Hydro Power Plant Simulator for Control Algorithm Testing

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Abstract

In this paper a design of a hydro power plant simulator for control algorithm testing purposes is presented. In micro, mini and small hydro power plants an asynchronous motor is often used instead of a generator in order to reduce the cost. Therefore the same type of motor/generator is used in our simulator. All the electro-hydraulic control equipment is designed in such a way that it resembles as closely as possible a real power plant. It is therefore ideal for the study of control related problems in hydro power plant applications.

1 Introduction

The energy consumption is steadily increasing worldwide. As human activities are directly related to energy consumption, it can be used as an indicator of economic and social development [1]. It not only contributes directly to improving living standards and eradicating poverty [2], but according to some authors it is also claimed to be the key indicator for both national and international economical development and sustainability of the majority of countries [3].

Electrical energy is considered to be the most desirable form of energy due to the fact that it can easily be transformed to any other form of energy and can also be transferred very fast and efficiently over the grid. There are many studies investigating correlation between GDP and electricity consumption [4]. In the last decades, world electrical energy consumption has significantly increased with a share that has reached 17.7% in 2010 and is predicted to double by 2025 [5]. The vast majority of electrical energy is produced by fossil fuel power plants (67.2% in 2010 [5]). This of course presents an enormous burden to the environment. Therefore there is an increasing tendency to produce electrical energy by renewable sources [6, 7]. It has also been shown that there is a causal relationship between the economic growth and electricity generation from the renewable sources [8].

Hydro power is the most important means of renewable power generation in the world [9]. It provides a little less than 20% of the world's electricity [10]. Although there are some environmental costs associated with hydro powerplants [11, 12] they are in general considered to be environmentally friendly. Compared to other renewable resources like wind power, hydro power plants are maneuverable and can modify their load easily, their production is rather well predictable and depends on the reservoir capacity [9].

Although hydro power can be considered to be mature among other renewable sources of energy and has the slowest growth it is still of enormous importance. There is still a lot of research going on in this field [13, 10] and especially in the application of micro, mini and small hydro power plants [14, 15, 16]. The exact division between them depends on the country [17].

Especially in the case of the micro, mini and small hydro power plants it is often very important to reduce the costs as much as possible. With that in mind asynchronous motor working in the generating mode is often used instead of a generator. In this paper the design of a real simulator is presented. It will be mainly used for control algorithm testing. As it will also be used for educational purposes it is of great importance that the simulator is actually built and not only a software simulation is made. It is namely very important for the students to actually see all the electro hydraulic components in one place. In real hydro power plant all the components are distributed over a large area so for the beginner it is difficult to get an overview at the beginning. We think the developed simulator will help from this point of view.

2 Simulator design

Hydro powerplants are plants that convert the gravitational potential energy of water into electrical energy. The main part of any real hydro power plant as well as our small scale version is a hydraulic turbine. Turbines can be broadly classified into two types, impulse and reaction, although designs may involve a combination of the two types of action [18]. The reaction type of turbines (Kaplan and Francis) are usually more difficult for students to comprehend than an impulse type of turbine (Pelton). That was the main reason for the decision that an impulse type of turbine will be used in the simulator. The modern impulse turbine has a split bucket with a central edge and takes its name from Pelton, who invented it around 1880 [19]. Pelton turbine is used in applications with relatively high pressure and low flow rate. As we don't want the simulator to be too large, low flow rate is a very desirable feature. This is another reason for the decision to use a Pelton turbine in our simulator. In the case of a Pelton

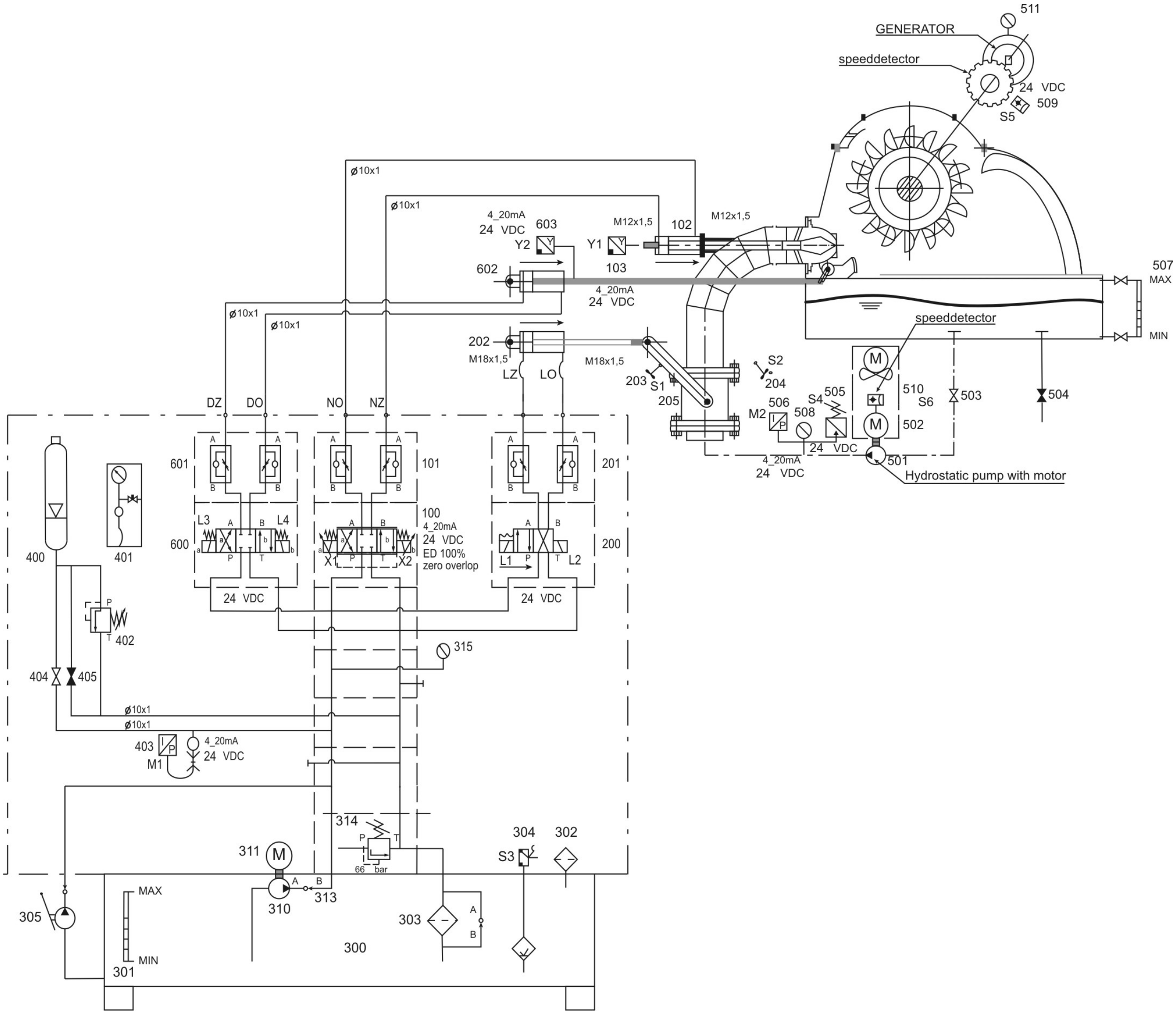

Figure 1: Hydraulic scheme of the simulator

turbine the gravitational potential energy of the water is first converted into kinetic energy in the supply pipe and the nozzle (shown in Fig. 1). The resulting high velocity stream is directed onto the moving buckets, which change the direction of the flow and consequently the momentum of the water [18]. The force needed to change the momentum of the water (action) also has the associated reaction. This is the force with which the water is acting upon the bucket and which results in the torque. In order for the Pelton turbine to be as efficient as possible, the velocity of the water after leaving the bucket should be as low as possible, because the associated kinetic energy is lost. In the simulator a Pelton turbine with a rated power of 6kW (rated head of 65m and rated water flow of 10l/s) has been used (see Fig. 2). Its rotational speed is 1500rpm. The diameter of the wheel is 274mm.

The main difference between the simulator and the real world powerplant is the input energy supply. In the case of the simulator the gravitational potential energy is replaced by an electric motor driven pump. The maximal motor power is 18.5kW. The maximal head of the pump is 85m and the maximal flow rate is 12l/s. The flow rate is

Figure 2: Photo of the Pelton turbine used

controlled by the position of the needle in the nozzle (see Fig. 1). The whole system has two safety features. One is the ball valve, which can stop the water flow through the pipe. In order to stop the water flow as soon as possible in the case of a grid failure a special deflector is also added to the turbine. These three control elements are driven by hydraulic servomotors. The largest one is the one used to move the needle. It has a 50mm diameter and a 17mm stroke. Both opening and closing times are equal to 1.0s. The deflector servomotor has a 25.4mm diameter and a stroke of 40mm. Opening/closing time is 0.3s. The diameter of the ball valve servomotor is 32mm and its stroke is 250mm.

The hydraulic system uses HLP(DIN 51524) hydraulic fluid at a maximal working pressure of 30bar. The nominal flow rate of the oil pump is 2.5l/min. The pump is driven by an electric motor with a nominal power of 0.37kW. The flow of the oil to the nozzle servomotor is controlled by a direct-solenoid-operated proportional valve as shown in Fig 1. The deflector position is controlled by a 4/3 valve (solenoid operated, spring return to center position). The position of the ball valve is controlled by a 4/2 valve (solenoid operated, with detention). All the hydraulic components are assembled in the hydraulic power unit shown in Fig. 3. The whole hydraulic

Figure 3: The hydraulic power unit (HPU)

system has an extra safety feature for the case of the hydraulic pressure drop (pump failure) or in the case of an emergency when the required hydraulic fluid flow is greater then the maximum pump capacity. The bladder accumulator shown in Fig. 1 is used to store the energy for such an event. The bladder is filled with nitrogen gas with the pressure of 14bar.

An asynchronous motor in the generating mode is playing the role of the generator. The rated power of the motor/generator is 7.5kW. The photo of the simulator assembly is shown in Fig. 4.

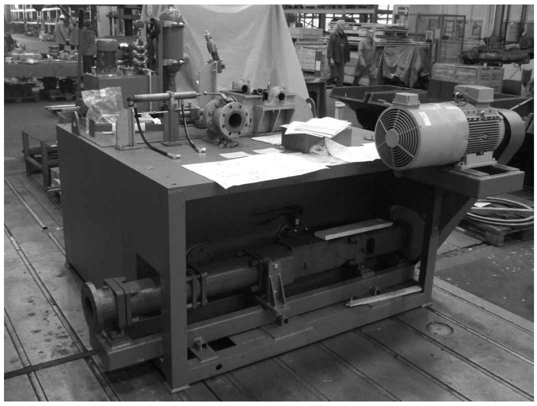

Figure 4: Photo of the simulator assembly

Figure 5: The programmable logic controller

3 Controller design

All the control tasks regarding the simulator are implemented in a programmable logic controller (PLC) Siemens S7-313C (see Fig. 5). The control algorithm is written in STL programming language. The control system is enhanced by an operator panel Siemens TP 170B, which enables user friendly parameter modification and process visualization. The control algorithm is a common PID, which can easily be implemented with a build in function. In first step the PID control algorithm parameters are selected based on the previous experience. The fine tuning is however always done by a trial and error approach. Beside the main control loop where the nozzle acts as an actuator, the controller is also a part of two safety related control loops where the ball valve and the deflector take role of the actuator.

4 Results

In order to test the control algorithms an emergency shutdown of the system was simulated. The result of the simulation is shown in Fig. 6. It can be seen that at the first instant we get quite a significant overshoot due to the closing time of the deflector servomotor. After that the whole system is acting approximately as a first order system without external torque. The rotating speed is therefore decreasing exponentially.

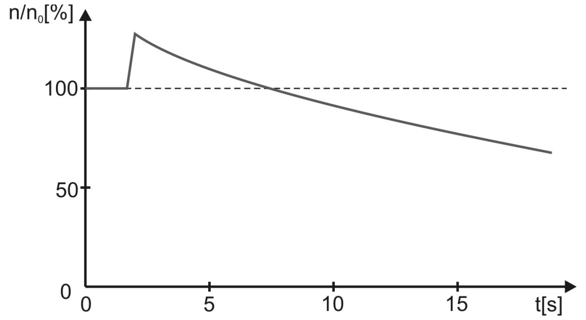

Figure 6: Rotating speed (in relative units) of the turbine vs time during an emergency shut-down

5 Conclusions

The presented simulator has proven to be a valuable tool for control related research in the field of hydro power plant applications. It is also used for educational purposes. Students have shown a lot of interest in it. For them it is a unique opportunity to see the hydro power plant operating principle in such a small device. All the electro hydraulic control elements can be observed easily and consequently it is much easier to understand the control related operating principles of the power plant. It is also easy to study the effect of different parameter settings on the overall performance of the simulator.

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