PUMPED STORAGE HYDROPOWER PLANTS MODELING IN THE POWER SYSTEMS RESEARCH

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Abstract

Renewable energy sources (RES) will play an essential role in the future of the power systems because they can provide several benefits including reducing dependency on the fossil fuels market e.g. oil and gas and their price fluctuations, reducing emission of greenhouse gases, and climate change improvement. Among different RESs technologies, highest share in the electricity production belongs to the hydropower systems which can be divided into the three main categories: run of river, storage, and pumped storage. In this paper, important techniques for modelling the pumped storage hydropower plants are presented and compared with simulation results in the MATLAB/Simulink program. According to the results, selecting proper modelling technique depends on the aim and outlook of the study. Finally, a powerful laboratory setup named power hardware in the loop (PHIL) system as a very useful laboratory equipment for power systems studies is explained for verifying the simulation results and analyzing the real electrical quantities instead of pure simulation study.

Introduction

Global warming and climate change are very important topics in the current century. Increasing the population and developing process lead to higher energy consumptions. Fossil fuels (oil, gas, coal) are main sources of energy production at the moment and they provide a large amount of CO_2 which is one of the famous greenhouse gasses. These gasses are responsible for global warming, air pollution, and climate change. Therefore, one possible way to control climate change and its effects is reducing emission of the greenhouse gasses. It means that clean and renewable energy sources have to be used instead of fossil fuels to provide energy in different areas. In the power systems, experts try to increase the share of RESs in the electricity production. Famous RESs in the power systems are hydropower, wind, and photovoltaic (PV) systems which have different benefits and challenges for the power systems. For instance, wind and PV systems can cause uncertainty in the power systems since they are dependent on weather conditions. However, hydropower, specially, pumped storage hydropower (PSH) plants are reliable RESs and they will play a vital role in the future power systems. Figure 1 presents the share of RESs in the electricity market in 2019 [1]. According to international energy agency (IEA), electricity production from hydropower will increase from 4333 TWh in 2019 to 5722 TWh in 2030 [2]. Hydropower has many advantages such as clean and renewable source of energy, flexibility, reliability, energy storage and backup source (green natural battery) to support uncertainty of wind and PV, and multi-functional applications including water management, irrigation, water supply, flood control, recreation, and transportation).

Hydropower can be divided into three categories: run of river, storage, and pumped storage hydropower (PSH) systems. In the run of river and storage systems, water flow and also energy conversion (mechanical energy to electrical energy) are unidirectional, however, pumped storage units have bidirectional water flow in addition to bidirectional mechanical-electrical energy conversion. In other words, when PSH unit works in pumping mode, it receives electrical power and convert it to mechanical power to pump the water; and when it works in turbine mode, it provides electricity from water energy. One drawback of conventional PSHs is that they need several minutes to be ready to connect to the power systems, or changing the pump-turbine mode. However, with the new technology achievement as variable speed (adjustable speed) PSH, it is possible to reduce the preparation time of these units to one minute which enables us to use them for crucial tasks such as fast transient response, very fast

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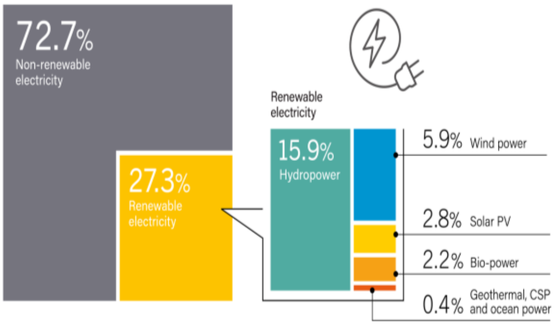

Figure 1: Estimated renewable energy share of global electricity production in 2019 [1].

power provision for the grid. Moreover, variable speed PSHs have higher efficiency for large head variation and also, they need less maintenance, have less cavitation and longer life span. The global PSH installed capacity in 2019 was 158 GW and it is predicted to be 240 GW by 2030 [3].

In the hydropower systems, turbine has a significant role. Generally, turbine is a mechanical equipment which provides rotational movements from kinetic or potential energy of the water. Table 1 shows turbine types and their subcategories and applications based on the available head [4]. Among these turbines, Francis and Pelton turbines are more common in PSH applications. Another important equipment of the PSH unit is the electrical machine which can work as a motor and generator in the pumping and turbine modes of PSH unit, respectively. The most common electrical machine in the conventional storage and PSH units is electrically excited synchronous machine (EESM) which has several benefits such as controlling the output terminal voltage and reactive power exchange, in addition, this type is suitable for variable speed PSH units, as well. Besides, doubly fed induction machines (DFIM) are well-known electrical machines in variable speed applications such as wind and variable speed hydropower plants. In recent years, hydropower industry pays more attention to variable speed PSH units since they can be promising technology for the future power grid based on high share of RESs. According to the International Hydropower Association (IHA): "*No country has come close to achieving 100 % renewables without hydropower in the energy mix*" [5]. To conduct research on the PSH, it is necessary to consider a reliable and exact model to gain more realistic results from simulation and calculations. In the power systems field, there are standard models for dynamic studies of electrical equipment such as electrical machines, transformers, transmission lines. Then it is important to implement a proper model for hydraulic parts regarding the purpose of the investigation to achieve an accurate outcome. Consequently, two main models for penstock and waterway are presented and their differences are compared afterward.

Table 1: Classification of hydropower turbines [4].

Head classification	***Impulse***	***Reaction***	***Gravity***
High (>50 m)	• *Pelton* • *Turgo*	• *Francis*	
Medium (10-50 m)	• *Crossflow* • *Turgo* • *Multi-jet Pelton*	• *Francis*	
Low (<10 m)	• *Crossflow* • *Undershot Waterwheel*	• *Alden* • *Propeller* • *Kaplan* • *Francis* • *Bulb* • *Straflo* • *Free-flow*	• *Overshot Waterwheel* • *Pitchback Waterwheel* • *Breastshot Waterwheel* • *Archimedes Screw*

The rest of this paper presents modeling approaches for dynamic of penstock and waterway. Then simulation results and discussion regarding modelling technique is presented. Finally, conclusion and future steps to improve and compare the simulation results with real quantities are explained.

References

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