Development of Speed Controller and its Application to a 680[MW] Rated Steam Turbine

In-Kyu Choi* · Joo-Hee Woo

Abstract

An analog type turbine control system in a nuclear power plant in Korea was replaced by a digital type control system successfully. The turbine simulator was used to verify and validate the perfection of newly developed digital control system prior to its actual installation. In this paper, the newly developed turbine speed control system, ie. governor will be introduced together with how to simulate entire control loop. After that, we will compare the comparison of simulation result in laboratory with pre startup simulation result. Eventually the performance of actual operation result was testified.

Key Words : Turbine, Governor, Digital Control, Speed Control, Simulation in Laboratory, Pre startup Simulation, Actual Operation

1. Introduction

Turbine Speed Control System(TCS) controls the speed of turbine and the load of generator. It's reliability directly affects the stability of turbine operation and the quality of electric power. In South Korea, the Nuclear Power Plants(NPP) have supplied fundamental portion of domestic electric energy consumption for over 20 years. Demands for retrofitting old TCSs have increased as time goes on because of maintenance difficulties and spare parts shortage.

Also the importance of NPPs as alternative energy source has increased, owing to concerns about air pollution from fossil fuel plants.

The NPP control system should provide safety and reliability all the time during operation.

For the system's safety and reliability, high technology needs to be adopted when designing and configuring the system.

Recently, Korea Electric Power Research Institute(KEPRI) developed and installed a speed controller and is operating it in a CANDU (Canadian Deuterium Uranium) type NPP in Korea.

The hardware of developed speed controller is based on triple modular redundant(TMR) structure to ensure the system reliability. With the TMR structure, any single component or signal fault does not cause to halt the system. The fault component can be identified and replaced while the remnant controllers execute normal control sequences. In the

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developed speed controller, the adopted hardware is commercially released therefore already proved in its reliability, and both control program and Human Machine Interface program for turbine operation was developed for various field conditions about NPP. The purpose of developed speed controller is aimed at actual application into the field, so the validation of reliability is an very important concern. The validation of such basic utilities as hardware and system software necessary to configure the system were solved by using a commercial product, and the validation of application program for turbine control was done by using simulator with dynamic models of steam turbine. So, the internal errors inside the application program were corrected by using the simulator for a long time and the expected problems in commissioning stage were removed. Therefore, the simulator was greatly helpful to testify reliability and to make commissioning period short.

This paper describes the constitution of developed speed controller and its control algorithm. Then it propose two simulation methods using the same simulator; the one is to test with the simulator and speed controller in laboratory, the other is to test the simulator and speed controller in actual power plant. Finally, we compare the simulation results of pre startup in laboratory with the actual operation results about the operation of turbine speed up.

2. Developed Speed Controller

2.1 Overview of conventional system

The conventional TCS about NPP was an analog system which consisted of electronic printed circuit board, analog controller and instrumentation devices. The control board consisted of push buttons, indicators, lamps etc. The controller consisted of such electronic components as integrated circuits, diodes, and operational amplifiers and valve control modules, etc. There were two Linear Variable Differential Transformers one of which was used for valve position control and the other for monitoring it. In addition to that, there were one servovalve which drives the valve actuator.

There was no data managing system. Therefore, it was very difficult to monitor and maintain process variables during operation which leads separated data manager system[1].

Fig. 1 shows that the turbine of this NPP consists of a high pressure (HP) turbine and three low pressure (LP) turbines. The rated generator output is 680[MW].

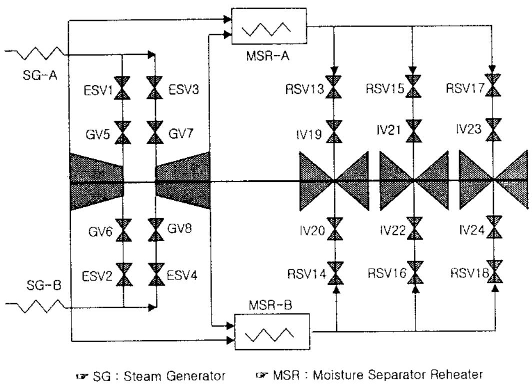

Fig. 1. Turbine Configuration in the target NPP

The steam flows to each turbine are controlled by following valves.

- Emergency Stop Valve (ESV, 4ea) : for isolation steam flow to HP turbine
- Governor Valve (GV, 4ea) : for control steam flow to HP turbine
- Reheater Emergency Stop Valve (RSV, 6ea) : for isolation steam flow to LP turbine
- Intercept Valve (IV, 6ea) : for control steam flow to LP turbine

The IVs are widely opened in normal operation and the GVs are controlled by the variation of speed and electric power.

2.2 Overview of new Speed Controller

Fig. 2 shows that new speed controller consists of human interface devices; Operator Interface Station(OIS), Engineering Work Station(EWS), and TMR. The TMR executes turbine control algorithm developed by KEPRI. The OIS and EWS are implemented with IBM compatible computer and provide the function of monitoring and operator control.

The TMR is composed of CPU with self-diagnostic function, power supply module, input-output module (Analog Input, Analog Output, Digital Input, Digital Output, Pulse Input, Actuator Driver, etc), which transmit and receive to and from local sensors, communicate with OIS in control room. And adopted hardware is a 'Micronet' of Woodward Company[2].

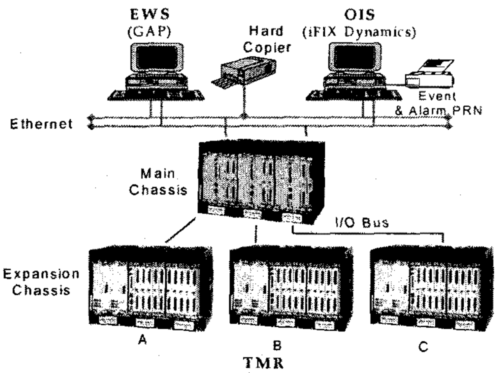

Fig. 2. The Constitution of developed controller

Plant operators operate the turbine using Human Machine Interface(HMI) and technicians can do maintenance of the system by use of the OIS and/or EWS. The TMR communicates with operator console by redundant ethernet networks. Operating status is monitored by the OIS, which was implemented by using the 'iFix Dynamics' program of Intellution Company.

The EWS can provide the function of control and monitoring during operation, design of control logic, and downloading. Engineers can develop or modify control algorithms using function blocks of application tool supplied by the TMR manufacturer.

2.3 The overview of Control Algorithm

The goal of TCS is to control turbine speed and generator load which is achieved by controlling steam flow into turbine from steam generator the source of thermal energy is nuclear reactor. TCS controls the position of governor valves (GV) to meet the amount of required steam flow dependent on an operation condition. The speed control algorithm is very simple as shown in Fig. 3. The ramp block outputs ramp at a certain rate depending on selected rate. Speed Set and Speed Ref Rate are selected by operator. Speed Set means a target speed and its pre-defined values are -180, 200, 400, 800, 1800 and 1944(OST : Over speed test)[rpm].

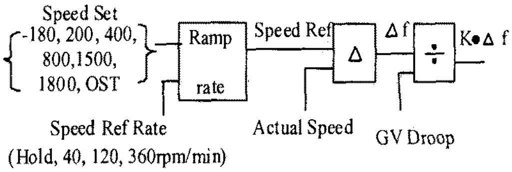

Fig. 3. Overview of speed control algorithm

Speed Ref Rate means the acceleration rate of turbine speed and its pre-defined values are Hold, 40, 120 and 360[rpm/min]. The "Hold" means the acceleration rate is 0[rpm/min]. Speed Ref is automatically calculated by the function of ramp block. $K \cdot \Delta f$ is decided by a speed error(Δf) and gain (the reverse of speed droop of governor valve) of proportional controller. K · △f increases when an actual turbine speed is lower than speed ref and GVs are more opened by increased steam flow demand(SFD) then the actual turbine speed increased. SFD is proportional to K · △f and controls all the GVs during speed up.

3. Simulation Method

Before the newly developed speed control system could be operable, there were two simulation methods to take measures against the unexpected problems such as control logic errors and to determine reasonable control constants. The two methods are described next step

3.1 Simulation in Laboratory

In laboratory, because the signal wires cannot be connected from the field instruments in actual plant into the control system directly, every control signal needs to be connected from simulator to the control system. Fig. 4 shows this configuration. In Fig. 4, when the operator selects command for speed up on OIS, this command goes to controller via communication and causes the target value of the controller to increase.

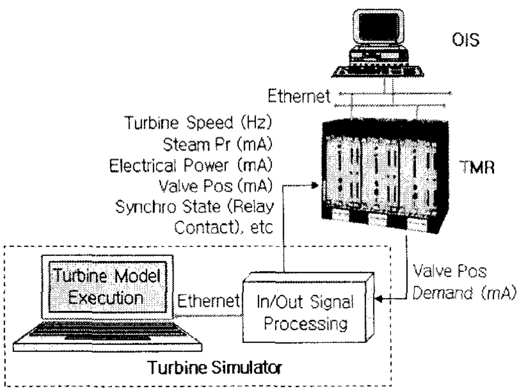

Fig. 4. Simulation in laboratory

This causes the valve position demands to go up and they enter into the simulator. Consequently, the model inside the simulator receives them and calculate the turbine speed and send it to the controller which regulates the positions of governing valves according to the speed signals from the simulator.

Above mentioned sequence is implemented in sequence for the engineers to testify their control logics in laboratory.

3.2 Pre startup simulation

This method is used only when the installation of control system is completed. Every control signal can be confirmed in its good state in this method. Fig. 5 shows this configuration.

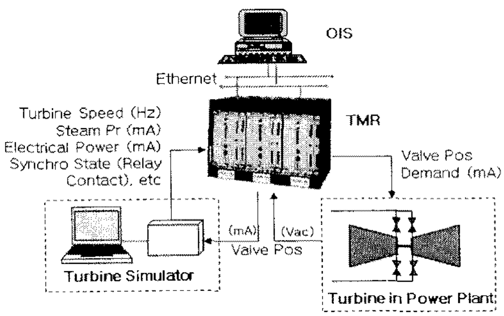

Fig. 5. Pre startup simulation

In Fig. 5, when the operator selects command for speed up on OIS, this command go to controller via communication and cause the target value of the controller increases. This causes the valve position demands to go up and they enter into the turbine in power plants. Since the field instruments including valve position system are ready for operation in this stage, all steam valves are being controlled according to the command. So, the controller knows the positions of steam valves and can send them into the turbine simulator to calculate turbine speed.

In this way, operator can increase or decrease turbine speed or electrical load and check every condition of field instruments.

We can find out and take steps against all the problems in the fields or mismatches between field and controller during this simulation.

4. The results of simulation and commissioning

The simulation test is to test all the functions of controller such as operator consoles and their subsidiaries prior to start up. The results of two simulation tests and the actual operation are described below about the turbine speed up.

4.1 The result of simulation in laboratory

Fig. 6 shows the simulation result of speed up. When the operator resets the turbine on the simulator, RSVs and ESVs are open. After that, when the operator selects a speed set and a speed rate, the positions of Intercept Valves(IVs) open until 100[%] at a predetermined rate, the positions of governor valves are regulated by controller which causes the turbine speed to increase. The following steps were executed for simulation test

- Speed Set : 200→400[rpm], (Rate : 40[rpm/min])
- Speed Set : 400→800[rpm], (Rate : 120[rpm/min])
- Speed Set : 800→1500[rpm], (Rate : 360[rpm/min])
- Speed Set : 1500→1800[rpm], (Rate : 360[rpm/min])

Fig. 6 shows that the positions of IVs fluctuate much at lower speed but becomes smaller according to the speed up. Fig. 6 shows also that the bigger the speed rate is, the more the amount of fluctuation of IVs is. The meaning of MSPL Ref., Load Set and Load Limit do not need to be explained since they are related with load control after synchronization.

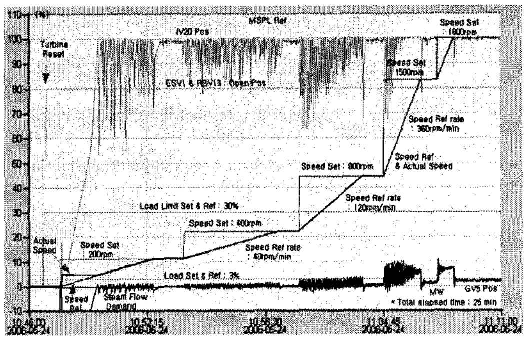

Fig. 6. The simulation result in laboratory

4.2 The result of pre startup simulation

The test results of pre startup simulation are described here Fig. 7. This simulation test was accomplished after the whole control system was installed in actual power plant. As the simulation in laboratory, when the operator resets the turbine on the simulator, RSVs and ESVs are open in actual power plant. After that, when the operator selects a speed set and a speed rate in control room, the positions of Intercept Valves(IVs) in field open until 100[%] at a predetermined rate. The

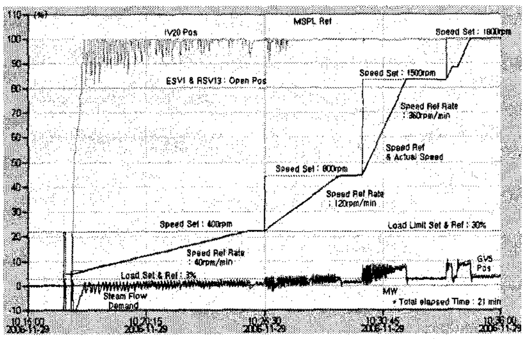

Fig. 7. The pre startup simulation result

simulation results of the pre start up is very similar with the simulation result in laboratory in Fig. 6. The Fig. 7 shows that the IV fluctuates less than that of Fig. 6. And the Fig. 5 shows that the IV go into stability faster than that of Fig. 6. These means that we can have better when we use.

4.3 The result of actual operation

The result of actual operation of control system without simulator are shown in Fig. 8. In actual operation, the operation trend is better than the two simulation results.

The IVs do not oscillate and the amplitude of the GVs is much smaller than that of two simulation results. The operation procedure is exactly the same with pre start up simulation.

This means that such parameters in simulator as friction loss, rotational inertia, or valve stroking time, turbine admittance etc need to be modified for more accurate simulation.

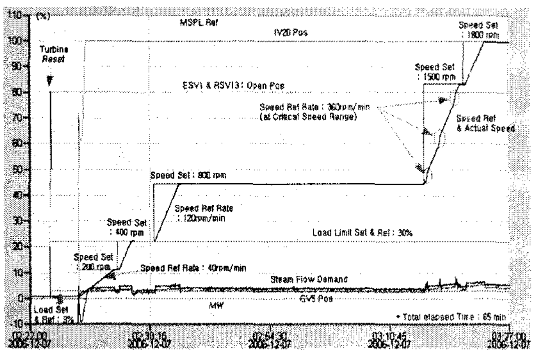

Fig. 8. The actual operation result

5. Conclusion

We described the results of test and operation of the digital speed control system, in other words governor. The simulator played a very important role in testifying reliability of control system. After the installation and operation of this control system, the following items can be considered.

First, the developed control system can be tested and the errors of application programs can be corrected by use of simulator in laboratory for a long time as described above

Second, the potential problems during installation can be corrected and removed by use of the method as described. It is very helpful to have the developed control system secure good reliability as well as to make the commissioning period short.

Third, It is very convenient for engineer to be able to simulate control system in two ways as described only if he change some configurations and signal wires.

This control system was started to be installed on 8 December 2006 and turned over to the plant operator on 5 January 2007 after all tests have been finished for load and safety.

References

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Biography

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Choi, In-Kyu was born in 1967. In 2004 He obtained master's degree in Department of Electrical Engineering from Chungnam National University. His research interests include such control in power plant machines as boiler, drum, turbine and generator. Now he is a senior member of Korea Electric Power Research Institute.

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