Presentation title:
Study of Energy Efficient Supercritical Power Plant Dynamic Responses and Control Strategy

Presented by:
Omar Mohamed

University of Birmingham, Power system control research laboratory

MEGS II Christmas Event
Presentation outline:

- Background.
- The mathematical model description.
- Parameter Identification.
- Parameter verification.
- Control strategy development.
- Simulation study of control performance.
- Conclusion
Background:

- By 2015, 48 GW generation capacity in the UK (60% of total present generation capacity) needs to be replaced.
- To achieve the government goals for reducing carbon emissions by 20% by 2020 and 80% by 2050, there is currently an exceptionally wide variety of renewable generation technologies being considered.
- Apart from renewable energy, it is likely that coal remains a dominant fuel for electricity generation from many years to come. No doubt, the new coal fired power plants must be cleaner.
- Supercritical coal fired plant technology is one of the leading options with improved efficiency and hence reduced CO₂ emissions per unit of electrical energy generated. Indeed, power plants using supercritical generation have energy efficiency up to 46%, around 10% above current coal fired power plants.
Background:

- There is an urgent demand to conduct the whole process of supercritical power plant dynamic response study for supercritical power plants to investigate its compliance with the UK grid code regulations.
- In this research, a mathematical model that represents the main dynamical characteristics of supercritical power plant has been developed and verified over a wide operating range.
- The model covers wide process from coal grinding/preparation to electricity to be delivered to the power system.
- A control strategy has been designed and applied to the process model to regulate the power plant key responses.
Background:

- Model predictive control (MPC) is considered to be one of the most advanced control system technologies in industry.

- The idea is based on using the MPC signals as correction (adjuster) to the reference of the plant local control.

- Simulation results have shown the controller and the plant performance in response to some load requests.

- It is proved that the grinding performance of the coal pulverisers play an important role in satisfying the regulations of the national grid code.
Coal fired power generation process
The mathematical model description

- The model is based on physical and other engineering principles.
- The method is based on considering lumped heat exchangers that are linked by algebraic equations.
- The turbine is coupled to the generator by torque balance equations and other algebraic equations.
The mathematical model description

\[
\begin{align*}
M_{rc} &= w_{rc} - K_3 M_{rc} \\
M_{pf} &= K_3 M_{rc} - w_{pf} \\
\Delta p_{mpd} &= K_8 M_{pf} + K_9 M_{rc} - K_{10} \Delta p_{mpd} \\
\dot{T}_{out} &= [K_1 T_{in} + K_{12}] \cdot \frac{\Delta p_{pa}}{w_{air} - K_{13} w_{rc} - [K_4 T_{out} + K_{15}] \cdot \frac{\Delta p_{pa}}{w_{rc}} + K_{16} P_{mill} + K_17 T_{out}] \\
w_{rc} &= K_1 \cdot F_s \\
w_{air} &= 10 \cdot \sqrt{\frac{273}{273 + T_{in}}} \times \frac{28.8}{22.4} \\
w_{pf} &= 2 \cdot \Delta p_{pa} \cdot M_{pf} \\
P_{mill} &= K_4 M_{pf} + K_5 M_{rc} + K_6 \\
\Delta p_{mill} &= K_7 \Delta p_{pa} + \Delta p_{mpd} \\
\dot{p}_{econ} &= \frac{Q_{econ} + w_{f}, I_{1} - w_{1} I_{o2}}{C_{econ}} \\
\dot{p}_{ww} &= \frac{Q_{ww} + w_{1} I_{o2} - w_{2} I_{o2}}{C_{ww}} \\
\dot{p}_{sh} &= \frac{Q_{sh} + w_{2} I_{13} - w_{3} I_{o3}}{C_{sh}} \\
\dot{p}_{ms} &= \frac{w_{3} I_{14} - w_{1} I_{o4}}{C_{ms}} \\
\dot{p}_{rh} &= \frac{Q_{rh} + w_{ms} I_{15} - w_{rh} I_{o5}}{C_{rh}} \\
\dot{\omega}_h &= \frac{1}{M_h} \left[ \frac{1}{\Gamma_{hp} - D_{hp} - \omega_{hp}} - K_h (\theta_{hp} - \theta_{ip}) \right] \\
\dot{\theta}_h &= \omega_{hp} (\omega_{hp} - 1) = (\omega_{hp} - 1) \\
\dot{\omega}_p &= \frac{1}{M_p} \left[ \frac{1}{\Gamma_{ip} - D_{ip} - \omega_{ip}} + K_i (\theta_{hp} - \theta_{ip}) \right] \\
\dot{\theta}_p &= \omega_{ip} (\omega_{ip} - 1) = (\omega_{ip} - 1) \\
\dot{\delta} &= \Delta \omega \\
J \cdot \Delta \dot{\omega} &= \Gamma_m / \Gamma_e - D \cdot \Delta \omega \\
\dot{e}_q &= \frac{1}{t_d} \left( E_{FD} - e_q - (x_d - x_d') \cdot i_d \right) \\
P_{hp} &= w_{ms} \cdot \Delta h_1 \\
P_{ip} &= w_{rh} \cdot \Delta h_2 \\
P_{mech} &= P_{hp} + P_{ip} \\
P_{hp}(p.u) &= \frac{P_{hp}}{600} \\
\Gamma_{hp} &= \frac{P_{hp}(p.u)}{\omega_{hp}(p.u)} \\
P_{ip}(p.u) &= \frac{P_{ip}}{600} \\
\Gamma_{ip} &= \frac{P_{ip}(p.u)}{\omega_{ip}(p.u)} \\
\Gamma_{mech}(p.u) &\approx P_{mech}(p.u) \\
\Gamma_{hp}(p.u) &\approx P_{hp}(p.u) \\
\Gamma_{hp}(p.u) &\approx \frac{V}{x_a} \cdot \delta' \cdot \sin \delta + \frac{V^2}{2} \cdot \left( \frac{1}{x_a} - \frac{1}{x_d} \right) \cdot \sin 2 \delta \\
\end{align*}
\]
Parameter identification

SUPERCRITICAL BOILER-TURBINE GENERATOR MODEL

FITNESS FUNCTION

≤ f_{min} → YES

NO → Measured responses

Simulated responses

GENETIC ALGORITHMS
(Reproduction, crossover, mutation... etc)

≤ f_{min} → YES

NO → Stop and save results
Parameter verification

- Electrical Power (MW)
- Main steam Flow (Kg/s)
- Main steam pressure (MPa)

Graphs showing the comparison of Plant response and Model response over time.
The Control Strategy

- The model has been identified by on-site measurement data. The generic SISO control loops is already installed.
- The idea is then should be based on using the signal of the designed multivariable controller as correction to the reference of the plant local controls (the mill controller, the turbine control or governor, and the feedwater pump).
- The MPC depends mainly on the quality of prediction of its internal model.
The Control Strategy

Model predictive control (Supervisor)

- Coal Mill Local Control
- Feedwater Flow Command
- Turbine control governor
The Control Strategy

- Reduced order linear model has been developed and identified to match the response of the process model which is regarded as a plant.
The Control Strategy

- It is noticed that the MPC performance are acceptable within a limited range of operation.
- This problem can be handled by extending the MPC internal prediction with three identified local models or by using compensators in parallel with the MPC.
- The MPC show good performance over a wide range of simulation studies.
- The MPC plays and the mill local control play an important role in speeding-up the response of the mill and thus improves the overall plant responses.
Simulation study

![Graph of Power vs Time for Case A and Case B]

![Graph of Main Steam Pressure vs Time]

![Graph of Main Steam Temperature vs Time]
Simulation study

- More coal have been discharged from the mills to the burners because which is the main reason behind the enhanced power response.
- More water is pumped to the boiler to avoid overheating the boiler surfaces due to the increased fuel firing.
This figure shows the variables of each mill in service. It is noticed that higher mill pressure is created to carry more pulverized fuel to the burners.

- the feeder speed is increased to fill in the mill with more raw coal and keep the energy storage in the mill at desired level for giving quicker responses.
A model based physical principles has been developed for SCPP.

Simulation results indicates the model can simulate the main dynamic response variation trends of the 600MW SC power plant process.

A coordinate control is proposed and tested through simulation study with relatively large load variations. The control considers the milling process as a key stage for power plant dynamic response improvement.

From the study, it is convinced that better control of the milling process can improve the power plant load following capability and/or primary response of the plant power.
Thank You

any questions???