. 16 shows the schematic of the hybrid power system.
Fig. 16. Hybrid power system

First, the air is pressurized by a compressor, and then it passes through a heat exchanger which uses the exhaust gas from the turbine to be preheated. The pressurized and preheated air enters the fuel cell. The chemical reaction between the fuel and air in the fuel cell produces electricity. Meanwhile the temperature of the fuel cell increases to a high value. The exhausted high temperature gas from the fuel cell injects to the oxidizer (burner) and heating up after burning with the fuel inside the burner. The mechanical power is produced by the expansion of the high temperature gas in the turbine. This mechanical power rotates the GT shaft which is coupled to a synchronous generator to generate electricity. To control the power produced by the generator, additional fuel is injected to the burner.

4.3 Hydrogen-fed power generation plant

Hydrogen is an energy carrier, which can be used in renewable energy and in environment protection. Fig. 17 shows the layout of an advanced system [20].

Fig. 17. Hydrogen and oxygen hybrid cycle

Pure hydrogen is used as a fuel and pure oxygen is used as an oxidant in this system. In the first combustion chamber (CC1), hydrogen is burned at the stoichiometric ratio and mixed with steam. The hydrogen to the oxygen ratio is 2:1. Then the steam discharged from the CC2 expands to the atmospheric pressure in the medium pressure gas turbine (MPGT), then flows to the heat recovery exchanger (HRE). In the HRE one part of the steam is condensed and pumped to the heat recovery system by the boiler condensing water pump (BCWP). The other continues to expand in the low pressure steam turbine (LPST). After that the steam enters the condenser and is condensed to water here. The condensed water is pumped to the HRE by the feed water pump (FWP) where it is heated up to ultra supercritical steam by the MPGT exhaust steam. Then the ultra supercritical steam expands in the high pressure steam turbine (HPST) and eventually the exhaust steam is induced to the CC1 to absorb the heat released from the hydrogen fuel [21].

Conclusion

The main goal of the implementation of a hydrogen buffer is to support and stabilize voltage in the local power grid. For this reason the use of an electrolyzer and a fuel cell in the systems "wind - hydrogen" requires of interface converters to be implemented for connection. Comparison of different converter technologies in this field requires further research.

Practical distribution of power flows helps to solve the following tasks:

1. Energy saving - because of an efficient use of renewable energy in the close location of the consumer. Efficiency will rise if the local groups of consumers and producers of heat are combined in the local network.
2. Improved quality of electricity - due to its accumulation of power electronics with the use of storage elements.

Acknowledgement

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