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Performance Evaluation of Retrofitted Coal-fired Plant Simulation Model

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SUMMARY

This study looks at improving the performance of old coal-fired thermal power plants (hereinafter, T/P) through retrofit to show output characteristics similar to those of a gas turbine power plant. The whole cycle process has been simulated to evaluate the effect on the power system when applied. The technology for improving the performance of coal-fired T/Ps in the aspect of the prime mover has been introduced, an analysis model based on PSS/E to evaluate the effect the coal-based flexible coal-fired T/P has on the power system when implemented has been developed, and the performance improvement work using the technology and model mentioned has been completed. The performance improvement has been focused on increasing the size of the available output buffer to cover the change in the output of renewable energy and reducing the time taken to cover the change. In this way, we improved the minimum operation load, start-up time, and rate of increasing/decreasing the power output so that now the performance is similar to that of a gas turbine power plant.

The analysis model for the flexible coal-fired T/P showed that its performance was most similar to that of a gas turbine when we modified the gain and reheater gain K1, representing the droop characteristics, from among the equipment parameters of the IEEEG1 model. Using this analysis model and the future power system DB of Korea, we verified the performance by comparing the line overload factors for various flexible coal-fired T/P deployments.

KEYWORDS

Flexible Power Plant, PSS/E Simulation model, Power system stability

1. INTRODUCTION

The type of generator within the power grid is rapidly changing from rotation-based generators, which are output-adjustable and provide inertia, to inverter-based renewable energy. [1-2]This change to an environment-friendly configuration has become a challenge to power system operators who supply electricity with a constant voltage and frequency despite disturbances such as supply-demand imbalances and failures. In particular, we need fast and large backup resources to balance demand and supply in response to the rapid fluctuations in renewable energy output at sunrise and sunset.[3] However, the costs of constructing power facilities amid civil complaints, etc., have become major obstacles to the establishment of new facilities, and when considering the value of existing facilities and the economic ecosystem surrounding them, it may be of great advantage to utilize these existing facilities.

The installed capacity of coal-fired T/Ps is gradually shrinking due to carbon neutrality, the change to renewable energy, etc. The sunk costs of facilities and costs for site conversion have also considerably increased. Suppose we can utilize such old coal-fired T/Ps to make flexible coal-fired T/Ps that are capable of changing output as gas turbines are. In that case, we can respond to the power supply-demand unbalance caused by the change in the output of renewable energy sources while providing a comparatively large capacity of inertia at the same time. This can be a cost-effective means of enhancing the stability of the system. In this study, we tried to determine what improvements are needed for conversion to such a flexible coal-fired T/P, modeled the flexible coal-fired T/P created through such improvements, and finally simulated the effect of the flexible coal-fired T/P on the line overload when applied to the system.

2. NECESSARY IMPROVEMENTS TO CONVERT THE ORDINARY COAL-FIRED T/P TO A FLEXIBLE COAL-FIRED T/P

The principal technical indicators of flexible operation are minimum stable load response speed (ramp rate) and start-up time.[4-5] When lowering the minimum stable load of the power plant and thus expanding the output range, the room for renewable energy can get larger. However, in this case, in low-load operation, the number of risk factors increases because the performance of each piece of equipment is degraded, and the plant is operated in an unstable state. In addition, when improving the speed of the load response, the responsiveness to the load change of the power system is also improved. However, taking into account the operating environment of the power plant, improving the load response speed is restricted to some extent. The principal limiting elements in the aspect of equipment are boiler combustion stability during low-load/varying-load operation, an increase in the thermal fatigue/corrosion tendency of the heat transfer piping and structure support, low-temperature corrosion of exhaust gas ducts, a decrease in de-nitration catalyst activity, low exhaust gas temperature in the stack, insufficient capacity and load-following capability of the desulfurization facility, etc., and technology is being developed to address these issues.[6-7]

In this study, a 500 MW supercritical pressure once-through boiler was used. The boiler uses tangential-firing combustion, in which the fuel and air input from the burners installed at the 4 corners on 6 levels are burned, forming a fireball in the center of the furnace, and the combustion is made stable by adjusting the amount of input fuel-air and the tilt angle, and by starting/stopping the burners on each level, etc., according to the composition of the fuel and the load. During the rated output operation, where the burners of 5 or 6 levels are used together, stable operation is accomplished based on the operator's know-how accumulated through experience and the guidelines. However, field experience and technology accumulation are not sufficient for the combustion instability, imbalances in heat load distribution, degradation in combustion efficiency and thermal performance, which might arise in the case of long-term low-load/load-following operation, the characteristics of environmental emissions and corresponding reduction measures, countermeasures for slagging/fouling adhesion characteristics, etc. Therefore, due to changes in operation, technology development is required for dynamic thermal performance analysis of dynamic boiler behavior and equipment configuration and low-load performance improvement.

Flexible operation is accompanied by sudden changes in temperature inside the furnace and thermal load distribution. The resulting changes in thermal stress may cause the accumulation of low-frequency thermal fatigue in the heat transfer pipes, valves, and supports overall. In particular, it is thought that erosion and fatigue damage may occur in the bends and welds of pipes and supports, and technology for damage analysis and evaluation of the influence of the material selection is required for such areas. Therefore, it is necessary to evaluate the influence of fatigue damage on the heat transferring pipes and auxiliary equipment by utilizing fatigue test data for the heat transferring material and performing structural analysis, and the operation method should be derived after reviewing the possibility of generating system accidents that are expected to occur due to flexible operation from a facility operation point of view. Also, frequent start/stop and load changes of coal-fired T/Ps causes degradation of water quality (pH, partial pressure of oxygen, et.) along with changes in temperature and pressurization of superheated/reheated steam, and that can accelerate oxidization and corrosion inside the steam side tubes. In particular, in the case that peeling of the inner tube scale occurs, the scales may accumulate in the bends of the boiler tubes and cause partial overheating or move to the turbine and cause erosion of the blades, thus leading to serious problems in equipment operation. So the technology to predict and mitigate such damage needs to be secured.

The currently operated environmental facilities comprise a de-nitration facility for reducing nitrogen oxides (NOx), the precipitator for reducing dust, and a desulfurization facility for reducing sulfur oxides (Sox). These facilities have been designed and operated to achieve optimal efficiency around the rated output (100%NR) due to the characteristics of the existing coal-fired T/Ps. However, it is expected that many problems may occur in maintaining the proper performance of each facility because the temperature of the exhaust gas discharged from the boiler and the composition of the gas varies greatly depending on the load during flexible operation. In particular, in the case of the de-nitration facility, which is based on the selective catalytic reduction (SCR) process, it uses a commercial catalyst (WO_3-V_2O_5/TiO_2) that shows optimal performance in the flue gas temperature range of 350∼400℃ and achieves a conversion efficiency of 90∼95% at the rated output. However, when being operated in the minimum stable load (30~40%) at which the temperature of the gas exiting the boiler decreases down to 250℃, it is expected that the de-nitration efficiency will be degraded to 65% or below because of the decrease in conversion efficiency due to not securing an appropriate catalytic reaction temperature and catalyst deactivation due to the formation/adhesion of NH_4HSO_4(ammonium bisulfate). Therefore, developing a catalyst for the low-load operation is required, which can raise the nitrogen oxide conversion efficiency to 90% and corresponding process improvements.

In the large-capacity thermal T/Ps, improving the control algorithm and the flexibilities of the process and unit equipment are required to improve the rate of output change and reduce the minimum stable load. In particular, in cases where overshoots of process variables such as fuel amount, main steam pressure, main steam temperature, etc., occur or it takes a long time for the actual value to reach the set value, these might be a serious obstacle to the operation of the facility. Therefore, it is necessary to improve the control algorithm reflecting the advanced control, transient compensator, and time delay model, and the like to improve the unit master control stability and fuel/water/air control loops stability and develop precise tuning techniques for various control parameters. In addition, for the verification of the control algorithm developed, we decided that it is necessary to enhance the dynamic performance of the control verification simulator. The focus has been on functions for simulating the steady-state in the past. However, the necessity to enhance the reliability of the control verification by raising the fidelity of the process model as functions for simulating the transient state of the temperature/pressure/flow, etc., of each system, is becoming important due to flexible operation.

3. ANALYSIS MODEL FOR FLEXIBLE COAL-FIRED T/Ps

To evaluate the effect of applying a T/P whose flexibilities have been enhanced on the system, we developed an analytical model for the flexible coal-fired T/P first. In the case of the PSS/E from SIEMENS, which is one of the most widely used tools in system analysis, only models for generic power facilities are provided, and for specific facilities or other facilities which users may want to utilize, the users have to create a corresponding user-defined model (UDM). Also, in PSS/E, there is no model for prime movers, and only models composed of turbines and governors are provided. So the model cannot reflect all the enhancement processes for the flexible coal-fired T/P mentioned above. However, modifications to create similar response characteristics are possible.

Three items need to be enhanced for an ordinary coal-fired T/P to become a flexible coal-fired T/P. The first item is a reduction in start-up time. This is unnecessary for the system stability simulation with which we do the static analysis or short-time (several seconds) analysis, which are the main targets of this paper. The second one is the minimum stable load, and no specific model is necessary for the simulation of this item because it can be simulated by reducing the generator output down to 40% of the rating. The last one is enhancing the output increasing/decreasing performance. However, there is no parameter for directly adjusting the ramp rate of the generator in PSS/E. Therefore, in PSS/E, the goal of such analysis model is to enhance the ramp rate (%/min), which represents the capability of increasing/decreasing the output in terms of percent of the rated output, from 3%/min to 5%/min, which is similar to the ramp rate of ordinary gas turbine generators.

Prime movers have not been modeled in PSS/E. This is because detailed modeling is not necessary for mechanical equipment. In PSS/E, the IEEEG1 model shown below is used.

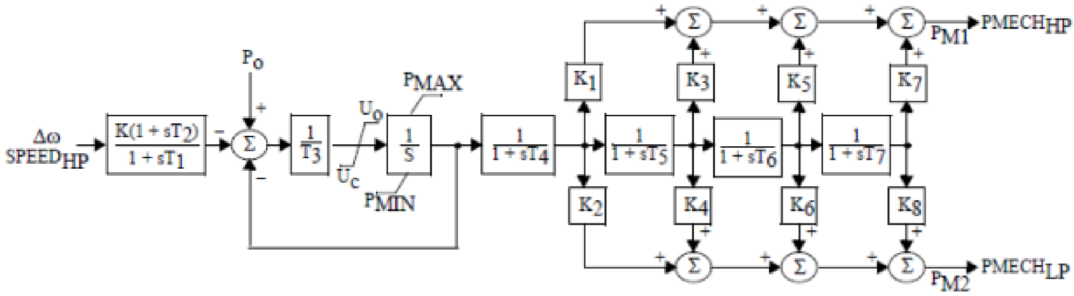

Figure 1. Block diagram of the IEEE G1 model

IEEEG1 is a steam governor model composed for frequency response or primary control, and it adjusts the amount of steam based on the measured turbine speed. In this model, if the system frequency goes down, the steam flow is increased, and the turbine speeds up, and if the system frequency goes up, the steam flow is decreased, and the turbine slows down. This is because the system frequency is synchronized with the rotation speed of the generator. The system frequency is controlled to be the rated frequency through such manipulation. Here, the manipulation being related to generator output adjustment, K represents the droop characteristics of the governor, T1 and T2 are the time constants of the lead-lag compensator, and T3 and U0 are the parameters related to the opening/closing of the steam supplying valve, representing the time constant associated with the speed of the servo motor and valve opening speed, respectively. K1~K8, T4~T7 are parameters of the stage cross-compound steam turbine. T4 ~ T7 are time constants representing the dynamics of the reheater stages, and K1 ~ K8 are gains related to the reheater stages. [8] This is contribution factor of connected turbine to rotate shaft. Normally K1, K3 are used and sum of them is become 1. The others set to be zero. Adjusting the factor K1~K8 means retrofit of turbine's structure and also needs a lot of cost and validation of design, we don't consider in this paper.

In this study, among the parameters mentioned above, we adjusted the time constant and gain of the governor, which have a great influence on the generator output while not affecting its unique properties, and checked the change in output. In the simulation, we measured the time taken for the change in generator output when adjusting the output instruction by 0.1 PU in PSS/E and additionally checked overshoot or settling time.

First, we changed the parameters of an 800 MW class generator, and the results were as shown in the figure below.

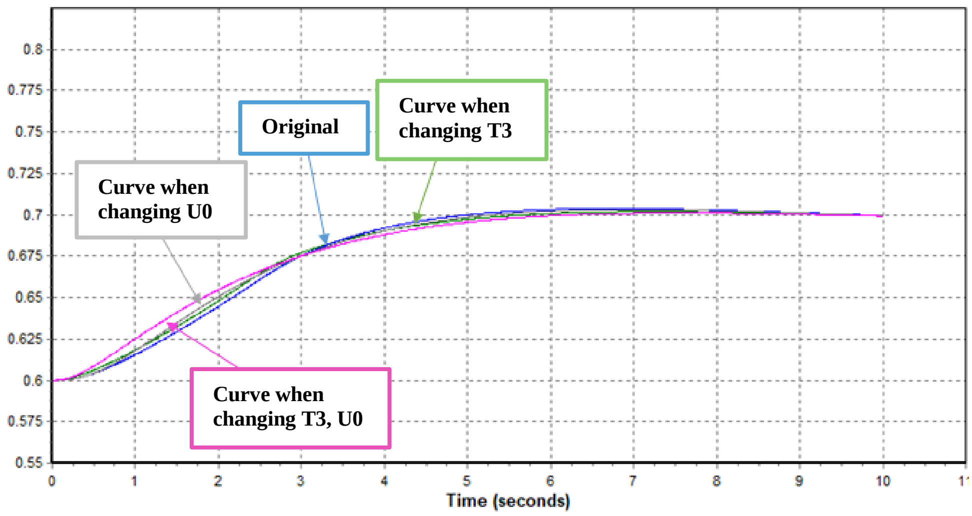

Figure 2. Changes in output due to the changes in U0, T3

We adjusted T3 and U0 separately and then adjusted both of them. We can see that, in three cases, the curves maintain similar characteristics as the original one. The simulation results for the 500 MW, 800 MW, and 1100 MW generators have been compared in the fig.3 below. This shows that the smaller the capacity, the faster the generator's response.

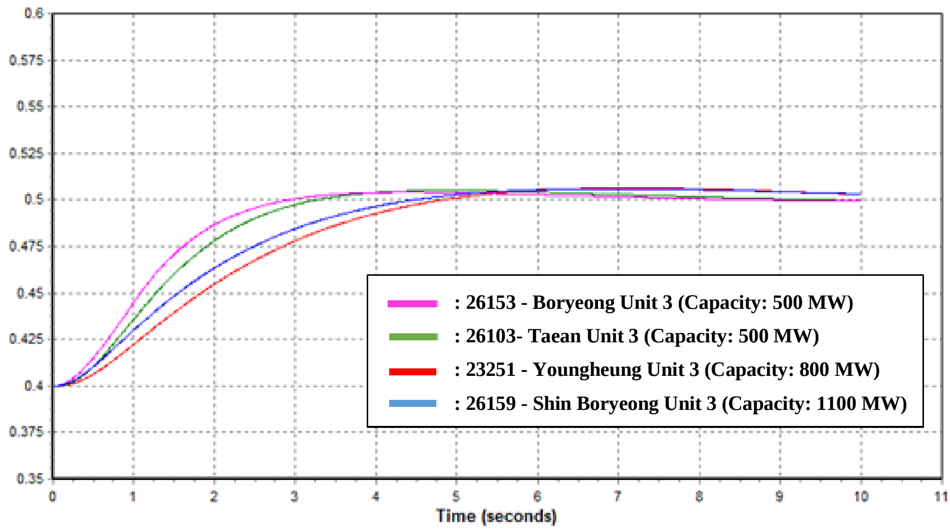

Figure 3. Response times of generators with different capacities

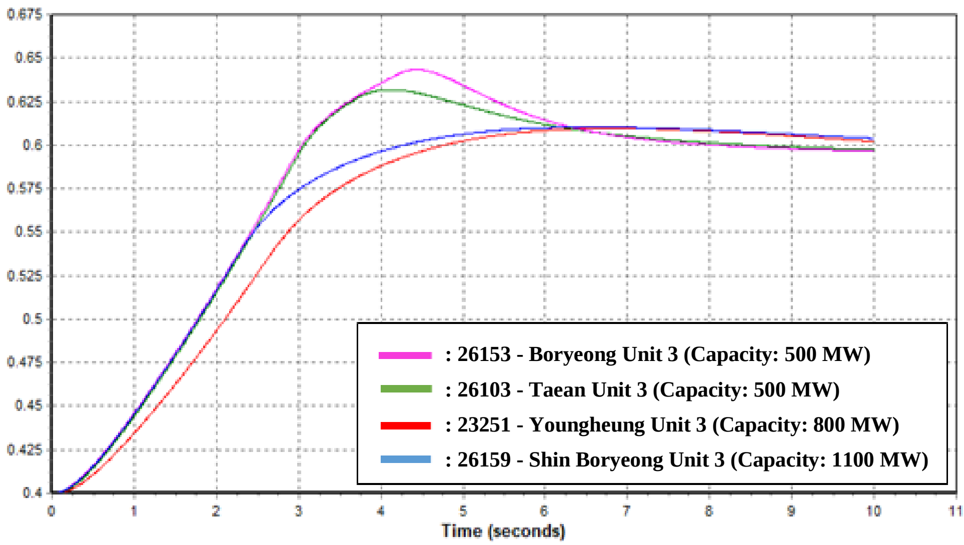

Figure 4. Overshoots of generators with different capacities (500 ~ 1,100 MW)

The fig.4 above shows the response patterns of generators when they received instructions to increase the output by 0.2 PU. As a result of the simulation, we could see that the smaller the capacity of the generator, the greater the overshoot that occurred. Therefore, we could see that, to make a generator a flexible resource, changing the parameters K and K1 is more effective than changing U0 and T3, and smaller generators respond faster but have a greater overshoot, so we cannot create the required response pattern by making one gain too big.

With such characteristics, by making the outputs of the T/Ps similar to those of gas turbines, we finally implemented the flexible coal-fired T/P, as shown in the fig.5 below. By changing K and K1 properly, we made the output of a T/P almost the same as that of a GT, and the actual time taken for changing the output, in terms of the time taken for a 0.1 PU increase when compared with an ordinary T/P, was reduced to 66%.

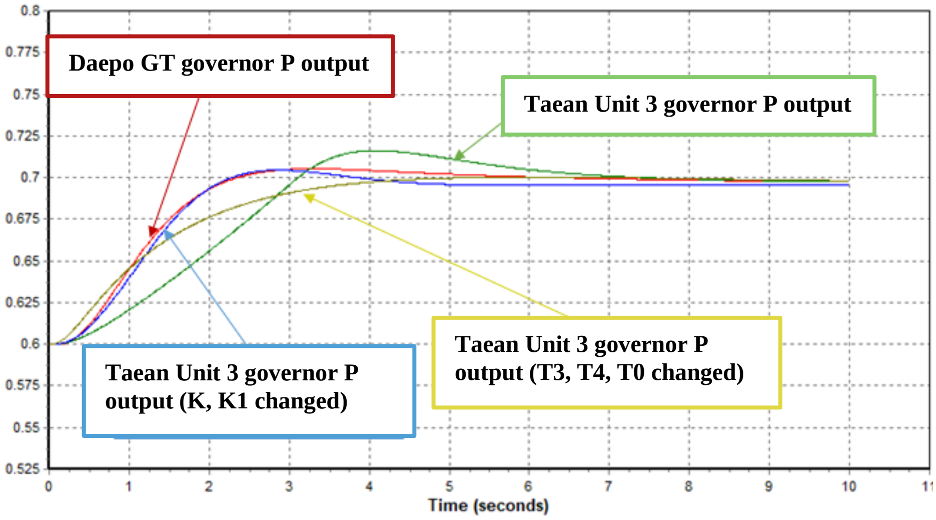

Figure 5. Output curves of coal-fired T/Ps (Existing T/P, T/P with changed K and K1, T/P with changed T3, T4 and U0) compared with a GT

4. EVALUATION OF THE EFFECT A FLEXIBLE COAL-FIRED T/P HAS ON THE SYSTEM WHEN APPLIED

In the case that flexible coal-fired T/Ps are applied, in the aspect of the power system, responses to the imbalance between demand and supply can be performed well due to the increase in the number of generators capable of adjusting the output. In this study, we applied flexible coal-fired T/Ps to the 2031 real power system in Korea based on the flexible coal-fired T/P analysis model described in the previous chapter and evaluated the effect of those flexible coal-fired T/Ps on the system. If flexible coal-fired T/Ps are applied, we can reduce the output of remote generators under operation to cover the base-load, and the line load factor or loss can be reduced accordingly.

The minimum stable load of flexible coal-fired T/Ps is about 40% of the rating. Taking this as a condition, we reduced the output of the remote, flexible coal-fired T/Ps by 1 GW and increased the generator's output near the demand by 1 GW to check the change in the line load factor. As a result of the analysis, when considering the enhancement of the line load factor, it was more effective to deploy the flexible coal-fired T/Ps on the east coast rather than the south or west coast. We need to establish a deployment plan through additional study.

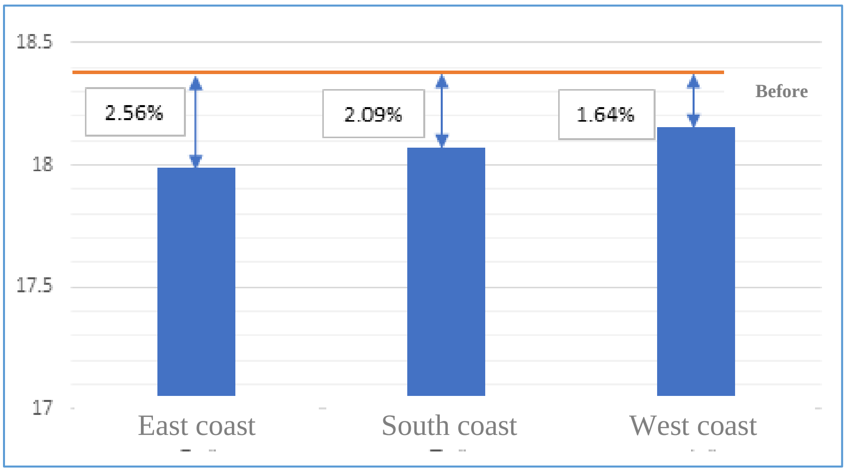

Figure 6. Enhancement of the line load factor compared with the current value

5. CONCLUSION

The purpose of this study is to retrofit old coal-fired T/Ps into flexible T/Ps and to evaluate the effect the flexible coal-fired T/Ps have on the power system when applied. We expanded the range of output adjustments through enhancements to plant boilers, heat transfer piping, desulfurization facilities, control systems, etc., and increased the speed of output increase/decrease, and thus, improved the flexible coal-fired T/P; we also established an analysis model for evaluating the effect that flexible coal-fired T/Ps would have on the system when applied and performed a simulation. As a result, we found that flexible coal-fired T/Ps effectively mitigate overloaded lines when successfully retrofitted and incorporated back into the power system. However, this study has focused on implementing flexible coal-fired T/Ps. Thus, to use high-reliability T/Ps in the system, further studies into the change in generator efficiency, increase of fatigue, etc., that can occur during facility retrofit are required, along with a continuous accumulation of operation data.

BIBLIOGRAPHY

[1] Review of the operational flexibility and emissions of gas- and coal-fired power plants in a future with growing renewables(Miguel Angel, Trevor Kirsten, Lubos Prchlik, Renewable and Sustainable Energy Reviews, Elsevier, 2018)

[2] Power system Flexibility for the Energy Transition(International Renewable Energy Agency, 2018)

[3] 9th Electric power supplement plan (government of Korea, 2020)

[4] Flexibility in thermal power plant(Agora Energiewende, 2017)

[5] Status of power system transformation (International Energy Agency, 2018)

[6] Flexibility of coal and gas fired power plants(Dr.Andreas, SIEMENS AG, 2017)

[7] Thermal power plant flexibility(Clean Energy Ministerial Campaign, 2018)

[8] PSS/E user manual MODEL