KEPCO Journal on Electric Power and Energy, Vol. 1, No. 1, September 2015

Development of a Hydro Turbine Governor and Validation Test

Jong-An Kim†, Joo-Hee Woo, In-Kyu Choi
김종안†, 우주희, 최인규

KEPCO Research institute, Korea Electric Power Corporation,105 Munji-Ro, Yuseong-Gu, Daejeon 34056, Korea
† jakim@kepco.co.kr

Abstract

A digital Governor (GOV) has been developed for being used for a Francis hydro turbine, and the validity of the GOV has been tested. As for the hardware system for the GOV, we purchased a basic digital control system that already had proven its reliability in the power industry. We developed a set of new GOV software and integrated it with the hardware system, and finally verified the performance of the whole GOV system. For the human-machine interface (HMI), we configured and implemented appropriate graphic interfaces for the turbine operations. This paper describes the major GOV control functions, approaches we took in developing the GOV control logics, and the validity tests and the results.

Keywords : hydro turbine, turbine governor, governor control logics, turbine speed and load control

I. INTRODUCTION

There has been a need for developing a new digital GOV that is to be used for a newly manufactured hydro turbine in Korea. A GOV of a hydro turbine is a device that controls the speed and load of the turbine, and provides protective functions. The GOV in the turbine functions like the brain in the human body. A digital GOV is basically a digital controller equipped with hardwares and softwares that should provide all the necessary control furnctions to the turbine [1]. There are a variety of different ways to design and implement a digital GOV system for a given turbine. This paper focus on the development of GOV control logics that are necessary for the operation and control of a 15 MW Francis turbine.

In the turbine, high-pressure water first passes from the spial casing and then flows through the guide vane (GV) impacting on the runner tangentially and exiting the runner axially, as depicted in Fig. 1. The water flow to the turbine can be controlled by regulating the GV openings thus energy supplied by water to the turbine controlled. The GV opening is controlled by the hydrauic actuator (A) which is driven by pressure oil from the electro-hydraulic servovalve (B). The pressure oil from the servovalve varies according to the servo current values ranging from 4 to 20 mA. Since the servo current is output from the digital GOV (C), the energy input from water to the turbine can be regulated by the output signal from the digital GOV.

II. GOV CONTROL LOGIC DESIGN

A. Required GOV Functions

The GOV should have suitable functions such that the turbine can be operated in one of the following three control modes. The operator should be able to switch between the three control modes according to the situation at any time without producing sudden changes in turbine operation status. Additionally, GV maximum opening should be restricted to a certain value to limit the maximum megawatt (MW) produced by the turbine, and that limit value can be adjusted by the operator [2]-[4].

1) Speed Control

This mode is only effective in off-line operation. In this mode, actual turbine speed signals are always compared to a target speed producing deviation values and trying to maintain the turbine speed at the target value. The target speed can be set manually by the operator or automatically by the GOV control logic according to the turbine operation states.

2) Load Control

This mode is only effective in on-line operation. In this mode, actual megawatt signal is always compared to a target megawatt producing deviations and trying to maintain the actual megawatt at the target value. The target value can be set manually by the operator or automatically by the GOV control logic according to the turbine operation states.

3) GV Opening Control

This mode is effective in both off-line and on-line operation. In this mode, the plant operator can directly control the GV opening by adjusting the GV opening demand at the command window. The generator megawatts signal or the turbine speed signal does not have any effects on the GV opening demand.

B. GOV control logic

To implement the required GOV functions, the following GOV control logic has been devised (Fig. 2). The final output of the following logic, which is GV Position Demand, determines the GV opening, thereby controlling water flow to the turbine.

This GOV control logic has been configured to satisfy the following objectives that are indispensable for a safe turbine operation [5].

1) One of the three control modes can be selected by the operator manually or by the GOV control logic automatically

ISSN 2465-8111 DOI http://dx.doi.org/10.18770/KEPCO.2015.01.01.105

based on the turbine operation status. The three control modes

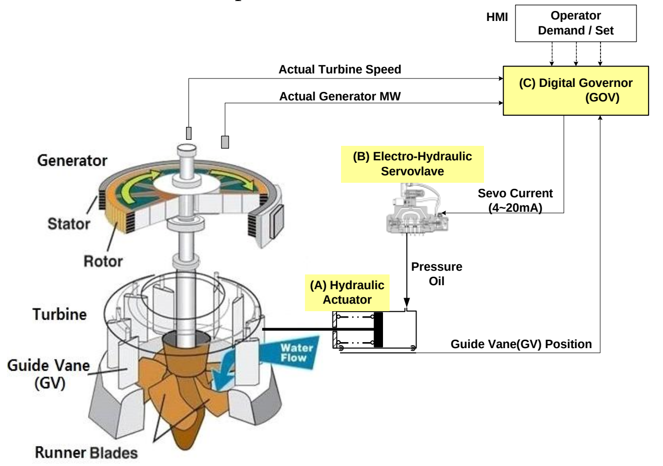

Fig. 1. Hydro Turbine and Governor System

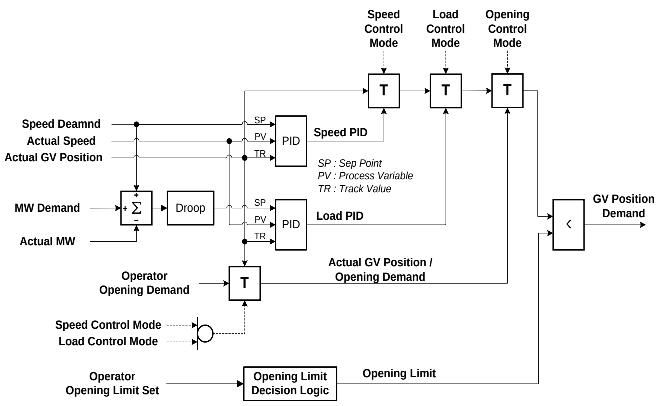

Fig. 2. Basic GOV Control Logic

Table 1. Control modes and PID Inputs

Control mode	Set Point (SP)	Process Variable(PV)	Error (PV-SP)
Speed Control	Speed Demand	Actual Speed	Speed Error
Load Control	Speed Demand + (MW Demand – Actual MW)	Actual Speed	Speed Error + MW Error
GV Opening Control	GV Opening Demand	Actual GV Position	GV Position Error

should be mutually exclusive such that only one control mode should be the active mode.

2) If two or more of the control modes fight for priorty, GV Opening Control should have the highest, Load Control have the second highest, and Speed Control have the lowest priorty.

3) At the time of transition from one control mode to one of the other two modes, no variation in GV Position Demand should occur. For this purpose, two inactive control modes always have to track the Actual GV Position witch is determined by the current active control mode.

Fig. 3 shows detailed GOV control logic that has all the necessary functions for the turbine operation. In addition, important control variables are displayed on the control logic so that operators can easily understand the realtime GOV control staus. In the following control logic, Speed Demand is the output of the function block (W), MW Demand is the ouput of the block (X), GV Opening Demand is the output of block (Y), and GV Opening limit is the block (Z).

C. Human-Machine Interface (HMI)

For the operator interface purpose, the graphic in Fig.4 has been developed. The purpose of this HMI is to provide means to operator to interact with the above GOV control logic of Fig. 3. In the graphic, all the realtime operation data from the turbine are displayed. Operator make commands to the GOV using control buttons located at the lower part of the graphic. In Fig. 4, The three GOV control mode selection buttons (Speed/Load/Opening) are located on the lower left corner (v). Operator setpoint input commands windows or INC/DEC control buttons for Speed Setpoint (w), MW Setpoint (x), Gate Opening Setpoint (y), and Gate Opening Limit Setpoint (z) are positioned at the bottom of the graphic.

The HMI software has been configured on a personal computer running MS Windows 7. The HMI graphics and relevant tag data base have been developed with a dedicated development software package which comes with the digital controller hardware system. Dual HMIs have been installed to assure that the hydro turbine can continue normal operation in the event when either one of the HMIs fails. The two HMI computers have identical software configration, and each of them commucates with the digital GOV independently through a redundant 100 Mbps - Ethernet network.

For a safe turbine operation, the setpoint INC/DEC control buttons in Fig. 4 for Speed, MW, GV Opening, and GV Opening Limit have a three second- maximum time limit function. By implementing this feature into the control buttons in the HMI, operator's demands such as Speed Demand, MW demand and other demands cannot increase rapidly thereby preventing unwanted sudden increase in the speed or MW of the turbine. In addition, real time trend, alarm & event log, and system self-diagnostic functions are implemented in the HMI

III. VALIDATION TEST

A. Test Methods

The following two different test methods have been utilizeded to verify the reliability and performance of the newly developed GOV control logic. An emulation method was applied first, and then a simulation method was utilized. Taking the following two different test approaches rather than applying only one test method, it was possible to save time and efforts debugging the GOV control logic.

1) Emulation Method

This method requires less preparation works because all the necessary signals and configurations for the test are made in the GOV control logic itself. In this method, essential input signals for the GOV control logic such as Actual Speed, Actual MW, Actual GV Position signals were created and calculated as functions of Speed Demand, MW Demand, and Opening Demand respectively. During the test, the GOV control logic

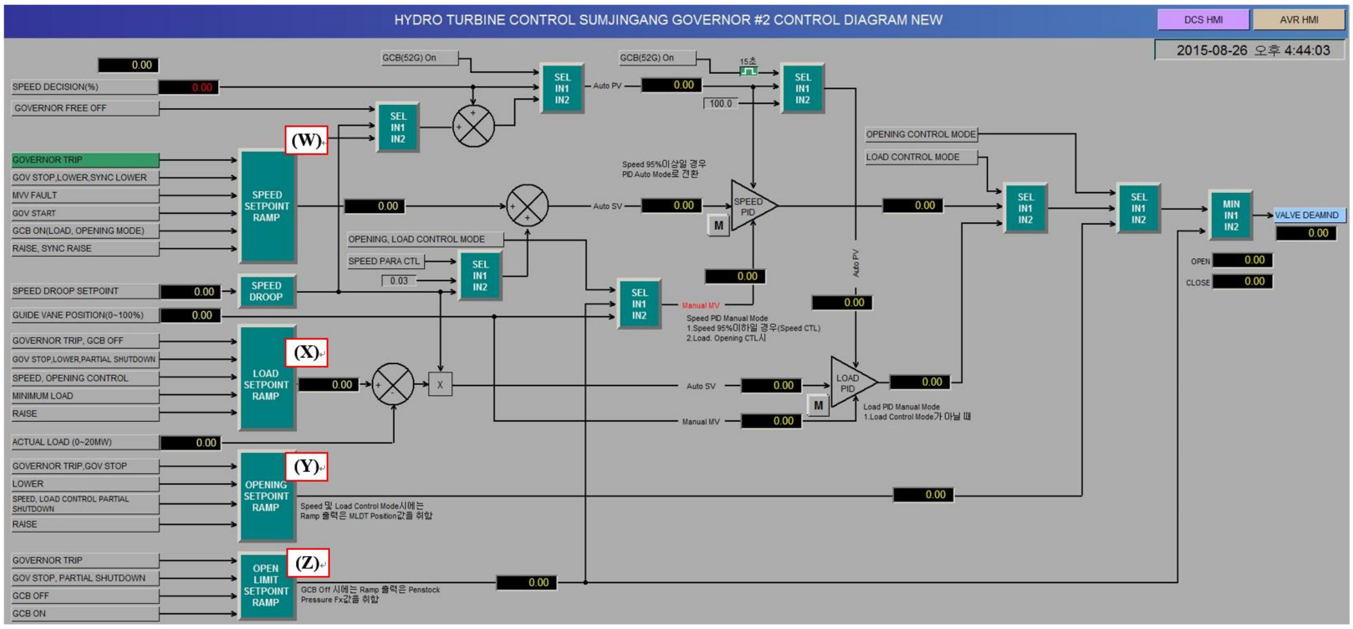

Fig. 3. Detailed GOV Control Logic

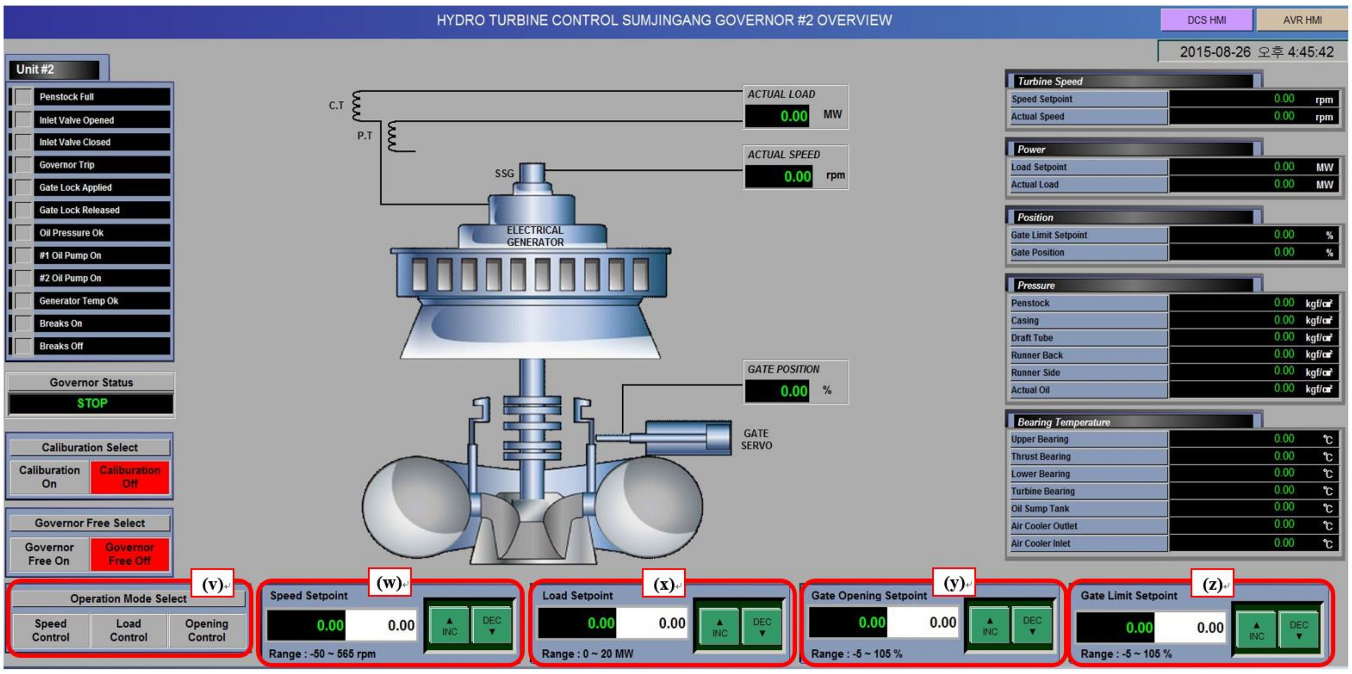

Fig. 4. HMI Graphic for Turbine Operation

had been running in response to these emulated input signals and comparing them with its output counterpart signals, which are Speed Demand, MW Demand, and Opening Demand. Using this test method as the first step, it was possible to remove majority of simple logic errors in a time efficient manner. Although the emulated signals had some degree of deviation from the real hydro turbine operation states, they were good enough signals to be used for this first step test.

2) Simulation Method

During this second step test, a specially designed independent turbine simulator was connected to the developed GOV system via hardwire cables. The turbine simulator calculates and provides signals such as Actual Speed, Actual MW, and Actual GV Position to the GOV. In this test, the GOV issues commnad signals, which are Speed Demand, MW Demand, Opening Demand, and others to the simulator according to the simulated turbine operation state. The simulator includes a software implemented turbine dynamics modeling and hardware input/output signal interfaces. This test method is more effective to apply when the GOV control logic has already been verified through the above emulaton test, and the logic has a considerable degree of fidelity. With the GOV control logic(Fig. 3) downloaded to the digital GOV hardware system, and the turbine simulator connected to the GOV as in Fig. 4, a number of test has been conducted while modifying and filtering out remaining bugs and adjusting some control parameters of the GOV control logic.

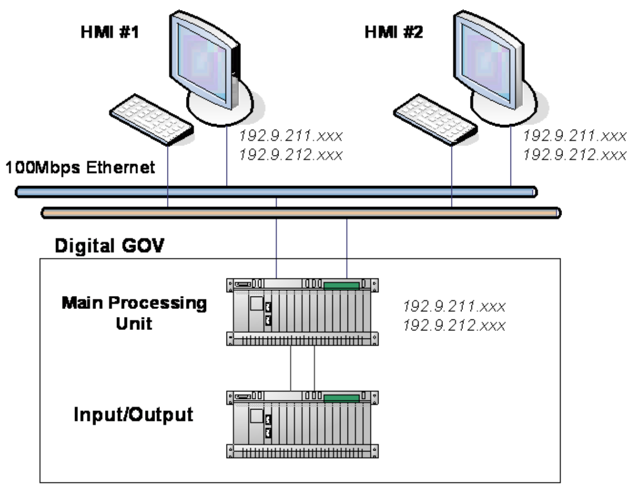

Fig. 5. HMI and Digital GOV

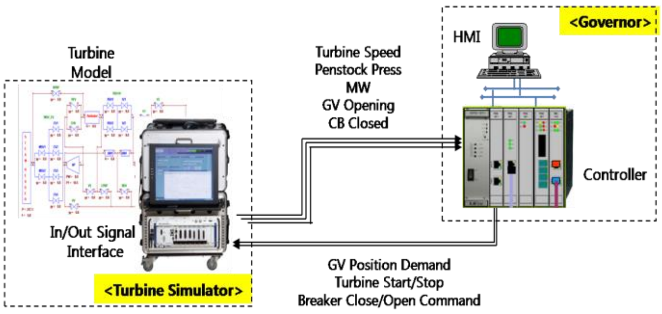

Fig. 6. Validation Test Using a Simulator

B. Test Results

As described in the above, validation tests had been carried out by the two methods, emulation method firstly and the simulation method secondly. Final test results are shown in the Fig. 7 and Fig. 8. During the final test, with the GOV running in the Speed Control mode, a forced step change in GV Opening Demand was made temperaily, then returned to Speed Control mode again. Fig. 7 shows this test result satisfying its performance requirement.

The GV opening limit function was verified during the Load Control mode, and Fig. 8 shows the test result. The priority among the three control modes -Speed Control, Load Control, and GV Opening Control has been verified during the tests such that GV Opening Control has the highest, Load Control has the second highest, and Speed Control has the lowest priorty. Any transition from one control mode to one of two other control modes has made no variation in GV Position Demand value.

IV. CONCLUSION

A Governor has been developed and the performance and reliability of it has also been verified successfully. The developed governor is scheduled to be installed at a 15 MW Francis turbine power plant early next year. Considering all the requirements of the turbine operation, a reliable GOV control logic was devised, designed and implemented. Then the GOV control logic had been tested in two different ways according to the development phase of the control logic. At the early development phase of the GOV control logic, an emulation test

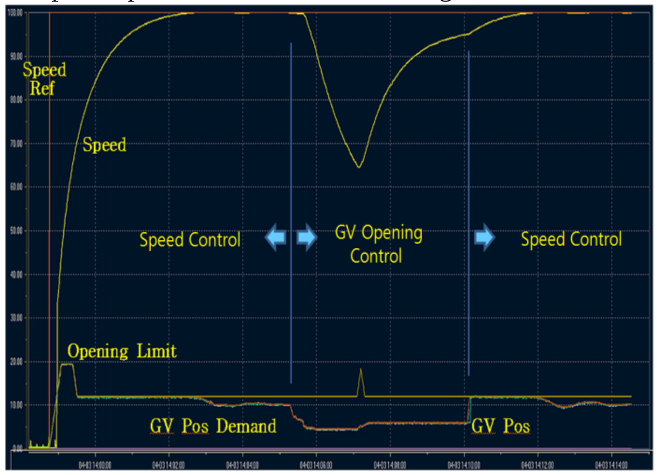

Fig. 7. Speed Control Test result

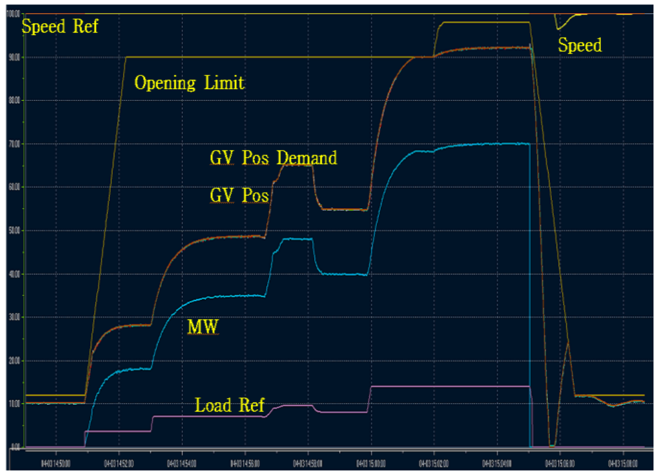

Fig. 8. Load Control and GV Opening Limit Test result

was applied effectively in a time efficient manner. For the later development phase, a simulation test method was applied to verify the whole integrated GOV system. The test results showed that all the control requirements of the target hydro turbine have been satisfied. The approaches we took in the designing, implementing, and testing phase in this project could be a good reference for other similar projects.

REFERENCES

[1] Ardul Munoz-Hernandez, and others, “Modeling and Controlling Hydropower Plants”, Springer, pp.27-36, 2013
[2] P. KUNDUR, “Power System Stability and Control” McGraw-Hill, Inc., pp.394-400, 1994
[3] IEEE Std 125-2007, “IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators” pp.7-10
[4] IEEE Std 1207-2011, “IEEE Guide for the Application of Turbine Governing Systems for Hydroelectric Generating Units” pp.4-10
[5] Joo-Hee Woo, and others, “ Implementation and Simulation of Governing Control System for a Hydraulic Turbine”, 2015 IEIE Summer Conference, p.878-881