MAVEN POWER

Gas Turbine
Control System Basics

Presented to: ASME South Texas Section
Gas Turbine Technical Chapter
Overview

- Introduction
- Basics of Turbine Control Systems
- Types & Technical Considerations
- Turbine Controls Differentiators
- Case Study on TCS Retrofit
Introduction to Maven Power

- Est. 2005, Houston-based
- Specialize in EPC support, Balance of Plant for On-site Power Generation
- Thermal Power Generation 2-20 MW range
- Engineering to Turn-key
  - Custom applications
  - Complex projects
  - Single source for integration
  - Repowering, rework
- Markets
  - Oil & Gas
  - Utility
  - Large Industrial
  - Hospitality
Offerings

- Engineering, design & integration
- Balance of Plant Procurement
- Fuel systems
- Swgr, Trafos, Distro gear
- Automation & Controls
- Startup & Commissioning
About Me

- Aircraft Controls to Stationary Power
- Turbine Controls Engineer for GE
  - From Relay Logic/Black Boxes
  - PLCs on new or refurbished packages.
- Legacy with GE, CAT, Solar, Alstom, and other OEMs.
- 20 years in EPC power generation projects.
Basics of Turbine Controls

- Inputs
- Outputs
- Controller
- Communications
- Data Analytics
Basics of Turbine Controls

- Inputs
  - Speeds
  - Temperatures
  - Pressures
  - Flows
  - Discrete Status/Control
  - Vibration Sensors
Basics of Turbine Controls

- **Inputs**
  - Speeds
  - Temperatures
  - Pressures
  - Flows
  - Discrete Status/Control
  - Vibration Sensors
  - A/D Converters
    - 16 bit (65,535 steps)
Basics of Turbine Controls

- Outputs
  - Fuel Actuator/Valve Positioners
  - Variable Geometry
  - Annunciations
  - Electrical (VFD speeds, excitation)
  - Discrete, Commands
  - D/A Converters
Basics of Turbine Controls

- Controller
  - Mechanical
  - Pneumatic
  - Hydraulic
  - Analog
  - Digital

Fig. 4.—Governor and Throttle-Valve.

R. Routledge - Image from "Discoveries & Inventions of the Nineteenth Century" by R. Routledge, 13th edition, published 1900
Basics of Turbine Controls

- Controller
  - Mechanical
  - Pneumatic
  - Hydraulic
  - Analog
  - Digital
Basics of Turbine Controls

- Controller
  - Mechanical
  - Pneumatic
  - Hydraulic
  - Analog
  - Digital
Basics of Turbine Controls

- Controller
  - Mechanical
  - Pneumatic
  - Hydraulic
  - Analog
  - Digital
Basics of Turbine Controls

- Communications
  - Peer to Peer
  - SCADA
  - LAN/WAN
  - Distributed Control
  - IIOT
  - HMI (Human Machine Interface)
  - Annunciations
Basics of Turbine Controls

- Industrial Data Analytics
  - Data Collection
  - Cloud
  - IED (Intelligent Electronic Devices)/Sensors
  - Condition Monitoring & Machine Learning
    - Performance
    - Availability/Reliability
    - Health Assessment
    - Predict Breakdowns
Types of Turbine Controls

- Legacy Relay Logic
- Black Box
- Digital Controllers
Types of Turbine Controls

- Legacy Relay Logic
  - Analog Systems
  - Obsolescence
  - Lack of OEM Support
  - Reliability
Types of Turbine Controls

- Black Box Types
  - Still Common Today
  - May be analog or digital
  - Perform higher level controls
  - Can be mixed with relays/PLCs
  - Dedicated to CGT or others
Types of Turbine Controls

- Digital Controller
  - PLCs
  - DCSs
  - Digital “Black Boxes”
Types of Turbine Controls

- Digital Controller
  - Most Common
  - High Flexibility
  - Open Source
  - Remote I/O
  - Speed/Memory
Types of Turbine Controls

- Programming Languages
  - Ladder Logic
  - Function Block
  - Sequential Flow Chart
  - Text Languages
Technical Considerations

- Today’s Turbine Control Systems – Extremely Complex
  - Turbine Controls
  - Auxiliaries (Steam Inj, Water, Oil)
  - HRSG/Boiler/STG
  - Cooling Towers, Condensers
  - Fuel Delivery, filtration, compression, treatment
  - Compressor/Pump
  - Pipe & Valve Skids
  - Safety Systems (fire & gas detection/suppression)
  - Backup/Blackstart Power
  - SCRs, Emissions Control
Technical Considerations

- But fundamentally, GTs controlled by only 2 controls....
Technical Considerations

- But fundamentally, GTs controlled by only 2 controls….
  - 1) Fuel Control
  - 2a) Excitation (Generators)
  - 2b) Pressure/Flow (Compressor/Mech Drv)
Technical Considerations

- PID Controller for Industrial Processes
  - Proportional
  - Integral
  - Derivative
  - 1911 Nicolas Minorsky - Navy Ship Steering
    - course correction based on current, past, and ROC errors
Some PID Basics

- PID Equation

\[ u(t) = K_p [e(t) + \frac{1}{T_i} \int e(t) dt + T_d \frac{de}{dt}] \]
Some PID Basics

- PID Equation

\[ u(t) = K_p [e(t) + \frac{1}{T_i} \int e(t) dt + T_d \frac{de}{dt}] \]

PI Controller

- NGP\(_{SP}\) = 100%
- e = 2%

Turbine System

- System Dynamics
- Friction, Ambients
- Actuator Character.
- Oper. Point/Load
- Inertia/Momentum

- NGP\(_{ACTUAL}\) = 98%
Some PID Basics

- PID Equation

\[ u(t) = K_p [e(t) + \frac{1}{T_i} \int e(t) dt + T_d \frac{de}{dt}] \]
Some PID Basics

- Unit Step: Proportional Control Only, $K_p$
  - Rapid Rise Time
  - Steady State Error
  - Overshoot
  - Settling Time
Some PID Basics

- Unit Step: Proportional + Integral Control, Kp + Ti
  - Slower Rise Time
  - No Steady State Error
  - Low Overshoot
  - Similar Settling Time
Some PID Basics

- PID Parameter Effect on Control Response

<table>
<thead>
<tr>
<th>Control</th>
<th>Rise Time</th>
<th>SS Error</th>
<th>Overshoot</th>
<th>Settling Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportional</td>
<td>Reduce</td>
<td>Reduce</td>
<td>Increase</td>
<td>Minimal Effect</td>
</tr>
<tr>
<td>Integral</td>
<td>Reduce</td>
<td>Reduce</td>
<td>Increase</td>
<td>Increase</td>
</tr>
</tbody>
</table>

- Manual or Automatic Tuning
  - Adjust manually until desired response is achieved
  - Ziegler Nichols, Relay oscillation, Commercially available software
Turbine Controls Differentiators

- Critical Systems w/ large consequential damages
- Require high reliability, no blue screens
- Control machine dynamics
  - High speed, Large inertias and rotational kinetic energy
  - Speeds of > 15,000 rpm
  - MPU, T/C signals still hardwired
- Risks
  - High pressures/temperatures
  - Combustible gases
  - High Voltage
Turbine Controls Differentiators

- Integration with other complex systems and controls
Turbine Controls Retrofit Case Study

- 6.5MW Tornado, STIG Unit, 60Hz, 4160V
- Methanol plant, South America
- Replacement of 1998 EGT Controls
- Fuel Valve and other instrumentation replacement
- Non-OEM replacement
- Significant re-engineering
Turbine Controls Retrofit Case Study
Control System Implementation Steps
- Understand the system (documentation, drawings, software)
- Is OEM support required?
- What engineering effort is required?
- Identify end devices and I/O count & type, compatibility
- Determine level of expandability and flexibility required
- Existing controls or DCS compatibility
- Capabilities of internal resources for support
- Impact on Balance of Plant
- Product support lifecycle
- Installed base, how common is each component?
Turbine Controls Retrofit Case Study

- Specialized Turbine Programmable Controller Selected
  - Lower Cost
  - No plans for expansion of GT systems
  - Specialty 3rd party expansion modules used for vibration, fire/gas systems
  - Simple BoP Requirements
  - Electrical system same
Thank you for your attention

David C. Oehl, P.E.
Managing Director

www.mavenpower.com
Tel: +1 (832) 286-1123
3707 Cypress Creek Parkway
Houston, TX 77068