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IMPROVED WIND ENERGY PENETRATION IN AN GRID CONNECTED POWER SYSTEM BY WIND PUMPED STORAGE HYDROPOWER PLANT

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ABSTRACT

Using pumped storage system in a power system is one of the ways to raise the wind energy penetration. The combination of hydro power(pumped storage energy system)with wind generation to improve the performance of overall hydro generating system, by providing continuous pumping of water from tail race to dam. The required amount of power for pump is given by means of wind generation and excessive power is fed to power grid. The challenge and possible structure of the system is presented. The system generates the power from wind and hydro pumped storage is fed to an utility grid system. When demand of electricity is high water is released into lower reservoir to generate the electricity When the demands for electricity is low the pumped storage facility stores the energy by pumping water from a lower reservoir to an upper reservoir.

Keywords- grid connected system; pumped-storage; wind energy

1. INTRODUCTION

The power regulating capability is needed for a grid when a fluctuating energy is to be integrated into it. In order to increase significantly the share of renewable energy sources, additional energy storage will be considered. Among several kinds of energy-storage technologies, pumped- hydroelectric storage can be the technically more mature and economically viable alternative [1, 2].

Wind-pumped storage power stations have been the subject of many publications in recent years and being considered for implementation, most of which function for the peak clipping, valley filling of the power demand of a grid, as well as for reducing the variability of the wind energy when they, as adjustable load, are connected to a grid together with wind turbines [1-12]. However, there are hardly any reports about the stand-alone operation of a system comprising of wind energy, large water flow pumps and hydroelectricity power generation. As an effective way to exploit wind energy on the islands, after the integration of wind power has reached to its maximum value, wind-pumped storage power station can be built to transform the variable wind energy into the conventional hydroelectricity power, in this way to increase the generation capacity of grid connected with a stable power source. This paper will focus on discussing the power balance in the grid connected system. There are three challenges to compose of a grid connected wind-hydro-pumped storage station: 1. Stability of a stand-alone system consisting of wind turbines and pumps; 2. Proper allocation (capacity ratio) of wind turbine water pump reservoir and hydroelectricity generator, and efficiency and economy of the system; 3. Control and dispatch of the wind-driven pumped storage hydropower plant when connected to the grid. Discussion in this paper only acts as a foundation for the research.

The challenge for power balance in a wind driven pump storage system is whether or not the power regulation range of pumps may cover the fluctuation range of wind energy for a given head lift and a certain flow. This paper will start with the discussion of the pump and the pipe system, and then put forward the main problems and possible structure of the system under the condition of variable wind energy as an electric power source. The system feasibility will be discussed under the consideration of wind, rainfall data and capacity reservoirs.

2. CONFIGURATION OF WIND-HYDRO-PUMPED STORAGE STATION

The proposed system is composed of wind turbines, pumping systems, reservoirs, hydroelectricity generator and a control unit, which is shown in Fig. 1. In order to assess the fluctuation of wind power, the pumping system should operate at variable speed. Considering the operational range, efficiency, lift head and water flow, the centrifugal pumps are more suitable for this kind of pump-storage. The regulating performance of a pump system and the system configuration will be shown as follow.

A. *Characteristics of Pipes*

Relation between the flow, q_v , and the head lift, H_c ,of a pipe for transporting liquid can be expressed as

$$H_c = H_{stat} + kq_v^2 \tag{1}$$

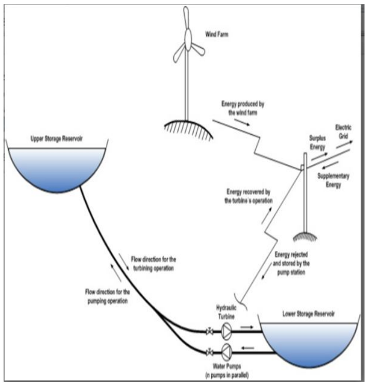


Figure 1. Basic structure of Wind-Hydro-Pumped Storage Station

Where, H_{stat} is the lifted height, i.e., the static head, and k is the frictional factor of the outward pipes of the pump, which depends on the material and the diameter of a pipe. The $H_c - q_v$ curve is shown in Fig. 2. The curve will becomes steeper with increased resistance of the pipe. Under the condition of the same diameter and material of a pipe, the water flow of the pipe is proportional to the head lift. If the characteristic curves of pipes are different, a relatively large flow variation will cause small variation in the head lift for a pipe with a flat curve. Meanwhile, small variation in the flow will causes large change in the head lift for a pipe with a steep curve.

B. *Characteristics of Pumps*

For a certain rotational speed (n), a flow of a pump has a corresponding head lift (H), shaft power, i.e., the input power of the pump (p_{sh}) and efficiency (η), and the flow and the head lift are inverse proportional to each other. The $H - q_v$ curve of a pump and the $H_c - q_v$ curve of a pipe have a crossing point, which is the operation point of the pump, as shown in Fig. 2. When water is transported, the shaft power of a pump can be expressed as Eq. (2).

$$p = \frac{\rho g H q_v}{\eta_p} \tag{2}$$

Considering the pipe's characteristic and the electro-mechanical efficiency, the electrical power and the flow have a relation given as [7]

$$P = \frac{\rho g q_v (H_{stat} + kq_v^2)}{\eta_p \eta_m \eta_t} \tag{3}$$

Where, ρ and g are the water density and the gravitational acceleration (9.81 m/s^2) respectively, and η_p, η_m, η_t are The efficiencies of the pump, driving motor, transformer and power transporting lines, respectively.

The $H - q_v$ curve of a pump changes with the rotational speed (n), resulting in a new operation point when the new

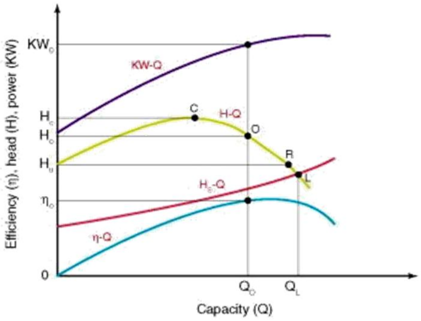


Figure 2. Characteristic curves under different rotational speed of a pump

curve intersects with the curve of the pipe, and consequently the pump's head and flow also change. If the speed changes in a small area (less than 20% of its rated speed), the change on the efficiency of the pumps and the pipe characteristics are slightly [10]. Therefore, to ensure the head lift varies within a limited range, the speed regulation range must also be limited.

The head lift is proportional to the square of the speed, $H = f(n^2)$, and the flow is proportional to the speed, $q_v = f(n)$, and thus the input power to a pump is proportional to the cube of the speed, $P = f(n^3)$.

The $H - q_v$ curve's slope is related with the designed equivalent speed. A small variation of head lift results from a large variation of the flow with a small slope. In conclusion, the pumps suitable for the wind-pump storage should have a flat curve, large speed regulating range and high efficiency, especially the power range with high wind energy density. The characteristics of a pipe (mainly the selection of diameter) are also important and should be matched.

To increase the system flow, multiple pumps of the same ratings may be used in a parallel manner to pump fluid to the same outward pipe. Ideally the total flow equals to the sum of each individual pump, while the head lift remains unchanged. However, for the same pipe's characteristics, due to the water resistance change caused by the variation on flow, the parallel operation does not bring about the multiplication of the total flow, and also the head lift will somewhat increase. Nevertheless, parallel operation with large number of pumps is not economic. Normally a parallel number of two is considered as appropriate.

C. Wind-pumped Storage System

1) Wind Turbine: For off-grid operation, a variable-speed wind turbine with direct-drive permanent-magnet synchronous generator is one of effective alternatives. The capacity of wind turbine can be determined in terms of wind data, capacity of reservoirs and rainfall.

2) Pumps and its control: As shown in the above analysis to the operational characteristics, input power of the pumps may be adjusted by adjusting the rotational speed. For the variable wind energy input, the input power and the output power may reach a balance through the variable frequency speed regulation. Limited by the speed regulation range, a single pump is not suitable for wide range fluctuation, and therefore we can choose several groups of pumps. A group of pumps consist of two pumps in parallel. First, choose the rated power of pumps in the first group to be 1/2 $P_{W\,\max}$ and then choose another pump groups for the rest fluctuation range of wind energy.

Every pump is driven by a squirrel cage induction machine, which is controlled by a variable frequency converter. Controller should adjust the speed of pumps and switch between the pump groups according to the wind power.

3) System connection: Multiple groups of pumps may be electrically connected in parallel at the electric source. When the wind farm is far from the pump station, a transformer is needed to boost the voltage. The system schematic is given in Fig. 3.

D. Control of Water Level of Reservoirs

Energy balance is very important in the stand-alone system. The wind energy must be absorbed by pumps and then transform to water inflow of high level reservoir effectively. The water volume of reservoir can be write as,

$$V_r = V_P + V_{rf} - V_T \tag{4}$$

Where the volume of pumped water is $V_p = f Q_p \cdot t$, rainfall is $V_{rf} = f Q_{rf} \cdot t$ and the volume outwards to water turbine is $V_T = \underline{\geq}_0^t Q_T\,dt$.

The problem is to find out maximum Q_T under the constraint $V_{r\,\min} \le V_r \le V_{r\,\max}$ and the water volume of low reservoir is large than a given minimum value.

A. System Description

1) Power system: Capacity of the isolated power system is about 101.88MW (276GWh a year), in which 60% is thermoelectric, 35% is hydroelectric, and 5% is wind power. The minimum load of the system is in the range of 14MW,

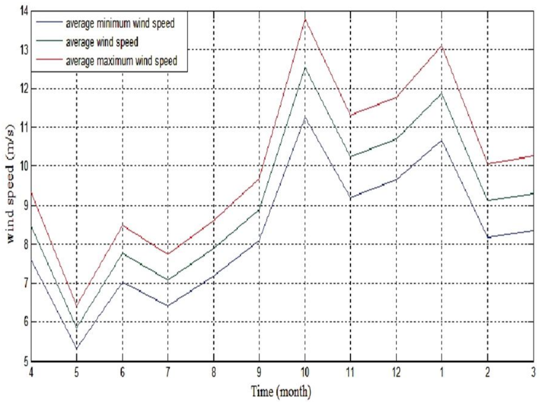


Figure 3. Average w speed curves in a year

while the maximum load can reach 70MW. It has been proved that the maximum integration of wind power is 12MW. But the demand is to increase the percentage of sustainable energy further.

2) Reservoirs: There are two reservoirs. The lower reservoir is at 107 meter above sea level while the high level reservoir is at 347 meter above sea level. The max volume of the low level reservoir is $2.1 \cdot 10^6$ m³ and the dam height is 23 meter, while the max volume of the high level reservoir is $4.1 \cdot 10^6$ m³ and the dam height is 12 meter.

3) Conditions of wind and rainfall: The wind energy of the island is comparative abundant. Real annual average wind speed derived from 10 minutes mean-values is shown in Fig. 4, including the mean value, the mean maximum and minimum value of wind speed. The density of wind energy is shown in Fig. 5.

Rainfall for every day in the year in the collection area on both reservoirs can be seen in Fig.6-7. It is shown that the inflow received by low-level reservoir is larger than high-level reservoir.

A 10 MW wind -pumped storage system will be built on the island in this case. The wind power from one 2MW variable-speed wind turbine, such as XEMC Windpower -XE87-2000, is shown in Fig.8. The cut-in speed of the wind turbine is at 3 m/s, and the wind speed for rated operation is between 11 m/s, while the cut-out speed is 25 m/s. The capacity factor is more than 56%. It can be seen that the wind power is larger around February and October, and is small from the middle of April to July

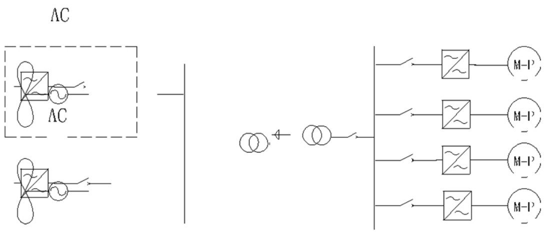


Figure 4. AC system schematic

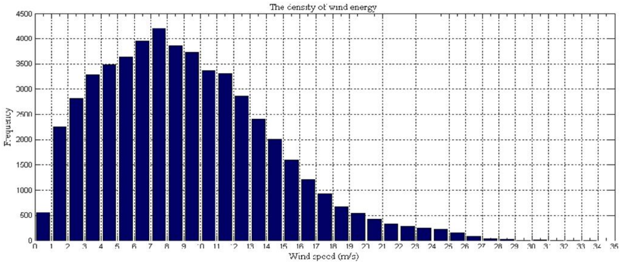


Figure 5. The density curve of wind energy in a year

3. SIMULATION STUDY

Sim Power Systems and other products of the Physical Modeling product family work together with Simulink® to model electrical, mechanical, and control systems. SimPower Systems operates in the Simulink environment. Therefore, before starting this user's guide, you should be familiar with Simulink. For help with Simulink, see the Simulink documentation Or, if you apply Simulink to signal processing and communications tasks (as opposed to control system design tasks), see the Signal Processing Block set documentation

Simulink uses MATLAB as its computational engine, designers can also use MATLAB toolboxes and Simulink block sets. Sim Power Systems and Sim Mechanics share a special Physical Modeling block and connection line interface.

The designed wind-pumped storage station can be controlled to operate either as a conventional hydroelectric power or as a large storage unit to pitch peak, and three modes of operation will be discussed as following:

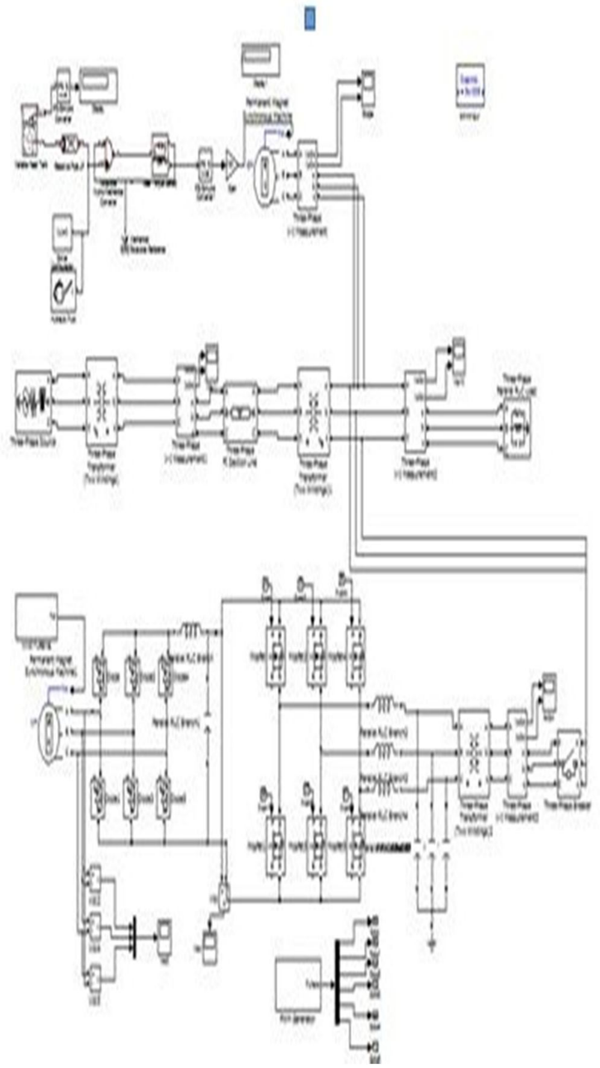
In mode 1, hydroelectric generator in wind-pumped storage station generates electric power continuously all the day in a year. It works like a conventional hydroelectric generator. The pumping water goes through another tube so wind-pumped isolated system can operate all the day as long as there is wind. According to the wind power, rainfall, control strategy of pump groups addressed above, the volume of inflow of high-level reservoir can be calculated. Using the water level control strategy presented in section II, the reasonable hydroelectric power produced by pump storage station and the water volume in the reservoir

Hydro turbine and generator are about 90% and 96% respectively, converter and transformer is 98%, average efficiency of pumps is 85%. Then it would be found from simulation result (Fig. 9) that the power generated is 4003.104kW from April to the medium of September (from 1h to 4099h), 6491.52kW from medium of September to the end of December (from 4100h to 6399h) and 5458.557kW from the end of December to the end of march next year (from 6400h to 8760h).

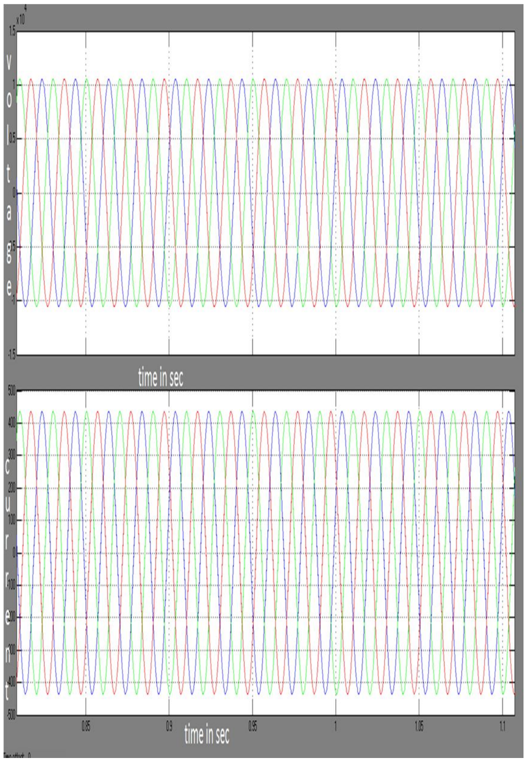
When a reversible hydro turbine is chosen, the Structure of the system. In this case, water pumping and electric generation can not assess at the same time. If we also choose the generator operate 8 hours in a work day, the pumping time is then 16 hours, mainly during night.

Assume the wind-pumped storage plant generates power 8 hours in a work day, from 9:00 am to 17:00 pm, and the other time pumps operate to pump water from the low-level reservoir to the high-level reservoir.

Circuit diagram for Wind Pumped Storage Hydropower Plant



The power production of three operation scenarios in a year is shown in Table1. The percentage of increased wind power integration is also shown. Increasing in wind turbine and rated of hydro turbine can increase the wind integration under the balance of water level of reservoir. Main aspect need to be considered is economic efficiency Output waveform for Wind Pumped Storage Hydropower Plant



The above waveform describes the percentage of increased wind power integration is also shown. Increasing in wind turbine and rated of hydro turbine can increase the wind integration under the balance of water level of reservoir.

5. CONCLUSION

The grid connected system of wind turbines and pumps to ensure the stable operation of the system. it is critical to have the regulating capacity of the pumps to cover the variation range of the wind energy. The penetration of renewable energy is increased with the high reliability, if we use pumped storage power generation system, it eliminates the shutdown of hydro power generation. The existing generation system has an instability problem also it does not generate maximum power. The stable operation of the electrical power system with pump modulating capability is technically feasible. More detailed research mainly by simulation will be needed for design of systems parameters, the evaluation of the system performance and optimal design.

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