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Review

Increasing wind power penetration in autonomous power systems through no-flow operation of Pelton turbines

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ABSTRACT

The integration of wind power in power systems results in a reduction in greenhouse gas emissions. Thus, it has a positive environmental impact. However, the operation of these power systems becomes increasingly complex, owing mainly to random behaviour of the wind.

In the case of island power systems, this problem is even more difficult. The traditional solution is to use diesel generators as an alternative power supply. For a wind-only power supply, an energy storage system is required. If the topography of the island makes possible the use of pumped storage hydropower plants, this is, nowadays, the most suitable energy storage system.

This paper presents a novel method of Pelton turbine operation with no water flow, as a way to provide fast power injection in the case of an abrupt wind power decrease, or a wind-generator trip. This operation mode allows maximizing wind power penetration in a reliable and efficient way. This method has been validated by computer simulations, and will be tested during the commissioning of a combined wind-pumped storage power plant in an autonomous power system, on a small island.

1. Introduction

In all power systems, frequency regulation should be carried out by the system operator, by balancing power generation and power consumption [1]. For this purpose, it is mandatory to have power plants that are easily adaptable to demand requirements. In the case of isolated power systems, frequency regulation is a very difficult problem owing to the small number of generators.

Moreover, in the case of some renewable power sources, such as wind power, it is not possible to supply the whole power demand in a reliable way, as a result of the intermittent behaviour of this type of energy source. Consequently, wind power penetration should be studied carefully [2] and limited, to prevent well-known network problems and incidents.

An additional problem in autonomous island power systems is the time response of the alternative power supply system, because in the case of a steep wind speed reduction, or a wind-generator trip, the power system frequency will drop quickly. To keep the power system in operation and to avoid a complete blackout, load-shedding systems must be installed [3]. When activated, they disconnect some consumers to balance power consumption and generation. As a result, the quality of the electricity supply service is reduced.

This paper presents a new strategy for operating hydropower plants. This strategy, applicable to plants equipped with Pelton turbines, consists of running the hydro generators synchronized to the grid, without water flowing through the Pelton turbines. Steep increase in the power demanded, abrupt wind power decrease or a wind-generator trip are detected upon system frequency drop, and lead to the injectors opening as quickly as possible, providing active power to the grid in the minimum possible time. In this way, power system frequency drop will be reduced, and consumer disconnections should be avoided. So it allows increasing the wind power penetration in a reliable way.

A Pelton unit power increase is limited by the hydraulics of the circuit; mainly the penstock. A negative water hammer occurs in the penstock during a fast opening of the injectors. Therefore, the limitation in the power injection ramp is imposed by the minimum allowable pressure in the penstock. If water pressure drops locally below vapour pressure, cavitation appears [4]. The development of

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a cavitation volume, resulting in a so-called water column separation, is followed by a collapse, leading to high pressure peaks that may load the hydraulic system structure severely, compromising system integrity.

Section 2 presents a brief overview of wind power integration, especially in small isolated power systems. Then, Section 3 presents the methodology, describing the low-pressure problem related to Pelton turbine steep power ramps, the principles of the proposed operating strategy for Pelton turbines and the computer model. Section 4 describes briefly a combined pumped storage-wind power plant where this new method of Pelton turbine operation will be tested. Its data have been used for the simulations. Section 5 analyses the software simulations of the proposed system. And, finally, Section 6 concludes with the main contributions of the proposed strategy.

2. State-of-the-art wind power integration

Large-scale integration of wind power generation is problematic, especially in small autonomous power systems.

To increase wind power penetration in such isolated power systems in a reliable way, it is important to have good wind-power forecasting [5] for the correct planning and operation of the power system [6].

However, even with a good wind-power forecasting system, it is essential to have an alternative power supply system for balancing generation and consumption, especially in low wind periods. In some cases, flywheels [7] or a battery energy storage system (BESS) [8] could be used as energy storage systems. There are other methods based on compressed air energy storage (CAES) [9], hydrogen fuel cells [10], or even ultra-capacitors [11]. Also, the combined use of several renewable energies and storage systems has been considered [12,13].

Nowadays, thanks to its larger capacity and its high efficiency, pumped storage hydropower plants are more suitable for this type of application, particularly in the case of high wind-power penetration [14].

A critical factor in island autonomous power systems is the time response of the alternative energy power supply system. Owing to the small number of generators, if a disturbance such as a wind-generator trip appears, the system frequency would fall quickly requiring a fast power injection to avoid load-shedding.

The time response of hydropower plants depends strongly on the hydraulic system layout and on the electro-mechanical equipment. There are several possibilities to improve the time response of pumped storage power plants, such as 3-machine-type [15] or variable speed operation [16].

The 3-machine-type combines an electrical machine, a pump and a turbine in the same shaft, with the same rotating direction. This configuration allows continuous power regulation in pump mode, and changing between pump and turbine operation modes in a shorter time.

In high-head hydro-pumped storage projects, and especially in the small power range, using two different hydraulic machines—Pelton turbines and high pressure pumps—coupled with two different electric machines, synchronous and asynchronous respectively, is a usual configuration [17]. This 4-machine-type allows the use of standard equipment, more easily available than tailor-made high-head pump-turbines. In addition, it is a more flexible arrangement than any other configuration, even the well-known 3-machine type.

Other important factors to take into consideration in this type of power stations are operating policies [18] and economic analysis [19].

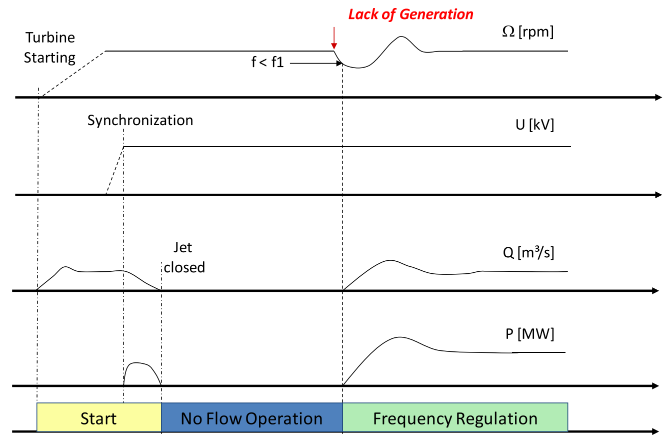

Fig. 1. Pelton turbine operation modes.

3. Methodology

3.1. Problem of fast load increase in hydraulic turbines: the negative water hammer

In all hydropower plants, a change in the plant operating point implies a flow change in the turbines and in the penstock. This flow change is achieved by a fast transient in the penstock. This transient produces oscillations, not only in the flow but also in the pressure. The actual pressures reached depend on the penstock characteristics, and their associated risk increases when the rated head increases.

Pelton turbines are used for high-head hydropower plants. Thus, hydraulic transients in these plants are critical and should be carefully addressed. The usual way to dampen transient pressure fluctuations is to increase the opening and closing time of the injectors. Thanks to the deflectors, these times are larger in Pelton turbines than in other hydraulic turbines.

The deflectors allow the deviation of the jet from the runner. They can be used during normal operation to achieve a fast reduction in the output power [20]. However, there is no device that performs a similar function when the output power must be increased quickly. The speed at which generated power rises depends on the opening time of the injectors, which is limited to prevent transients in the penstock. From the power response point of view, it should be as short as possible, but other considerations must be taken into account, to avoid cavitation problems.

Indeed, every increase in the flow is accompanied by a decrease in the pressure at the penstock: the negative water hammer. During transients, the pressure oscillations depend on the rate of flow change: a larger rate implies larger pressure oscillations. Therefore, a fast increase of flow could lead to negative transient pressures on some point of the penstock; penstocks may collapse under negative pressures. Also, low pressures could produce cavitation. Cavitation means the separation of the water column when the vapour pressure is greater than the pressure in the water conduit. The pressure peaks that appear when the vapour cavity collapses may reach amplitudes several times greater than the maximum amplitude of a direct water hammer. Therefore, for the penstock, the opening time of injectors should be as large as possible.

From the above description, it is obvious that the limiting element of the power generation ramp, in this type of hydropower plant, is the penstock.

3.2. No-flow operation of Pelton turbine-driven generators

In this paper, a new method is proposed to reduce the time needed to generate power in Pelton turbine-driven generators. This