Hybrid System that Integrates the Lost Energy Recovery on the Water-Water Heat Pump Exhaust Circuit

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Abstract. Exceeding intermitence and the stochastic character associated with most renewable energy sources in order to maintain the balance between generation and consumption require the most efficient energy storage methods. This balance is important to maintain the quality of the power supply by adjusting the frequency and voltage of the grid. Storage is the capture of the energy produced at a given time for later use. It is known that electricity cannot be stored directly unless it is stored in condenser batteries or in superconducting coils. Other methods of electricity storage presuppose the conversion of these into other forms of energy: mechanical storage, electrochemical storage. The optimization of RES operation and, implicitly, of the energy system implies the choice of a suitable conversion / storage system that must take into account a number of factors, such as: capacity and minimum storage time, loading and unloading conditions, minimum number of cycles download loading, power supply required by the storage system, system lifetime. It is not to be neglected the space required for the installation of the storage systems and their impact on the environment during their exploitation as well as during the post-use and recycling period. There are RES that contain natural storage systems (hydro-electric power plants and biomass and biogas generators). The article proposes an analysis of how to store electricity by approach a Pelton water-water-turbine hybrid system. The heat pump consumes electrical energy for action, producing a thermal effect. By integrating a system with Pelton water storage tank and turbine on the heat pump outlet circuit, the lost hydraulic energy can be recovered. The experimental hybrid system was made to develop HRES optimization models. Hybrid systems may exceed the limits of individual generators in terms of efficiency, economy, reliability and flexibility. An energy storage system can alleviate the problems associated with uncertainties and fluctuations from renewable sources. The large number of random variables and parameters in a hybrid energy system requires optimization to increase the efficiency of hybrid system components to achieve economic and technical benefits.

1. Introduction
The European Commission (EC) adopted on 28 November 2018 a long-term strategy for a clean planet. In this respect, the states and citizens of the European Union (EU) are encouraged to promote actions to fund research in order to achieve a modern and competitive climate-neutral economy by 2050 [1]. As the Romanian energy sector is responsible for 60% of the amount of greenhouse gas (GHG) emissions, to reach the EU targets. Romania needs to further adopt decarbonisation policies for
the energy sector [2]. In this respect, Romania needs to adopt investments in the energy sector to build new energy capacities from renewable energy sources (RES) and renounce investments in thermal power plants (CHPs).

Environmental Fund Agency has launched the Classical Green House Program for individuals and legal entities that have funded and funded the following types of programs: installing non-pressurized solar panels, installing pressurized solar panels and installing heat pumps [3].

By adopting the program to install photovoltaic panels (PFVs) by individuals, it is desirable to create small power generation units (3kW) for their own consumption and surplus delivery to the NES. This program aims at locally producing electricity and reducing the power flow on distribution system (SD) lines and power transmission (ST) lines.

The amount of GHC reduced by implementing the PFV installation program is the performance index of the program and can be calculated with (relation 1):

$$I = \sum_{i=1}^{n} E_i \cdot f$$

Expanding financing programs to provide the installation of wind kinetic energy conversion systems or recovery of the kinetic energy of the exhaust air jets from the exhaust systems [4], small scale hydroelectric conversion systems and the recovery of potential water energy from evacuation or gravity induction systems could be efficient solutions for RES.

This approach could be the National Climate Change Strategy that exploits all forms of energy and, exceptionally, the lost energy.

Besides the issue of the conversion of RES energy into electricity and the efficiency of systems, the researchers' concern is also directed towards the integration of RES into the National Energy System (NES).

The unpredictable character of the RES is an open theme for their integration into SES, and the establishment of the energy storage method.

2. Energy independence for consumers

The renewable energy potential may have been fully exploited by adopting programs such as the ‘CASA VERDE’ program. Programs that encourage the use of RES provide some degree of energy independence for consumers with a major impact on the quality of life. Zonal savings can be resized on the basis of available renewable energy resources, thus constituting the engine of sustainable development and technological progress in a cleaner environment.

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The widespread use of renewable energy sources can lead to increased consumption by marking economic growth, the difference from the past is the decrease in the amount of polluting emissions (in the past economic growth was quantified by increasing pollutant emissions).

Considering the expected increase in the built-up fund, the implementation of investment support programs in RES is increasingly justified because for the new built areas there is no need to strengthen the electrical networks. Every prosumer is directly interested in delivering as much electricity as possible to the NES. In doing so, he will take all measures for energy efficiency of the built space, thus achieving the goal of NEARLY ZERO ENERGY BUILDINGS (NZEB).
The built surface in Romania is 49300ha, with residential buildings occupying an area of 42400ha, with single-family buildings being dominated by 4.94 million buildings [5]. Through the CASA VERDE CLASSIC program in Romania, 42,000 thermosolar panels were installed, less than 1% of the number of single-family houses.

Injecting into NES the energy savings made by prosumers involves optimizing the operation of interconnected renewable electricity networks. Photovoltaic (PV) and wind systems are unsafe without storage systems. Their reliability is dependent on their hybridization and the integration of storage systems. The integration into SES of small-scale RES systems is highly dependent on energy storage systems [6]. Energy storage systems must be capable of storing energy produced in favorable climatic conditions and return it to cover the peak hours during the diurnal period or when the production of renewable systems is not possible.

In a Renewable Energy Hybrid System (HRES), increasingly indispensable in the current context of the energy and environmental crises, energy storage plays a particularly important role. Figure 1 shows the structure of a hybrid power generation system.

![Figure 1](image1.png)

**Figure 1.** Hybrid renewable energy system

Electricity storage has been known since the beginning of the 20th century to ensure the need for electricity during the nighttime when power plants were closed, and lead-acid batteries were used to store electricity [7].

The term storage of electricity is practically improper. The storage of electricity involves its conversion to another form of energy, Figure 2.

![Figure 2](image2.png)

**Figure 2.** Power storage technologies

Choosing the optimal energy storage system can be done according to: storage capacity, storage time, power and energy that can be stored, the type of fluctuations to be compensated, the lifetime, the HRES properties, and last but not least the size of the system storage and available space. The time at which an energy storage system can return the stored energy can be in the order: seconds-minutes-hours-days. Factors that affect the storage capacity of the stored energy are: power density (kW / kg) and energy density kWh / kg. By energy density we understand the capacity of the energy storage
system to continuously return to a consumer the energy stored over a long time with high energy
densities at low power densities, Figure 3.

![Figure 3. Energy Return Chart of energy Stored in Storage Systems](image)

2.1. Hydroelectric storage (PHS)
Hydroelectric storage consists of storing potentially hydraulic energy by pumping water from a lower
tank into a higher tank. PHS is a proven technology with long-term storage, high efficiency and
relatively low cost per unit of energy [8-12]. On the other hand, PHS can return large amounts of
energy at high power, Figure 3.

The scale of hydrotechnical developments, the cost of investment and environmental issues make
major constraints for PHS. To reduce negative environmental impacts, investing in new energy
capacities using hydropower or hydroelectric storage must be subject to EU nature legislation [13].

In this context, it is considered appropriate to install micro hydroelectric plants on the water outlets
in the treatment plants, on the pipeline of gravity feeds or on other pipes from which the potential
energy lost in these systems could be recovered, Figure 4.

![Figure 4. Adduction systems with renewable potential](image)

2.2. Compressed air energy storage (CAES)
In 1949, Stal Laval laid the foundations for compressed air storage in sunter caverns [7]. The storage
of renewable energy in the form of compressed air to be used after the generation period is largely
similar to the operation of the pumped hydropower plants (in terms of their use, output and storage
capacities). CAES instead of pumping water from a lower accumulation reservoir into a higher one
during times of surplus power, they produce compressed air that it injects into underground caverns. In
order to return the stored energy, the pressurized air is heated and expanded into an expansion turbine
unit and generator which converts the kinetic energy of rotation into electricity, Figure 5.
CAES can be carried out near mining or petroleum exhausted exits and are associated with gas turbine power plants. For this reason CAES are less attractive to researchers looking for solutions to reduce emissions (nitrogen oxides and carbon oxide) [7].

The storage of renewable energy in the form of compressed air to be used after the generation period can be done in order to increase the efficiency of the pneumatic technological installations. In this case, the costs of conversion into electricity are eliminated, figure 6.

3. Description of the experimental installation
The proposed experimental installation (Figure 7) highlights the conversion and storage of energy and the possibility of recovering the lost energy from the technical systems.
The water discharged from the primary circuit of a water-water heat pump is stored in a storage tank R1, coupled via a solenoid valve to a Pelton turbine. The head of the hydraulic turbine is achieved with the compressed air stored in the R2 tank. The compressed air is pre-stressed by the C-powered compressor from a hybrid photovoltaic conversion system (PV).

The experimental installation does not practically consume the electricity from the NES, the electrical energy required for the operation of the heat pump and for the production of the compressed air is provided by HRES, Figure 8.

In the proposed testing rig the turbine head is simulated varying the compressed air pressure with the pressure regulator RPAC. Varying the turbine head and the volumetric flow rate, through the 2 injectors (Rr), there can be simulated different running regimes for the Pelton water turbine.

4. Results and discussions
The Pelton turbine is used for small flow rates, having specific speeds between 3 and 36, and heads from 50m up to 2000m.

In figure 9 is presented a Pelton turbine with 2 injectors with divided penstock.
In figure 10 and 11 are presented the characteristic curves, torque and efficiency as a function of speed, for a laboratory model Pelton turbine. The results are obtained for 3 testing regimes:

- regime 1: turbine head \( H = 16.5 \) m and the volumetric flow rate \( Q = 0.37 \) l/s;
- regime 2: turbine head \( H = 12 \) m and the volumetric flow rate \( Q = 0.52 \) l/s;
- regime 3: turbine head \( H = 8 \) m and the volumetric flow rate \( Q = 0.62 \) l/s.

Utile power for the hydraulic turbine, in this case is mechanical power defined as (relation 2) [14]:

\[
M_P = T \cdot \omega \ [W] \tag{2}
\]

where \( T \) [Nm] represents the torque and \( \omega \) [rad/s] is the angular speed.

The absorbed power is the hydraulic power (relation 3) [14]:

\[
H_P = \rho \cdot g \cdot Q \cdot H \ [W] \tag{3}
\]

where \( \rho = 1000 \) [kg/m\(^3\)] is water density, \( g = 9.81 \) [m/s\(^2\)] is gravitational acceleration, \( H \) [m] represents the turbine head and \( Q \) [m\(^3\)/s] is the volumetric flow rate.

The hydraulic turbine efficiency is the ration between the utile and absorbed power (relation 4) [14]:

\[
Efficiency = \frac{M_P}{H_P} \cdot 100 \ [%] \tag{4}
\]
5. Conclusions
From figures 9 and 10, 11 it can be seen, that the Pelton turbine can be used with quite good efficiencies even at low heads.

Considering that for achieving nearly 50% efficiency, at turbine drops and relatively low flows, the proposed solution is suitable for the installation of Pelton microturbines on the water outlet pipes of the technical systems.

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