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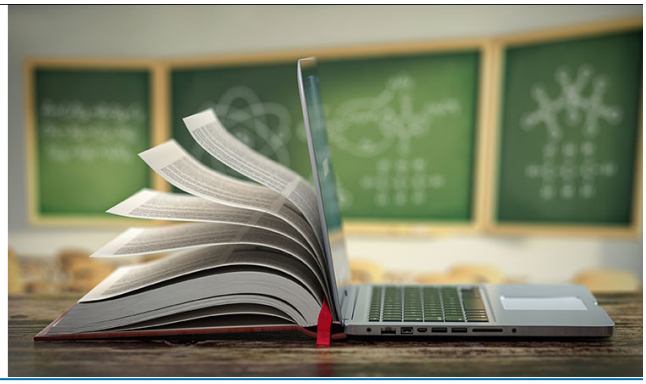
To cite this article: Weijia Yang *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **774** 012151



IOP Conf. Series: Earth and Environmental Science **774** (2021) 012151 doi:10.1088/1755-1315/774/1/012151

An experimental platform of variable speed pumped storage unit under wave disturbance: introduction and preliminary progress

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Abstract. The importance of pumped storage plants (PSPs) is continuously increasing in power systems with more and more variable renewable energies. For the research and development of PSPs, variable speed technology and sea-water PSP are two important new orientations. In this paper, an experimental platform of variable speed pumped storage unit under wave disturbance is introduced. The purpose of the platform is to study the design and operation mechanism of variable speed PSP based on various common technical problems, especially for the four aspects: transient processes, variable speed unit, coordination control, wave disturbance. The platform adopts a Chinese sea-water PSP in feasibility stage as the prototype, and a model scale of 1:4 is applied. It consists of nine sub-systems, including waterway system, variable speed reversible model unit, circulating water system, speed governor system, AC excitation and electric protection, coordination control, monitoring system, intelligent AC load and measurement system. The model unit contains a reversible pump turbine, a doubly fed induction machine, etc. The speed variation range is ±8%, and the rated power is 78.13 kW. The model runner meets the IEC standard with a reference diameter of 284.3 mm. The upstream water tank is a closed pressure tank that can adjust the pressure and discharge. The downstream water tank is an open water tank that can simulate wave level fluctuation. Regarding the control system, it has four core parts: local control unit, speed governor, converter and coordination controller. The experimental study content contains three key aspects: (1) performance validation for variable speed unit; (2) operating stability under complex disturbances; (3) capability of variable speed PSP during transient processes. The experimental study based on the platform aims for laying a theoretical and technical foundation for the follow-up construction and operation of real sea-water PSPs with variable speed units.

1. Introduction

The importance of pumped storage plants (PSPs) is continuously increasing in power systems with more and more variable renewable energies. For the research and development of PSPs, variable speed technology [1] and sea-water PSP [2] are two important new orientations. In this paper, an experimental platform of variable speed pumped storage unit under wave disturbance is briefly introduced.

Regarding the model experiment facilities for hydropower generation and pumped storage, currently there are mainly three types, as condensed below. (1) Hydraulic machinery model: Various hydraulic machinery model test rigs are developed by different hydraulic machinery manufacturers, universities and research institutions, e.g. in [3, 4]. (2) Waterway system model in many labs of hydraulics in different countries, e.g. in [5, 6]: this kind of model methodology replaces the turbine/pump turbine with a valve, ignoring the hydraulic machinery property: mainly studies the impact of the waterway subsystem in hydropower plants on the safety operation during the transient processes. (3) Hydroelectric generator (AC machine) model, e.g. in [7, 8]: the emphasis is on the characteristics of electric machines.

Based on the three types of model experiment methodology, numerous meaningful study results are achieved. Specifically, for variable speed pumped storage units, interesting experimental studies are conducted, e.g. the works in [9-14]. Meanwhile, the operation and control of hydropower system is complex with the "hydraulic-mechanical-electrical" coupling mechanism, and ignoring any of these subsystems will adversely affect the experimental study results. Each type of the above model test rig mainly focuses on one aspect, inherently ignoring or simplifying the influence factors. Hence, the research and development of an experimental platform which includes the "hydraulic-mechanical-electrical" coupling subsystems is necessary. Therefore, an experimental platform is recently in development, and its preliminary progress as well as the experimental study plan are briefly presented in this paper.

In Section 2, the overall introduction and preliminary progress of the experiment platform is shown. In Section 3, the experimental study plan is introduced. The summary is given in Section 4.

2. Introduction on the experiment platform

The experimental platform of variable speed pumped storage unit under wave disturbance is in the experimental hall of pumped storage plants of the State Key Laboratory of Water Resources and Hydropower Engineering Science of Wuhan University, and it is located in the suburb of Wuhan, China. The photo and illustration of the experiment platform are presented in Figure 1 and Figure 2, respectively, and the nine sub-systems of the experimental platform are listed in Table 1. The information of the experimental hall also can be found in [15, 16], and it is worth noting that the experiment platform in this work is a new one, different from the "experiment platform for transient processes of pumped storage plants" in [15, 16].

Table 1. Nine sub-systems of the experiment platform.

No.	Sub-systems	Descriptions
1	Waterway system	Based on a 10 MW real power plant with a scale of 1:4, including upper and lower reservoirs, pipelines, branch pipes, a tailrace surge tank, etc., and the two units shared the common pipeline.
2	Variable speed reversible model unit	Including reversible pumped turbine, DFIM, bearing and shaft system, supporting platform, etc.
3	Circulating water system	Providing circulating water for the model experiments
4	Speed governor system	Enabling various operation and control modes for the model pumped storage units

5	AC excitation and electric protection	Variable frequency AC excitation, including machine control and protection, etc.
6	Coordination control	Coordination control between governor and converter based on efficiency optimization
7	Monitoring system	Including local control unit, upper computer, command desk, etc. for synchronization, operation and switch between operating modes
8	Intelligent AC load	Controllable R-L-C load for simulating isolated grid feature
9	Measurement system	Measurement, collection and post-processing for various physical quantities

Figure 1. Photo for part of the experiment platform of variable speed pumped storage unit under wave disturbance.

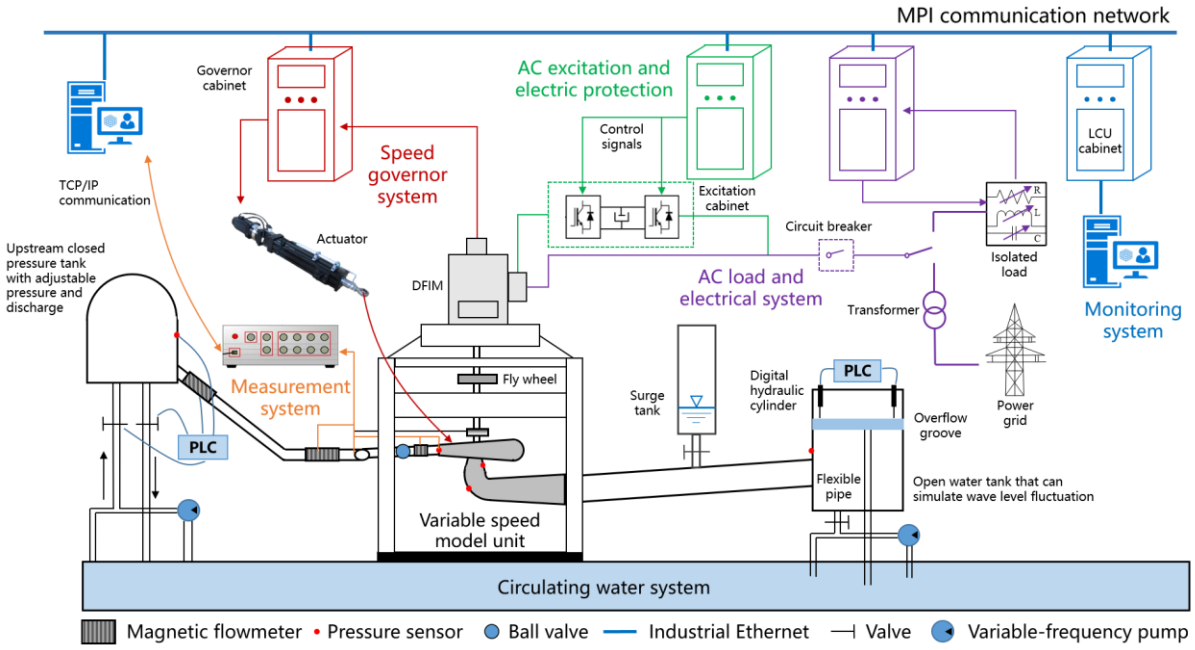

Figure 2. Illustration of the experiment platform.

The purpose of the platform is to study the design and operation mechanism of variable speed PSP based on various common technical problems, especially for the four aspects: transient processes, variable speed unit, coordination control, wave disturbance. The platform adopts a Chinese sea-water Variable speed pumped storage plant (VSPSP) in feasibility stage as the prototype, and a model scale of 1:4 is applied. Several featured parts of the experiment platform are introduced below.

2.1 Waterway system

For the prototype VSPSP, the upper reservoir is a manual excavation reservoir with a normal water storage level of 124.2 m; the lower reservoir of the power station is the sea, the normal water level is 0 m, the highest tide level is 3 m, the lowest tide level is -2 m, and the tidal variation range is 5 m. The total length of the waterway system is 806 m, of which: the length of the water diversion system is 357 m and the length of the tail water system is 449 m.

For the model waterway system that is designed according to the scale of 1:4, based on the prototype plant, the pipeline system is composed of upstream pipelines, downstream pipelines, steel frame support, stairs and reinforced concrete foundation, etc. The length of the up-stream pipeline and down-stream pipeline is 89.25 m and 111.25 m respectively.

The upstream water tank is a closed pressure tank that can adjust the pressure and discharge. The maximum pressure is 70 m, the maximum discharge is 0.6 m^3/s, and the volume is 40 m^3. In order to adjust pressure and flow flexibly, the variable frequency pump, pipeline valve and overflow valve are adopted for comprehensive adjustment, and two electromagnetic flowmeters and several pressure sensors are configured. Through a programmable logic controller (PLC), the automatic adjustment function of pressure and flow can be realized. The 10-meter pressure variation can be achieved, and the sinusoidal and random fluctuation of the upstream water level can be simulated.

The downstream water tank is an open water tank that can simulate wave level fluctuation. The adjustable range of water level is ±0.25m, and the highest frequency is 0.1Hz. The flow-stabilizing device is driven by 4 digital cylinders, connected to the water tank through 4 sliders and a corrugated rubber tube. Sinusoidal fluctuations and random fluctuations can be realized with a PLC.

The model surge tank is applied to validate the effect and characteristics of the surge tank in the operation of seawater pumped storage power plant, and study the influence of water level fluctuation on the operation of variable speed unit. For the model surge tank, the height and diameter are 7.63 m and

1.74 m, based on the geometric scale. A plate valve is installed at the joint of surge tank and the tail-race tunnel, and the working conditions with and without the surge tank can be simulated by opening and closing the plate valve, respectively.

2.2 Variable speed reversible model unit

The variable speed reversible model unit is developed according to a series of parameters for the prototype, such as the rated head, the range of the water head, the range of the specific speed coefficient *K* and the efficiency, etc.

Model unit contains the reversible pump turbine, the doubly fed induction machine, thrust bearings and shafting, etc. The model pump turbine includes volute, socket ring, fixed guide vane, head cover, movable guide vane, runner, bottom ring and draft tube, etc. The speed variation range is ± 8%, and the rated power is 78.13 kW. The model runner meets the IEC standard with a reference diameter of 284.3 mm, and the number of runner blades is 7. A specific fly-wheel is installed to provide inertia of the model unit, and it can be disassembled flexibly to adapt to different model scales.

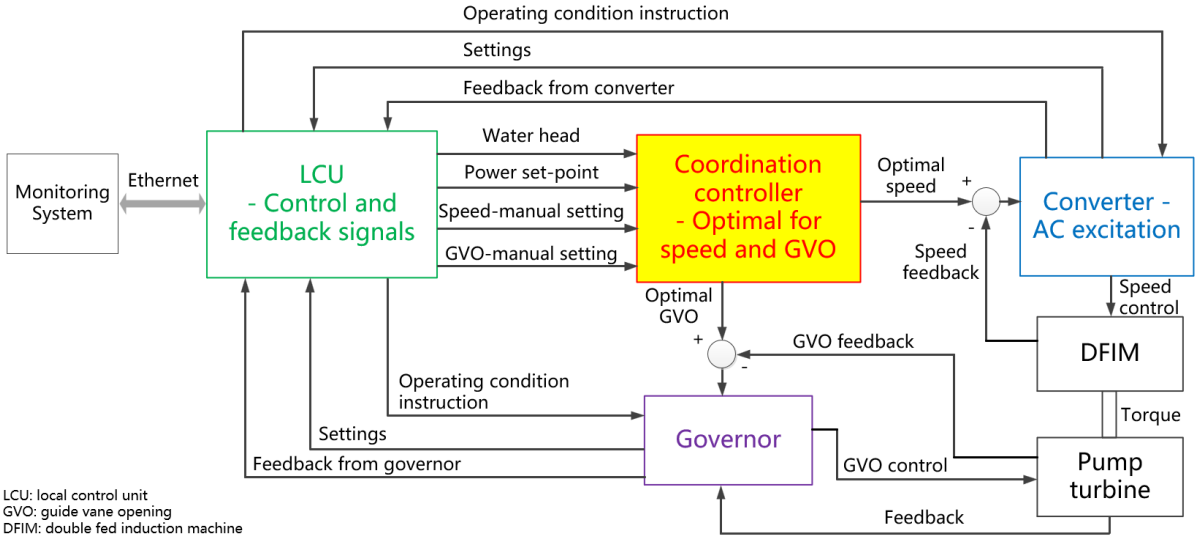

Figure 3. Overall block diagram of the control system.

2.3 Control and electrical system

For the variable frequency AC excitation, the three-level voltage source converter is adopted. Two operating modes are included: i.e. grid-connection and isolated operation. The generating condition can be connected with the large power grid and isolated load device respectively; the power for pumping condition is supplied by the large grid. Electrical protection and mechanical protection are included.

Regarding the control system, it has four core parts: local control unit (LCU), speed governor, converter and coordination controller, as shown in Figure 3. The LCU mainly sends operating instructions and displays feedback signals. The speed governor mainly operates in opening control for pump turbine, and could also act as regular governor for various regulation modes. The converter and AC excitation system is for the excitation, speed regulation, synchronization, power control, and self-start-up of pump. A very important part for controlling the variable speed unit is the coordination controller, which is for the coordinated operation between the governor and the converter; a core aspect is the optimization algorithm for the optimal speed and optimal guide vane opening. The coordination controller is specifically introduced in another paper in this symposium.

3. Experimental study plan

For the four key common technical problems stated above, i.e. transient processes, variable speed unit, coordination control and wave disturbance, the planned experimental study content contains three key aspects, as follows.

(1) Performance validation for variable speed unit: including the performance validation of speed variation, power generation during generation, power regulation during pumping and efficiency performance, etc.

(2) Operating stability under complex disturbances: including disturbances of frequency, power, voltage and wave, etc.

(3) Capability of variable speed units during transient processes: including transient process of small-disturbance conditions, large-disturbance conditions, start-up condition and the coordination control for converter and governor, etc.

4. Summary

In this paper, preliminary progress and brief information of an experimental platform of variable speed pumped storage unit under wave disturbance is introduced, and the planned experimental study content is shown. The experimental study based on the platform aims for laying a theoretical and technical foundation for the follow-up construction and operation of real sea-water PSPs with variable speed units.

Acknowledgements

The authors thank the support from the National Key Research and Development Program of China (No. 2017YFB0903700) and the National Natural Science Foundation of China (No. 51809197, No. 51879200).

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