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Editorial

Small-Scale Hydropower and Energy Recovery Interventions: Management, Optimization Processes and Hydraulic Machines Applications

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The overuse of fossil fuels has brought considerable climate change to our planet, affecting not only human life, but also the ecosystem of the Earth (e.g., the melting of glaciers, drought in warm/hot seasons, etc.). Indeed, an effect of raising CO_2 concentration in the atmosphere is the steep gradient of the global temperature increase (almost +0.08 °C per decade, starting from 1900), which can be slowed down only by rethinking the current paradigms of energy production and use.

The introduction and promotion of technologies capable of exploiting cleaner and renewable sources, as well as delivering core energy-related services such as electricity and drinkable water, is currently one of the main paths to be followed for tackling the global warming issue. Water, as one of these sources, is an essential input for life and energy production; conversely, a significant amount of energy is required for the extraction, treatment, distribution, and disposal of water for civil and industrial uses. Thus, these resources must be managed properly to grant a secure supply to the population while meeting sustainability goals. This tradeoff constitutes the so-called water–energy nexus that motivates scientists to further investigate, optimize, and invest in this important research topic dealing with the correct and smart use of water.

Renewables are considered the key factor to proceeding with the decarbonization path. According to the International Energy Agency (IEA), renewables have increased electricity production by 7% in one year, namely, from 2019 to 2020 [1]. In particular, wind and photovoltaic (PV) technologies together accounted for almost 60% of this increase. The share of renewables in the global electricity market reached almost 29% in 2020. Renewable power deployment still needs to expand significantly to achieve net-zero emissions by 2050. In the medium term, the target is to reach more than 60% of the electricity generation using renewables by 2030 [2]. Hydropower is the largest source of electricity worldwide; indeed, its generation increased by 124 TWh (+3%) in 2020, reaching 4418 TWh and generating more than all other renewable technologies combined. Hydropower is supposed to have a 3% average annual generation growth until 2030 to provide 5870 TWh/year of electricity; thus, an average of 48 GW of new capacity must be installed to achieve the net-zero emissions target [3].

Currently, most of the hydropower plants worldwide are large-scale systems; these systems were widely installed in the twentieth century, exploiting the most convenient locations in terms of high height differences and flow rates, as these sources were the ones that granted the highest payback in energetic and economic terms. The technologies used in these installations are now considered to be mature, even though there are some recent studies regarding the further revamping and digitalization of large-scale hydraulic turbines, such as Francis turbines or pump turbines, in the case of storage power plants. For instance, Chen et al. (Contribution 1) proposed an analytical model of a Francis turbine operating at the best efficiency point (BEP). This shows a much faster response in predicting the internal flow field and working performance compared to experimental campaigns and computational fluid dynamics (CFD), which both require high investments in equipment and supercomputers. On the other hand, the problematic of pressure pulsations during the operation sequences of pump-storage power plant has been investigated by Himr et al. (Contribution 2), which addressed this energy dissipation phenomenon to the second (bulk) viscosity of water.

As an alternative option to further foster the exploitation of hydropower potential, the small-scale hydropower sector is currently being considered for future hydropower scenarios, for example, as a downsized alternative to traditional plants, and as a solution to exploit the so-called "hidden hydropower potential", which involves energy recovery solutions and the exploitation of alternative hydraulic geodetic potentials, such as pressurized water networks and irrigation systems. These solutions are particularly attractive in regions where traditional hydropower sites have been extensively exploited, such as in Europe and North America. Generally, the water pressure in distribution networks is lowered through pressure-reducing valves (PRVs) down to 3–4 bar from higher values that depend either on the height of the water source or the outlet pressure of pumping stations used to distribute the water to the end-users. During this process, the energy of the water is wasted in the forms of heat, noise, and vibration [4]. For this reason, a kind of energy recovery intervention in water distribution networks can be the replacement of PRVs with hydraulic turbines capable of exploiting the water potential available in these networks. Biner et al. (Contribution 3) proposed a new micro-hydroelectric system whose core element is a counter-rotating micro turbine, focusing on a gross capacity between 5 kW and 25 kW. This kind of hydraulic machine requires low capital expenditure with an economic return within 10 years.

However, other technologies that have been used in several traditional hydraulic applications can be adopted for energy generation and recovery purposes, such as pump as turbines (PATs), which are considered an effective and much cheaper solution than traditional hydraulic turbines. PATs are hydraulic pumps (e.g., axial or radial type) that operate in reverse mode, namely, as a turbine, to produce power. The main advantages of this kind of technology are (i) their large availability of different scales in the market, (ii) low investment cost, i.e., 10–20 times lower than a traditional hydraulic turbine, and (iii) easiness of installation, while one drawback might be their lower efficiency compared to conventional hydraulic turbines. PATs are usually applied in a power range between 5 and 500 kW, and their producibility can be varied by modifying their rotational speed according to the operating conditions onsite, leading to a payback periods (PBPs) of approximately 6 years. In recent years, several studies have been carried out by analyzing this technology to better assess its pros and cons, as well as room for possible improvement. Binama et al. (Contribution 4) investigated the behavior of a PAT from a fluid dynamic point of view, focusing on the flow structure formation mechanism when the impeller rotational speed changes. The results showed a worsening of both flow and pressure fields by increasing the flow rate exploited by the hydraulic machine, but a slight improvement in pressure pulsation levels by increasing the rotational speed of the impeller. Contrarily, the increase in the rotational speed when dealing with part-load operating conditions led to worse results. Kan et al. (Contribution 5) focused on the hydrodynamics of PATs, which have been shown to cause progressive deterioration in inner surface smoothness. This phenomenon leads to an increase in friction losses that affect the overall performance of the hydraulic machine. CFD simulations in an axial-flow PAT have been carried out to address this problem, while the hydraulic machine operates at different operating conditions. The results showed that the wall roughness gradually decreases the head, the mechanical power, and the efficiency of the analyzed PAT due to the axial velocity distribution uniformity and the increase in velocity-weighted average swirl angles. PATs can be used not only for producing/recovering energy in water systems, but also as storage technology. Lugauer et al. (Contribution 6) focused on the operation of a micro-pump storage system from an economic point of view. A custom-built simulation model was based on pump and turbine maps that were either given by manufacturers/other works in the literature, or obtained through similarity laws. In particular, 11 PATs controlled by a frequency converter for various generation and load scenarios were evaluated. The results showed that systems with 22 kW power output and heads greater than 70 m are the most profitable since a levelized cost of electricity (LCOE) of 0.292 €/kWh and total storage efficiency of 42% have been reached.

In addition to energy recovery interventions within distribution networks, the residual water energy content can also be recovered in tap-water systems within buildings (e.g., faucets). In this regard, Chen et al. (Contribution 7) developed a suitable micro-pipe mixed-flow turbine with a 15 mm diameter. This turbine has been designed firstly with CFD, and then the obtained results have been validated with experiments, showing a power output and an efficiency of 6.40 W and 87.13%, respectively, after using a multi-objective orthogonal optimization method to enhance its performance. Such a small device can be used, for example, to power some microelectronics adopted in water distribution lines as digital devices to monitor the performance and the reliability of the network.

Moving to the irrigation systems, there are a lot of weir structures that are used to control the water elevation, water velocities, etc., thus representing an energy waste in terms of unexploited potential. The installation of a hydraulic turbine in this kind of system, in addition to performing the same task of the weir structures previously mentioned, allows recovering energy, thus contributing to distributed energy production. Therefore, a two-fold advantage could be achieved by both controlling the natural water flow and also recovering unexploited hydraulic energy potential. Cassan et al. (Contribution 8) studied a hydrostatic pressure wheel capable of regulating flow discharge and water height in open channels, and elaborated a model of the water depth–discharge–rotational speed relationship that considers the different energy losses present in the turbine. Experimental tests were made to calibrate the head loss coefficients before the hydraulic machine was installed in a real application. Finally, the wheel was able to achieve the goals of both water level regulation and energy recovery, and can be described as simple, robust, and environmentally friendly.

Nevertheless, the use of turbines is not the only solution for improving water systems; indeed, besides the optimal management of water supply systems through variable-speed pumping stations that has been studied by Drăghici et al. (Contribution 9), there are water networks all over the world that are subjected to considerable water leakages due to the limited maintenance of both supply and distribution pipelines. Just to give an idea, the World Bank (WB) estimates the average value of non-revenue water at 25–30%, which is due to water losses [5]. In addition to the loss of an important life source, water leakages also lead to economic losses: to limit them as much as possible, smart meters are a suitable solution for achieving satisfactory results in terms of both water, energy, and economic savings. A smart meter records the water consumption and provides information to both suppliers and end-users, such as water quality and temperature. Furthermore, smart meters monitor the supply network in real-time, and are highly responsive in detecting issues in the network such as leaks. Water distribution networks can be then divided into sub-branches where a fixed number of smart meters are installed, thus facilitating the control of these sub-networks. This division is called district metered areas (DMAs), and allows companies to check zones where water leakages, both physical (e.g., inside the water network and on the residential side) and apparent (e.g., authorized and unauthorized consumptions), might appear. Bonthuys et al. (Contribution 10) focused on the study of leakage reduction in a water distribution system located in Stellenbosch (South Africa), and a genetic algorithm was used to identify and optimize the location and size of hydro-turbine installations for energy recovery purposes. Both energy recovery installations and pipe replacements showed a reduction in leakage of up to or more than 6% by replacing 10-year-old pipes.

As deeply analyzed and discussed in this Editorial, several topics in the small-scale hydropower sector are of great interest for pursuing the goal of a more sustainable relationship with the environment. The goal of this Special Issue entitled *"Small-Scale Hydropower and Energy Recovery Interventions: Management, Optimization Processes and Hydraulic Machines Applications"* was to collect the most important contributions from experts in this research field and to arouse interest in the scientific community towards a better understanding of what might be the main key aspects of the future hydropower sector. Indeed, the Guest Editors are confident that the Special Issue will have an important impact on the entire scientific community working in this research field that is currently facing important changes in paradigm to achieve the goal of net-zero emissions in both the energy and water sectors.

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