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Field Adaptability Test for the Full Load Rejection of Nuclear Turbine Speed Controllers using Dynamic Simulator

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Abstract

This paper describes the speed control functions of the typical steam turbine speed controllers and the test results of generator load rejection simulations. The goal of the test is to verify the speed controller's ability to limit the steam turbine's peak speed within a predetermined level in the event of generator load loss. During normal operations, the balance between the driving force of the steam turbine and the braking force of the generator load is maintained and the speed of the turbine-generator is constant. Upon the generator's load loss, in other word, the load rejection, the turbine speed would rapidly increase up to the peak speed at a fast acceleration rate. It is required that the speed controller has the ability to limit the peak speed below the overspeed trip point, which is typically 110[%] of rated speed. If an actual load rejection occurs, a substantial amount of stresses will be applied to the turbine as well as other equipments. In order to avoid this unwanted situation, not an actual test but the other method is necessary. We are currently developing the turbine control system for another nuclear power plant and have plan to do the simulation suggested in this paper.

Key Words : Nuclear Power Plant, Speed Controller, Load Rejection, Simulation Test

1. Introduction

In a power plant, the steam turbine drives the generator while its speed controller, in other words, governor, controls the turbine speed and power at desired values by adjusting the inlet flow of a high temperature and high pressure steam coming from the steam generator. After the generator becomes paralleled with the electrical power system, an increase in steam flow to the turbine would contribute an increase in generator output, which is electrical load. In case of generator load rejection, steam flow into the turbine cannot be reduced as quickly as the electrical load loss.

The turbine controller should be capable of full load rejection without a turbine trip. The trip speed setting will vary with the class of governor. Parameter trip speed Class per NEMA SM 23A is 115[%] of rated speed and for SM 23B is 110[%] of rated speed[1]. Prevention of turbine trip is essential if the turbine trip is to carry its auxiliary load until it is resynchronized to the power system. Following the initial overspeed, the unit

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will reach a steady-state speed determined by the droop characteristics. The standard 5[%] regulation will result in a steady-state speed slightly below 105[%] of rated speed. Continuous operation at this frequency is forbidden as it may cause damage to the low-pressure blades[2]. It is introduced in this paper that the simulated generator load rejection tests were carried out on the newly developed two turbine speed controllers in two nuclear power plants before their startups after the speed controllers were installed in the actual nuclear power plant. And the test results were testified to be satisfactory for the speed controllers to begin their actual operations.

2. Turbine and Generator

Fig. 1 is the steam flow diagram of the turbine of Kori Nuclear Power Plant #1, which consists of one high pressure turbine and two low pressure turbines on the same shaft. There are two MSRs(Moisture Separator Reheater) which are used to improve the quality of the steam exhausted from high pressure turbine.

The 4 HPSVs(High Pressure Stop Valve) are used to speed up the turbines to the rated speed with the 4 HPGVs(High Pressure Governor Valve) open at a certain position and with 4 LPSVs(Low Pressure Stop Valve) and 4 LPGVs(Low Pressure Governor Valves) wide open.

At the rated speed, the HPGVs close slowly whereas the HPSVs go to wide open positions. Since then, the HPGVs are used for the generator synchronization with the power system and load control.

The turbines in other nuclear power plants have the almost the same operation principles with that of the Kori Nuclear Power Plant #1 with which other nuclear turbine is configured similar.

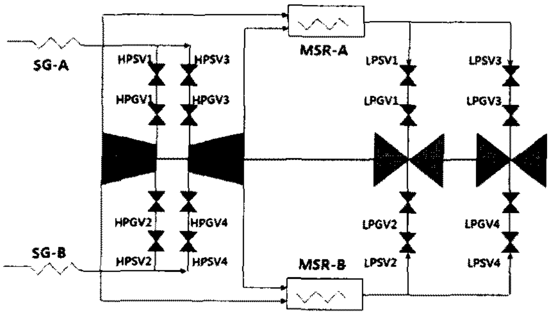


Fig. 1. Steam Flow Diagram of Kori Nuclear Power Plant #1

2.1 Steam Turbine and Generator

The steam turbine in the power plant converts the thermal energy into mechanical energy. The generator is an energy conversion device which produces electric energy by converting the mechanical energy of the rotating steam turbine.

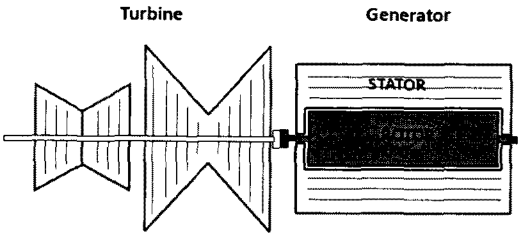


Fig. 2. Turbine Generator

In general, as depicted in Fig. 2, the turbine and the generator are connected together directly on one shaft which gives the generator rotational torque.

The generator converts the rotational mechanical energy into the electrical energy through which the electromagnetic interactions between the two magnetic field, the one of which is from rotational field current and the other of which is from fixed stator coils, thus providing electricity to the load[3].

2.2 Rotational Equation of Motion

The rotational equation of the machine can be expressed as following equation[3].

$$\frac{d\omega}{dt} = \frac{\omega}{M}(P_m - P_e) \qquad ①$$

where, ω is its angular speed,
Pm is the mechanical input,
Pe is the electrical output,
M is the per unit inertia constant.

This shows that the difference between the two opposing forces acting on the same shaft in parallel operation with the electrical grid system produces the speed change on the shaft[4]. A constant speed means that the driving force is equal to the summation of the braking force and the total loss. By the way, if the generator load is rejected, the armature current(Ia) goes to zero, which means that the braking force disappears, resulting in the turbine rotor's acceleration and overspeed condition.

3. Turbine Speed Controller

3.1 Overview

One of the most important functions in a turbine control system is the speed control function. Generally speaking, the speed controller is also called as governor. The first automatic control device in history, so called governor, which regulates the machine, was created by James Watt in England in 1788 during the Industrial Revolution Period in order to maintain his steam engine at a constant speed. It was a mechanical type governor using the centrifugal force of the two fly balls as shown in Fig. 3[4].

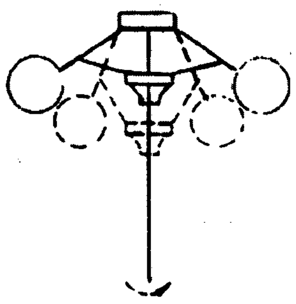


Fig. 3. Fly Balls

Nowadays, All most of the governors are digital type which employs advanced computer technologies and can implement not only speed control function but also many other complicated functions including overspeed protection. The magnetic pick up device is used to detect the turbine speed. It acts as a single pole alternating generator using static magnetic field. It consists of both a permanent magnet and a coil around it. As shown in Fig. 4, when the teeth go through the magnetic flux, the electric voltage is induced across the coil terminals. The frequency of the voltage is proportional to the speed of the rotational gear shaft connected to the turbine[5].

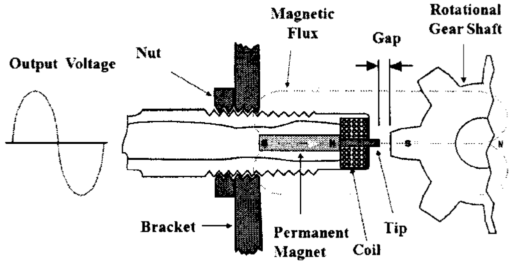


Fig. 4. Speed Detector

3.2 Turbine Speed and Generator Load Control

When a turbine starts its operation, the speed goes up from the turning gear speed as the steam flow increases. After the turbine speed has reached to its rated speed and the generator connected to the electrical power system, further increase in steam flow into the turbine, in other words, additional increase in mechanical energy of turbine, will only contribute to an increase in the generator output. Actually, an imperceptible turbine speed increase would be present, but its magnitude is so small that it almost cannot be measured. This phenomenon results from the fact that the speed of generator rotor coupled to the turbine rotor is restricted to the revolving magnetic flux speed of the generator stator that is paralleled to the infinite electrical power system. Even though, the increased turbine mechanical energy tries to speed up itself, it cannot overcome the huge restriction force of the generator, but the additional energy input is only converted into electrical energy. Thereby, we can control the generator electrical output by means of the turbine speed control[6].

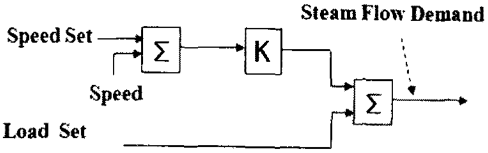


Fig. 5. Speed Control Circuit for Steam Turbine

Fig. 5 shows the control circuit for turbine speed and generator load.

Before synchronization, the steam flow demand is calculated by taking consideration into the controller gain K after speed error is calculated from the difference between the speed set and the actual speed. After synchronization, the speed set is fixed at 100[%] and load set is adjusted according to the desired value, and these two signals are added together to produce the steam flow demand signal.

3.3 Turbine Overspeed Control

Another the most important function in turbine control system is an overspeed control function. Turbine overspeeds arise from the unbalance between the mechanical input and the electrical output. The followings are two algorithms that we adopted in the two different turbine control systems for preventing excessive turbine overspeed. First, in case of Kori #1 with 587[MW] and 1,800[rpm], the speed controller detects the acceleration rate and stops the steam flow into the turbine before an excessive overspeed occurs.

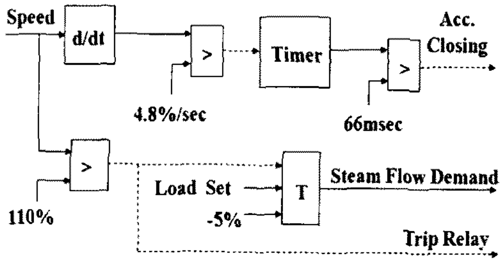


Fig. 6. Overspeed Protection of Kori #1

As shown in Fig. 6, when the acceleration rate is bigger than 4.8[%/sec] and continues for more than 66[msec], the acceleration closing(Acc. Closing) occurs and stops the steam flow by closing both HPGVs and LPGVs quickly. The turbine is in its emergency condition in this situation. Thereafter, the turbine speed goes down naturally due to the turbine internal friction losses. At around the rated speed, the speed controller takes control again and regulates the HPGVs positions and maintains the turbine at the rated speed. There are similar algorithms for overspeed protection in Kori Nuclear Power Plant #4 as represented in Fig. 7.

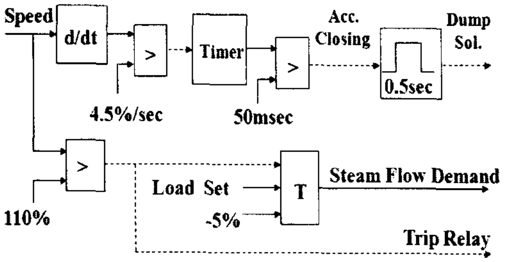


Fig. 7. Overspeed Protection of Kori #4

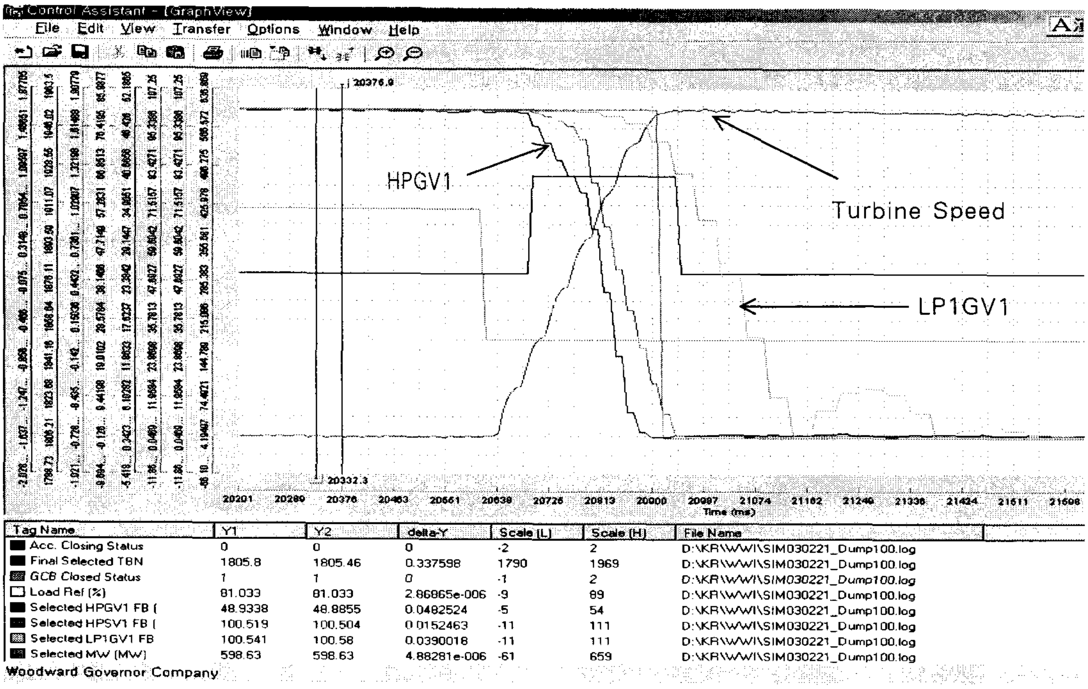
4. Turbine Generator Simulator

We used the turbine dynamic simulator for field adaptability test for full load rejections. The simulator has the thermal dynamic model of the turbines, the valves, the moisture separator reheaters, the condenser and the generator in the nuclear power plant. The simulator receives control signals from controller and can generate transient states in order to perform many tests. The thermodynamic energy equation is used in the process which the steam flow into the turbine is converted into the speed and electricity. At a constant pressure, the steam flow into the turbine is determined according to the value of the valve positions and the energy can be calculated. The actual operation data gathered from the site is referred to as the calculation. This simulator is described in detail in our previous paper[7]. Fig. 8 shows the graphic user interface for dynamic model in the simulator.

5. Load Rejections Tests using Simulator

5.1 Overview

Fig. 8 shows the configuration of actual input and output signals during field adaptation test for load rejections.



Tag Name	Y1	Y2	delta-Y	Scale (L)	Scale (H)	File Name
■ Acc. Closing Status	0	0	0	-2	2	D:\KR\WWI\SIM030221_Dump100.log
■ Final Selected TBN	1805.8	1805.46	0.337598	1790	1969	D:\KR\WWI\SIM030221_Dump100.log
▨ *GCB Closed Status*	1	1	*0*	-1	2	*D:\KR\WWI\SIM030221_Dump100.log*
☐ Load Ref (%)	81.033	81.033	2.86865e-006	-9	89	D:\KR\WWI\SIM030221_Dump100.log
■ Selected HPGV1 FB (	48.9338	48.8855	0.0482524	-5	54	D:\KR\WWI\SIM030221_Dump100.log
■ Selected HPSV1 FB (	100.519	100.504	0.0152463	-11	111	D:\KR\WWI\SIM030221_Dump100.log
▨ Selected LP1GV1 FB	100.541	100.58	0.0390018	-11	111	D:\KR\WWI\SIM030221_Dump100.log
■ Selected MW (MW)	598.63	598.63	4.88281e-006	-61	659	D:\KR\WWI\SIM030221_Dump100.log

Woodward Governor Company

Fig . 9. Result of Load Rejection Kori #1

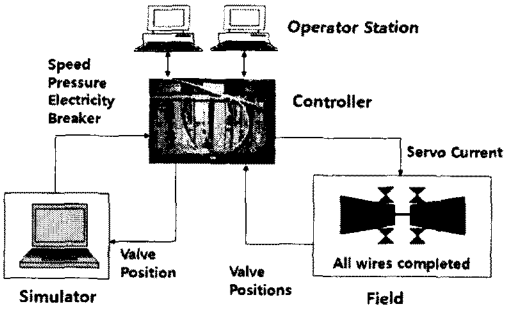


Fig. 8. Field Adaptation Test Circuit

This method is implemented not in laboratory but in the power plant.

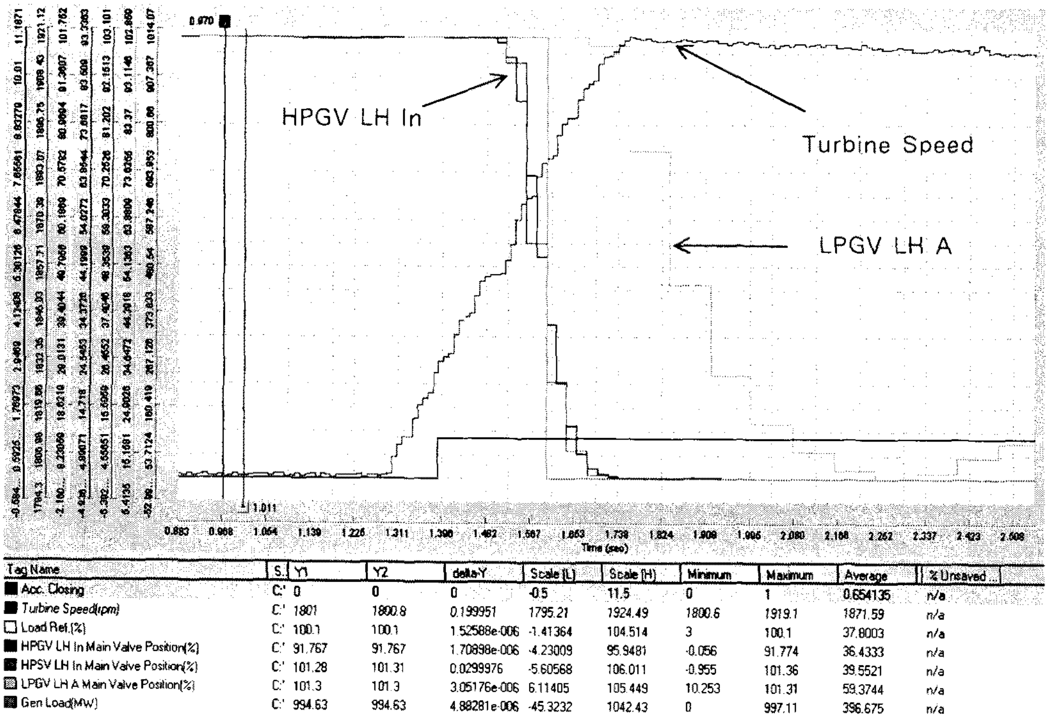
The operation commands such as start up, stop and load regulation is transmitted from the operator to the controller which executes the control programs, produces servo current and regulates the steam control valves in field. The servo valves receive these commands and drive the steam valves using hydraulic fluids pressure of 120[bar] or 140[bar].

The values of the steam valve positions go into the simulator through the controller. The simulator calculates the speed and the load and then transmits them into controller. For this calculation, the simulator uses the steam conditions, the inertia, loss and the valve positions based on previously collected operation data already tuned by engineers.

5.2 Kori #1

Fig. 9 is an operation trend which is a result of the circuit breaker opened at the full load with the 4 HPGVs' positions at 49[%] in Kori #1. In Fig. 9, the time interval of x axis per division is about 40[msec].

Immediately after the load rejection, the turbine speed increased at its maximum rate from the



Tag Name	S.	Y1	Y2	deltaY	Scale (L)	Scale (H)	Minimum	Maximum	Average	% Unsaved ...
■ Acc. Closing	C:'	0	0	0	-0.5	11.5	0	1	0.654135	n/a
■ *Turbine Speed(rpm)*	C:'	*1801*	*1800.8*	*0.199951*	*1795.21*	*1924.49*	*1800.6*	*1919.1*	*1871.59*	*n/a*
☐ Load Ref.(%)	C:'	100.1	100.1	1.52588e-006	-1.41364	104.514	3	100.1	37.8003	n/a
■ HPGV LH In Main Valve Position(%)	C:'	91.767	91.767	1.70898e-006	-4.23009	95.9481	-0.056	91.774	36.4333	n/a
■ HPSV LH In Main Valve Position(%)	C:'	101.28	101.31	0.0299976	-5.60568	106.011	-0.955	101.36	39.5521	n/a
▨ LPGV LH A Main Valve Position(%)	C:'	101.3	101.3	3.05176e-006	6.11405	105.449	10.253	101.31	59.3744	n/a
▨ Gen Load(MW)	C:'	994.63	994.63	4.88281e-006	-45.3232	1042.43	0	997.11	396.675	n/a

Fig. 10. Result of Load Rejection Kori #4

rated speed of 1,800[rpm]. After 66[msec] elapsed from the load rejection, the acceleration closing signal occurred. And the turbine reached to its peak speed of 108.6[%], at 262[msec] after the load rejection.

The dead time and the closing time of the steam valves were as in the following table 1.

Table 1. Dead Time and Closing Time of Kori Unit #1

	Dead Time	Closing Time
HPGV1	60[msec]	200[msec]
LP1GV1	140[msec]	360[msec]

5.3 Kori #4

Fig. 10 is Kori #4 test trend in which the generator circuit breaker opened at the full load with the HPGV LH positions at 91[%]. The trend time interval of x axis is about 40[msec].

After 100[msec] elapsed from the load rejection, the acceleration closing signal occurred. And the peak speed reached to 106.6[%] after 440[msec] from the load rejection.

The dead time and the closing time are summarized as table 2 about the steam valves.

Table 2. Dead Time and Closing Time of Kori Kori #4

	Dead Time	Closing Time
HPGV LH In	200[msec]	180[msec]
LPGV LH A	320[msec]	520[msec]

5.4 Test Results

The turbine model is determined based on both the operation data and the design data of the construction in a nuclear power plant and the simulator is integrated. The simulation test for the full load rejection shows very good results after installation. The peak speeds after load rejections are 1,954[rpm](108.6[%]) in Kori #1, 1,918[rpm](106.6[%]) in Kori #4 respectively. The margins are 1.4[%] in Kori #1, 3.4[%] in Kori #4 respectively toward 110[%], the overspeed trip set point. Therefore, the tested speed controllers obviously correspond to the power industry code that the speed controller must have a control function capable of limiting the speed at the full load rejection below the emergency governor set point.

6. Conclusion

It is confirmed that the full load rejection test can be performed not actually but by simulation. *In the actual load rejection test, there must be a* big life consumption induced from the abrupt changes of such process variables as temperature, pressure, flow and speed. The simulator can be used to prevent those severe conditions. During the commissioning period after the installation of control systems, the simulator plays a very important role in obtaining two strong points. The one is that the mechanical life consumption can be prevented and the other the commissioning period is made short because the generator output of nuclear power plant does not need to be reduced. This simulation method of the load rejections will be applicable to thermal power plants as well as nuclear power plants.

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Biography

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