Modeling of Gas Turbine and Its Control System

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Gas Turbine Scheme
Brayton Cycle

• The cycle is made up of four completely irreversible processes:
  1-2 Isentropic Compression;
  2-3 Constant Pressure heat addition;
  3-4 Isentropic Expansion, and
  4-1 Constant Pressure heat rejection

Temperature Entropy diagram
Brayton Cycle

- Air is first compressed in an adiabatic process with constant entropy within the compressor (process 1–2), usually an axial compressor. Pressure of 13–20 times that of atmospheric is achieved after the compression stage.
- Fuel, either liquid or gas is then mixed with the compressed air and burnt in the combustor (process 2–3). After which, the hot gasses is allowed to expand through the turbine (process 3–4). This gas expansion drives the blades of the turbine and consequently the shaft of the generator connected to it.
Transfer Function Block Diagram: Rowen’s Model
GT Controls modelled

• There are four blocks related with **speed/load control**, **temperature control**, **fuel control**, and **air control**.

• **Speed/load control**: determines the fuel demand according to the load reference and the rotor speed deviation.

• **Temperature control**: restricts the exhaust temperature not to injure the gas turbine. The measured exhaust temperature is compared with the reference temperature. The output is the temperature control signal.
GT Controls

• The fuel demand is compared with the temperature control signal in the **fuel control block**. The lower value is selected by the low value selector, and it determines the fuel flow.

• The **air control block** adjusts the airflow through compressor inlet guide vanes (IGV) so as to attain the desired exhaust temperature. The exhaust temperature is kept lower than its rated value (say 1%).
Airflow Control

- The adjustable airflow is about 30% of the rated airflow. The adjusting speed is slow compared with the fuel flow.
- The airflow is proportional to the rotor speed.
GT Operating parameters

$W_f =$ fuel flow,
$W =$ the airflow, $T_e =$ Exhaust temperature,
$Tr =$ reference temp. $T_f =$ turbine inlet temp
Generation of Valve Control signal
Power Output
Temperature control
Rotor Inertia
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>Gain = 1/ droop (pu MW / pu speed)</td>
<td>16.7</td>
</tr>
<tr>
<td>X</td>
<td>Governor lead time constant (s)</td>
<td>0.6</td>
</tr>
<tr>
<td>Y</td>
<td>Governor lag time constant (s)</td>
<td>1.0</td>
</tr>
<tr>
<td>Z</td>
<td>Governor mode (1=droop, 0=isochronous)</td>
<td>1</td>
</tr>
<tr>
<td>MAX</td>
<td>Demand upper limit (pu)</td>
<td>1.5</td>
</tr>
<tr>
<td>MIN</td>
<td>Demand lower limit (pu)</td>
<td>-0.1</td>
</tr>
<tr>
<td>a</td>
<td>Valve positioner</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>Valve positioner</td>
<td>0.05</td>
</tr>
<tr>
<td>c</td>
<td>Valve positioner</td>
<td>1</td>
</tr>
<tr>
<td>$W_{MIN}$</td>
<td>Minimum fuel flow</td>
<td>0.23</td>
</tr>
<tr>
<td>$T_F$</td>
<td>Fuel control time constant (s)</td>
<td>0.4</td>
</tr>
<tr>
<td>$K_F$</td>
<td>Fuel system feedback</td>
<td>0</td>
</tr>
<tr>
<td>$E_{CR}$</td>
<td>Combustion reaction time delay (s)</td>
<td>0.01</td>
</tr>
<tr>
<td>$E_{TD}$</td>
<td>Turbine and exhaust delay (s)</td>
<td>0.04</td>
</tr>
<tr>
<td>$T_{CD}$</td>
<td>Compressor discharge volume time constant (s)</td>
<td>0.2</td>
</tr>
<tr>
<td>$T_R$</td>
<td>Turbine rated exhaust temperature (°F)</td>
<td>950</td>
</tr>
<tr>
<td>$T_T$</td>
<td>Temperature controller integration rate (°F)</td>
<td>450</td>
</tr>
<tr>
<td>$f_1$</td>
<td>$T_x = T_R - 700(1-W_F) + 550(1-N)$</td>
<td></td>
</tr>
<tr>
<td>$f_2$</td>
<td>$1.3(W_F - 0.23) + 0.5(1-N)$</td>
<td></td>
</tr>
<tr>
<td>$T_I$</td>
<td>Inertia = 2*H</td>
<td>15.64</td>
</tr>
</tbody>
</table>
Simplified GT Model
PID Governor Detailed Model

The droop circuit includes an intentional filter time constant, $T_d$, of 0.8 s.
GT Models in PSS/E

- GAST Gas turbine-governor model
  - Simple model
- GAST2A Gas turbine-governor model
  - Similar to the Rowen model
- GASTWD Gas turbine-governor model
  - Suitable for Woodward governors
## GAST Model in PSS/E

![Diagram of GAST Model in PSS/E]

- **Fuel valve opening**
- **Flow**
- **Exhaust Temp**

### Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R (speed droop)</td>
<td>0.05</td>
</tr>
<tr>
<td>T1 (&gt;0) (sec)</td>
<td>0.4</td>
</tr>
<tr>
<td>T2 (&gt;0) (sec)</td>
<td>0.1</td>
</tr>
<tr>
<td>T3 (&gt;0) (sec)</td>
<td>3</td>
</tr>
<tr>
<td>Ambient temperature load limit, AT</td>
<td>3</td>
</tr>
<tr>
<td>KT</td>
<td>1</td>
</tr>
<tr>
<td>VMAX</td>
<td>2</td>
</tr>
<tr>
<td>VMIN</td>
<td>0.95</td>
</tr>
<tr>
<td>Dturb</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
Step change in Speed Reference

Each division 10 Seconds
Each division 10 Seconds
Twin Shaft GT
Permanent Droop using CDP

- Compressor Discharge Pressure (CDP) rather than valve position or electrical power feedback is used for permanent droop setting on some units

- Typical values of CDP versus output power is shown in the table

<table>
<thead>
<tr>
<th>Active Power (MW)</th>
<th>Compressor Discharge Pressure (PSIa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>110.6</td>
</tr>
<tr>
<td>11</td>
<td>211.5</td>
</tr>
<tr>
<td>30</td>
<td>326.7</td>
</tr>
<tr>
<td>40</td>
<td>386.5</td>
</tr>
<tr>
<td>45</td>
<td>408.8</td>
</tr>
<tr>
<td>48</td>
<td>426.6</td>
</tr>
</tbody>
</table>
The discontinuity between 25% and 40% power is when the water injection and inlet guide vanes go into service.
On line Step response
Off line Step response
Typical frequency response curves
OUTER LOOP CONTROLS:  
*Load control*

- Some units are operated with an outer-loop active power controller. Digital Unit Controller produces a pulse to the governor raise or lower input that is proportional to the distance away from the MW set-point.
- The governor is programmed to ramp the reference at a rate of 0.3%/s when receiving these pulses.
Outer Loop Control : pf/VAr Controller

- Many gas turbine units are equipped with a pf/VAr controller which is in service whenever the unit is on-line. This is an outer-loop control, which monitors generator stator reactive current and controls to a fixed VAr or pf set-point.
- The controller is often used in pf mode, controlling to unity power factor.
- The control structure is an “integrator with gain” feedback to the AVR set-point.
Pf/ VARController

• To ride through system transient disturbances, the control should be as slow as possible, however, too long a setting will result in operator intervention and overshoot in the resulting unit operating point.
Simulink Model
FIG NO.  BLOCK DIAGRAM OF A GAS TURBINE
SIMULATION OF GT GOVERNOR SYSTEM

Different positioner gains
Combined cycle

• Heat engines are only able to use a portion of the energy their fuel generates (usually less than 30%). The remaining heat from combustion is generally wasted.

• Combining two or more "cycles" such as the Brayton cycle (Gas Cycle) and Rankine cycle (Steam Cycle) results in improved overall efficiency.
Simple GT cycle

- AIR INLET
- FUEL
- COMBUSTOR
- EXHAUST GAS
- COMPRESSOR
- TURBINE
- DRIVEN EQUIPMENT
Combined cycle plant
Combined Cycle (Brayton & Rankine Cycles)

- Low Pressure Steam (For Deaeration)
- Intermediate Pressure Steam (To Intermediate Pressure Steam Turbine)
- High Pressure Steam (To High Pressure Steam Turbine)

Diagram:
- Air inlet
- Fuel inlet
- Combustor
- Heat Recovery Steam Generator
- Generator
- Electric power
- Gas turbine
- Steam turbine
- Condensate return to HRSG
- Steam exhaust
HRSG

- Steam is generated by firing hot exhaust gases from Gas turbines (GTs)
- Remaining steam required is generated by firing Supplementary fuel.
Typical Industrial Cogeneration System

- AIR INLET FILTER
- AIR INLET FILTER
- GENERATOR
- GAS TURBINE
- EXHAUST BYPASS SILENCER
- DIVERTER VALVE
- HEAT RECOVERY STEAM GENERATOR (HRSG)
- SUPPLEMENTARY BURNER
- EXHAUST SILENCER
- PROCESS STEAM
Steam Turbine
Combined Cycle Power Plant
GAS TURBINES

- 3 Nos, GE Frame-6 machines supplied by NP, Italy.
- GT # 1 & 4 are having BLACK START CAPABILITIES.
- All gas turbines are capable to run at base load with spread well within the limit:

<table>
<thead>
<tr>
<th>Machine</th>
<th>Design output (MW (ISO))</th>
<th>Design output (MW (35°C))</th>
<th>Site output (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 6541</td>
<td>37.52</td>
<td>32.64</td>
<td>28.7</td>
</tr>
<tr>
<td>PG 6551</td>
<td>38.48</td>
<td>33.48</td>
<td>28.7</td>
</tr>
<tr>
<td>PG 6561</td>
<td>38.82</td>
<td>33.77</td>
<td>28.7</td>
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</tbody>
</table>
### HRSG

**HHP Steam (TPH)**

<table>
<thead>
<tr>
<th></th>
<th>BHEL HRSGs (06 nos.)</th>
<th>DBPS HRSG (01 No.)</th>
<th>Thermax HRSG (01 No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>53-55</td>
<td>53-55</td>
<td>53-55</td>
</tr>
</tbody>
</table>

### Steam (TPH) | Design (TPH) | Max (TPH)

<table>
<thead>
<tr>
<th></th>
<th>BHEL HRSGs (06 Nos.)</th>
<th>DBPS HRSGs (01 No)</th>
<th>Thermax HRSGs (01 No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam (TPH)</td>
<td>125</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>Design (TPH)</td>
<td>125</td>
<td>125</td>
<td>134*</td>
</tr>
<tr>
<td>Max (TPH)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

(* Steam flow for one hour in 08 hrs. shift)
All 4 STGs are tested to deliver 30 MW of power.

Steam turbines are provided with HP and MP extractions.

Maximum steam flow through one steam turbine shall be as follows:

- **262 TPH HHP steam (Max)**
  - Pressure: 109 Kg/CM² @ 505 DegC

- **180 TPH HP steam (Max)**
  - Pressure: 44.8 Kg/CM² @ 383 DegC

- **80 TPH MP steam (Max)**
  - Pressure: 18.8 Kg/CM² @ 282 DegC

- **60 TPH to Condenser (Max.)**
- **20 TPH to Condenser (Min.)**

**Normal steam flow**

- **HP section = 15.27 MW**
- **MP section = 5.73 MW**
- **LP section = 11.81 MW**
Auxiliary Boilers

- All 4 Auxiliary Boilers are capable to deliver 125 TPH, at 115 KG/CM² (g) and 510 Deg C.
- 10% overload margin i,e 137 TPH at 110 KG/CM² (g) and 510°C also tried for 01hr.
Six PRDS are provided to supply HP, MP & LP steam to the process. PRDS is sized to meet the demand normally met by two steam turbines on the basis that one trips whilst another is out of service for maintenance.

Design flow rates (TPH) of PRDS are:

<table>
<thead>
<tr>
<th></th>
<th>Min.</th>
<th>Normal</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHP to HP</td>
<td>21.4</td>
<td>80</td>
<td>186.3</td>
</tr>
<tr>
<td>HP to MP</td>
<td>24.9</td>
<td>47.4</td>
<td>138</td>
</tr>
<tr>
<td>MP to LP</td>
<td>9.1</td>
<td>34.9</td>
<td>120</td>
</tr>
<tr>
<td>Start up &amp; letdown (HHP to HP)</td>
<td>-</td>
<td>12.5</td>
<td>25</td>
</tr>
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</table>
# STEAM SYSTEM

<table>
<thead>
<tr>
<th>Boilers</th>
<th>Nos.</th>
<th>Nos. in operation</th>
<th>Generation (TPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary Boilers</td>
<td>4</td>
<td>4</td>
<td>500</td>
</tr>
<tr>
<td>HRSGs</td>
<td>8</td>
<td>8</td>
<td>880</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>12</td>
<td>1380</td>
</tr>
</tbody>
</table>

- Auxiliary boilers able to ramp up 9 MT /Min/boiler in case of emergency without much pressure variation at HHP level.
- Able to meet steam demand when both PRTs trip.
- Able to supply HP and MP steam, without pressure drop, if STG trips.
CPP Generation and Distribution Overview
Power Plant Control

• Plant parameters are to be maintained by closed loop control
• Boiler: Steam parameters like pressure, temperature, other process parameters like furnace pressure, drum level
• Turbine- Generator : Power (MW), speed or frequency
Need for Control

- **Mismatch** in generation and consumption causes deviation in plant parameter
- Mismatch in steam flow: pressure change
- Mismatch in heat flow: temperature change
- Mismatch in power: speed change
- Mismatch in gas flow: furnace. pr. change
Control Systems

• GTG Control System (GE Mark V)
• STG Control System (GHH Borsig)
• Burner Management System (AB PLC): 48
• Foxboro DCS
Control Systems

- Distributed control System (Foxboro) - 38 nodes
- Emergency Shutdown System (Triconex) - 26 no.
- Fire & Gas System (Wormald) - 35 no.
- Machine Condition Monitoring System (Bentley Nevada) - 23 no.
- Automatic Tank Gauging System (SAAB) - 259 no.
Electrical Load Distribution Management System

- **Two major functions**
  - Load management System (LMS)
  - Electrical Distribution Management System (EDMS)

- **LMS functions:**
  - Load shedding
  - Active/Reactive power control
  - Synchronisation

- **EDMS main functions:**
  - Data logging & reporting
  - Circuit breaker control
  - Power System Event Recording & Alarm Annunciation's
Combined Cycle Plant: Scheme for Modeling
Model of Combined Cycle Power Plant