Energy storage in AirHES

AirHES, as well as other RES (renewable energy sources: solar, wind, etc.), is meteodependent and needs in energy accumulation, unless AirHES used only for water. While RES, including AirHES, connected to a common power and occupy a small share of the energy generation, accumulation problem is not too hot, as the traditional sources will be able to cover the uneven productivity of RES. However, these arguments are not acceptable when using AirHES as an independent energy source, for example, for the purposes of the Army, the Navy or the Ministry of Emergency Situations.

On average, according to NASA's cloud cover 67% of Earth's surface, therefore in terms of natural factors on the power generation uniformity, AirHES looks even better than other renewable energy sources with a typical capacity factor ~ 20-40% [1]. Nevertheless, we can distinguish three levels of non-uniformity, which should be considered:

1. Local unevenness - gaps in the flow of clouds.
2. Meteo unevenness - such as weather changes (for example, with the "cloudy" to "clear").
3. Seasonal unevenness - the season changes (for example, onset of winter).

It is obvious that for each type of unevenness is possible to use different approaches. In general, we can offer the following range of possible measures:

1. The traditional chemical batteries. Many studies [2] shown that of all existing methods of energy storage, the conventional lead-acid batteries still remain the cheapest way to accumulate [3] (~ $150/kWh investment, with the limit of 500 full discharge cycles or terms of the costs for battery lifetime ~ $0.30/kWh at the characteristics of ~ 0.013 m3/kWh, ~ 25 kg/kWh, the efficiency of ~ 80%).
2. Local "pumped storage". This is one of the advantages of AirHES vs other RES. AirHES can store some amount of the water on upstream, which will require additional expenditure for aerostatic retention. It is easy to calculate that at a height of 2 km each kg of water stores 1kg*10m/s2*2000m = 0.02 MJ = 0.0056 kWh, to hold which takes approximately 1 m3 or 0.1kg of hydrogen with a minimum current cost of ~ $0.2-0.3, equivalent to ~ $35-53/kWh, which is at least three times cheaper than chemical batteries. Real benefit even more, since AirHES does not buy hydrogen, but produces its own, ie does not create external costs. At the same time there are no limits of cycles for hydro accumulation and generally it has higher efficiencies. In addition, regulation of the amount of water in the upstream provides an additional convenient control mechanism of lifting height of AirHES to optimize water collection.
   However, even without this additional storage of water on upstream, AirHES still will use water, which is in the hose and on the mesh. For example, for the basic technical prototype of feasibility study, the amount of water in hose for the average productivity is 3572 kg. Given that the average pressure of the water in hose is only half of the altitude, ie 1 km, we get the value of energy storage ~ 10 kWh, which corresponds to several minutes, during which AirHES will continue to work, gradually reducing the power of the rated power of 185 kW (for example, in case of a break in the flow of clouds).
3. Cascade "pumped storage". This is one more fundamental advantage of fixed AirHES. As you know one of the best solutions for today of this task is a pumped-storage plant (PSP) [4]. By using a suitable hill, you can build a reversible hydroelectric power plant, which operates either the pump mode, or the regenerative mode. At the same time the efficiency of reversible hydroelectric units are generally much worse than conventional water turbines. AirHES of cascade type can elegantly solve this problem, and at the same time solve the problem of the meteo dependence. If there is a suitable hill, but there is no a river, the AirHES can easily create this artificial "river" and the intermediate upstream by draining its

water in natural (meteo dependent) mode NOT to the downstream, BUT to this intermediate upstream of the cascade hydro-power plant. Then the lower hydroelectric power station and will play the role of accumulator (PSP) with usual hydraulic turbines, and coordinated work of the AirHES and this cascade conventional HPP will completely eliminate the problem of the meteo dependence. The pump mode in this case can be eliminated - Sun will operate itself as the pump by lifting the water up to the clouds.

4. Induced or surface condensation. Another possibility of reducing the non-uniformity associated with the physical principles of AirHES. In normal mode AirHES mesh designed to capture the micro droplets of clouds, that is the mesh uses the bulk moisture condensation. However, it is assumed that in the absence of the cloud, the surface condensation (like dew) must occur on the mesh raised (by the AirHES technology) definitely above the dew point. According to preliminary estimates, the effect, of course, will give significantly less water than cloud screening, but nevertheless, this effect must exist and can be verified experimentally.
5. The accumulation of hydrogen. Here AirHES also has a significant advantage vs other RES. Transformation, accumulation, and further use of energy in the form of hydrogen is one of the main ideas of alternative energy to replace fossil fuels. With relatively minor changes, hydrogen can be used in almost all the energy and transport units that currently use hydrocarbons, which creates the possibility of a gradual transition to the new green energy with minimal cost and without a radical destruction of the previous energy infrastructure. The main problem for all other types of RES in getting hydrogen from the excess energy is the absence at the location of solar panels or wind turbines of the sources of fresh water with high-quality purification which is necessary for the operation of the electrolyzer. Vice versa, AirHES has in excess and energy and fresh water of perfect quality (almost distillate). Moreover, structurally and technologically AirHES can naturally store hydrogen in its balloons or even transport hydrogen accumulated in such balloons (in the form of airships) to consumer.
   It is easy to calculate that AirHES can easily be modified to increase its energy storage about 600 times! It's enough to add hydrogen hose and to use ballonet aerostat, which in this case will not only ensure the maintenance AirHES elements, but also to keep a stock of hydrogen as an energy storage agent. It is easy to show that 1 kg of hydrogen (with a calorific value 120.9 MJ/kg) holds in the upper reach of about 10 kg of water with a supply of hydro power only 0.2 MJ. So AirHES during overproduction of energy will always add into balloons the hydrogen (produced by electrolysis) and support balanced drain to provide the necessary amount of water in the upper reach (to maintain steady-state design and to minimize the tension holding the ropes) in order to store 600 times more energy which, if necessary energy, can always be balanced so as to get back in the fuel cells (from hydrogen) and a turbogenerator (from water).

So we see that out of five possible ways of dealing with meteo dependence, four are either exclusive or significant advantage of AirHES vs other RES. Consider the approximate impact on the feasibility study [5] taking into account the need for energy storage for the minimum (1.85 kW) and the base (185 kW) technical prototype.

Local unevenness - gaps in the flow of clouds

Since AirHES performance in the feasibility study is based on the integrated data collecting fog and the corresponding flow of water, the data already include the initial non-uniformity, which is quite difficult to assess. Also we assume the AirHES will use low clouds (nimbostratus, stratocumulus, stratus) and vertical development clouds (cumulus, cumulonimbus) [6]. Most of these clouds have a duty ratio close to 1, that is almost continuous layer. Lets suppose for our conventional calculation that AirHES must work stably even when the duty ratio is 2 and that such a regime can be up to 10% of the time. For typical dimensions clouds ~ 1 km, and a typical wind speed at 2 km ~ 10 m/s, this means that AirHES should provide a nominal productivity at gaps in flow of clouds ~ 1 km, that is for about 100 seconds, which corresponds to energy accumulation 185 kJ (~ 0.05 kWh) and 18500 kJ (~ 5 kWh), respectively, and with total time of such mode of accumulation for about one year, that is up to half the output energy from generating during 10% of the estimated life-time of 10 years.

The prototype by estimated feasibility study	**Minimum**	**Basic**
One-time necessary accumulation, 100 s, kWh	0.05	5
Total accumulation, ~ 10% for 10 years, kWh	~8000	~800000
Total cost without accumulation, $	2906	85459
Lead-acid batteries		
Additional capital costs $150/kWh, $	7.5	750
Total operating costs, ~ 10% for 10 years, $0.30/kWh, $	~2400	~240000
Total additional costs with this accumulation, % increment	~82	~281
Local "pumped storage"		
Water storage in the upstream, kg	~10	~1000
Load weight gain (and increment of balloon volume), % (G)	~7	~17
Increment of balloon shell cost, % (~ G^(2/3))	~3.7	~6.7
Increment of balloon shell cost, $	~16	~325
Total additional costs with hydro accumulation, % increment	~0.6	~0.4
Accumulation of hydrogen using reversible fuel cells [7][8][9]		
Additional capital costs $3400/kW, $	6290	629000
Total operating costs, ~ 10% for 10 years, $170/kW/year, $	~315	~31500
Total additional costs with H2 accumulation, % increment	~227	~773

Thus, AirHES easily eliminates a local unevenness due to local hydro accumulation (local "pumped storage") that already gives AirHES a global advantage over the solar and wind energetics, where to address this problem have to use lead-acid batteries with multiple cost increment for the RES [10].

Meteo unevenness - such as weather changes

Meteo unevenness to a certain place can be estimated by the meteorological archives [11] or according to data of NASA weather satellites [12]. For example, in St. Petersburg an analysis of cloudiness in the warm period of the year shows that the change in the type of weather with a "cloudy" to "clear" may be for the duration of approximately one week at intervals of about a month, that is the total number of charge-discharge cycles (120) of the battery does not exceed the limit of cycles (500), and therefore the operating costs can be neglected. It is obvious that the local power plant of any type of renewable energy can not cope with the accumulation of weekly production (unless it is a permanent installation, which can realize a cascade scheme of AirHES-HPP). Nevertheless, see the appropriate calculations.

The prototype by estimated feasibility study	**Minimum**	**Basic**
Weekly accumulation, 168 hours, kWh	310.8	31080
Total cost without accumulation, $	2906	85459
Lead-acid batteries		
Additional capital costs $150/kWh, $	46620	4662000
Total additional costs with this accumulation, % increment	~1600	~5500
Local "pumped storage"		
Water storage in the upstream, kg	~56000	~5600000
Calculated radius of balloon (by aerostatic balance), m	23.9	110.34
Balloon shell weight (155 g/m2), kg	1112	23700
Cost of balloon shell ($3/m2), $	~21500	~459000
Total additional costs with hydro accumulation, % increment	~740	~537
Accumulation of hydrogen using reversible fuel cells		
Additional capital costs $3400/kW, $	6290	629000
Total operating costs, ~ 25% for 10 years, $170/kW/year, $	~787	~78700
Total additional costs with H2 accumulation, % increment	~244	~828

Thus, as expected, no option is not acceptable. Meanwhile, according to Wikipedia [13] can be expected to reduce the cost of the reversible fuel cell to the level of $254/kW (General Electric, 2006), and then this option will be acceptable. Furthermore, this type of fuel cell can be used not only for hydrogen but also for an ordinary propane, which allows its use in place of backup diesel generator (DG).

Accumulation of hydrogen using reversible fuel cells (GE)		
Additional capital costs $254/kW, $	~470	~47000
Total operating costs, ~ 25% for 10 years, $170/kW/year, $	~787	~78700
Total additional costs with H2 accumulation, % increment	~43	~147
Specific cost, including operating costs for 10 years, $/kW	~2250	~1141

However, to date, we still have to use the DG as a backup source of power.

Seasonal unevenness - the season changes

As already mentioned, AirHES can work all year round only in the southern countries. In the conditions of Russia a water drop cloud exists in the lower troposphere of only about half of year, that is AirHES has to for the warm season or accumulate a sufficient amount of water for cascade hydro power plants, or accumulate a sufficient amount of hydrogen (in order to use it for remaining six months in the fuel cells or in place of natural gas in the existing energetics), or simply be replaced for this time by conventional energy sources. In the case of a stand-alone application is now for all renewable energy as a backup power source the DG is used. Let us compare the technical and economic characteristics for year round when used alone DG or DG+AirHES in central Russia. Let us assume that, given the winter season and meteo changes, AirHES will actively operate only a third of the time of year. According to the market analysis of diesel and petrol generators we will take the average valuation of capital costs ~ $150/kW and operating cost ~ $0.15/kWh.

The prototype by estimated feasibility study	**Minimum**	**Basic**
Total cost of AirHES without backup source, $	2906	85459
Additional capital costs (DG) $150/kW, $	~278	~27800
Fuel costs (DG), ~ 67% for 10 years, $0.15/kWh, $	~16287	~1628700
Total additional costs with backup source (DG), % increment	~570	~1938
Total cost, including operating costs for 10 years, $	~19471	~1742000
Specific cost, including operating costs for 10 years, $/kW	~10525	~9416
Using only standalone DG	**1.85 кВт**	**185 кВт**
Capital costs (DG) (with life time ~ 10 years), $	~278	~27800
Fuel costs (DG) for 10 years, $0.15/kWh, $	~24309	~2430900
Total cost, including operating costs for 10 years, $	~24587	~2458700
Specific cost, including operating costs for 10 years, $/kW	~13290	~13290
Total savings from using DG+AirHES, $	**~5116**	**~716700**

Also we consider the use of a fuel cell instead of DG, suggesting that we have to use for the warm season three modules AirHES instead of one, to reserve 2/3 of the energy for the winter in the form of hydrogen.

Accumulation of hydrogen using reversible fuel cells (RFC)		
Total cost of 3 AirHES without backup source, $	8718	256377
Additional capital costs $3400/kW, $	6290	629000
Total operating costs, ~ 67% for 10 years, $170/kW/year, $	~2107	~210700
Total cost, including operating costs for 10 years, $	~17115	~1096000
Specific cost, including operating costs for 10 years, $/kW	~9251	~5924
Total savings from using RFC + 3 AirHES, $	**~7472**	**~1362700**

Thus, even the option of using the existing reversible fuel cells for hydrogen storage required for long-term six-month reserve, together with 3 AirHES (when issuing the same power) is advantageous in comparison with the DG alone.

Comparing the cost of water

Since AirHES produces not only energy, but also fresh (almost perfect distilled) water, then we can estimate the cost of such water compared to alternative technologies [14], for example, for the needs of the Navy or the Ministry of Emergency Situations.

Technology	Reverse Osmosis	Atmospheric Distillation	Mechanical Vapor Compression	Vacuum Distillation	Multistage flash	M-Cycle
Waste heat consumption, Btu per lb recycled water	0	0	0	1000	104	312
Operating temperature, F	50-90	212	220	130-150	220-240	90-110
Electricity consumption, kWh per m^3 recycled water	1-5	0.5-1	20	1-2	3.5-4	0.1-0.5
Fuel energy consumption, Btu per lb recycled water	0	1000	35	0	0	0
Clean water quality (total dissolved solids reduction)	95%	99%	99%	99%	99%	99%
Water recovery, %	40-50	70-98	95-99	70-98	70-98	90-95
Concentrate discharge, %	50-60	2-30	1-5	2-30	2-30	1-5
Cooling water requirement, lb per lb recycled water	0	50-60	0	50-60	0	0
Unit capacity, GPD	175000	175000	175000	175000	175000	175000
Operating cost, $ per 1,000 gallons of recycled water	2.91	1.49	3.07	1.44	1.51	0.91

A feasibility study shows that even if AirHES will only be used for the production of water, the cost of this water will be extremely small. For example, even the minimum technical prototype will produce daily about 10 tons or m3 of water, that is for the life time of 10 years gives 36500 tons or ~ 9.64 million gallons, hence the water cost is ~ $0.08/m3 or ~ $0.3 per 1000 gallons, which is several times less expensive than other techniques listed in the table. The basic technical prototype will give water even cheaper: ~ $0.02/m3 or ~ $0.09 per 1000 gallons. Given that the production of such water will not consume energy rather will produce energy...

[1] OpenEI database, Capacity Factor http://en.openei.org/apps/TCDB

[2] FUNDAMENTAL LIMITATIONS OF RENEWABLE ENERGY https://oneinabillionblog.com/energy/renewable-energy/fundamental-limitations-of-renewable-energy/

[3] Got Storage? How Hard Can it Be? http://physics.ucsd.edu/do-the-math/2011/09/got-storage-how-hard-can-it-be/

[4] THE RENEWABLE ENERGY GRID PARITY REALITY CHECK https://oneinabillionblog.com/energy/renewable-energy/the-renewable-energy-grid-parity-reality-check/

[5] Feasibility studies for various examples of AirHES http://barixa.net/AirHES_feasibility.pdf

[6] Cloud https://en.wikipedia.org/wiki/Cloud

[7] LOW COST, HIGH EFFICIENCY REVERSIBLE FUEL CELL (AND ELECTROLYZER) SYSTEMS https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/30535aw.pdf

[8] Reversible fuel cell goes both ways for the US Navy http://newatlas.com/boeing-reversible-us-navy-fuel-cell/41726/

[9] Fuel Cell of the Future http://www.controlglobal.com/articles/2008/223/?show=all

[10] THE IMPACT OF ENERGY STORAGE ON SOLAR PV GRID PARITY https://oneinabillionblog.com/energy/renewable-energy/the-impact-of-energy-storage-on-solar-pv-grid-parity/

[11] https://www.windguru.cz/archive.php?id_spot=4859

[12] Giovanni. The Bridge Between Data and Science http://giovanni.gsfc.nasa.gov/giovanni/#service=TmAvMp&starttime=&endtime=&data=MAIMCPASM_5_2_0_QL(z%3D1000)&variableFacets=dataFieldMeasurement%3AAtmospheric%20Moisture%3B

[13] Solid oxide fuel cell https://en.wikipedia.org/wiki/Solid_oxide_fuel_cell

[14] Analysis of distillation systems http://sssrregion.ru/pics/Khalatov_perspectivi.pdf