Gas Turbine Control & Protection Systems
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PAL Engineering
Control Systems
What must be "controlled" on GE gas turbines?
✓ **Turbine Shaft Speed**
✓ **Rate of Change of Speed**
  (a.k.a. Shaft Acceleration)
✓ **Exhaust Temperature**
✓ **Rate of Change of Temperature**
✓ **Air Flow through Compressor**
TNH units: RPM or % speed

Acceleration: RPM/second or % speed/second

TTX units: Degrees Fahrenheit (°F)

Exhaust Temperature Rate: °F per second

Airflow: lbs-air per hour

(actual flow not measured)
What devices do the controlling?
- Liquid Fuel Bypass Valve
- Gas Stop Speed/Ratio Valve
- Gas Control Valve
- Variable Inlet Guide Vanes
Modern GE
Control Systems
Mark IV Control Panel, TMR
(1982 – 1989 Era)
Mark IV Operator Panel

SPEED TRONIC
GAS TURBINE CONTROL SYSTEM

RUN STATUS 23 AUG 88 14:18:38

BASE LOAD
SELECT AUTO + BASE SPREAD 17 deg F
CTRL TEMPERATURE IGV 84.00% GA
TX 9000 deg F MAX 765 0.25 in/s
SPEED 100.0% SPD
TNSSET 103.84% SPD
FSR 78.9% FSR
FUEL 100.0% OIL IGV FULL OPEN

SELECT

1 2 3
4 5 6
7 8 9
* 0 #

EMERGENCY OFF

SELECT

1 2 3
4 5 6
7 8 9
* 0 #

EMERGENCY OFF
Mark IV Screen
Mark V Control Panel, TMR

(1989 – 2000 Era)
Human Machine Interface
Original <I> versus New <HMI>
Human Machine Interface
(Close-up of HMI Main Screen)
Typical HMI Screens
(Mark V)
Control Principles
Minimum Value Select:

The control sub-system “calling for” the least fuel flow will be in command.
Simplified
Minimum Value Select

(18) TC’s

%TNH
SPEED
GEN. LINE VOLTAGE
SYNC
ACCELERATION RATE
START UP

FSR Limits

MINIMUM VALUE SELECT LOGIC

TO CRT DISPLAY

FSR

FUEL SYSTEM

TO TURBINE
Min & Max Value Gates

MIN (6 inputs)

MAX

MIN (6 inputs)
✓ Liquid Fuel Bypass Valve, BPV
✓ Gas Stop Speed/Ratio Valve, SRV
✓ Gas Control Valve, GCV
✓ Variable Inlet Guide Vanes, IGV
Triple Modular Redundant (TMR) (Speedtronic™ Mark IV thru VI)

![Diagram of TMR system with connections to various components like BPV, SRV, GCV, and IGV.]
Temperature Profile Diagram
(Base Load Operation)

Temperature Profile Diagram
(Base Load Operation)

INLET                EXHAUST

- INLET: Ambient temperature is 59°F.
- COMBUSTION: Temperature rises to 3000°F.
- TURBINE: Temperature drops to < 2020°F.
- EXHAUST: Temperature drops to 500°F.

TTX = 1000°F
Pressure Profile Diagram
(Base Load Operation)

INLET

EXHAUST

150 psia >

14.7 psia

14.3 psia

< Pressure >

< 149 psia

14.7 psia

dotted line graph >
Gas Turbine Start-up Curves

- TTX = 900°F
- TTX = 550°F
- %TNH
- Exh. Temp
- Speed
- Fuel Stroke Ref, FSR
- 26%
- 19.5%

Graph showing start-up curves for a gas turbine.
# Fuel Stroke Reference

*(FSR constants for Start-up)*

## Start-up FSR Algorithms

### Constants List

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<tr>
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<th>Value</th>
<th>Units</th>
<th>Scale</th>
<th>Definition</th>
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<td>FS_KSU_AR</td>
<td>37.5000</td>
<td>%</td>
<td>PCT</td>
<td>STARTUP FSR ACCELERATION LIMIT</td>
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<tr>
<td>FS_KSU_FI</td>
<td>26.2500</td>
<td>%</td>
<td>PCT</td>
<td>STARTUP FSR FIRING</td>
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<tr>
<td>FS_KSU_IA</td>
<td>0.05100</td>
<td>%/sec</td>
<td>PCT_S</td>
<td>STARTUP FSR ACCELERATION RAMP RATE</td>
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<tr>
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<td>5.00100</td>
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<td>PCT_S</td>
<td>FSR RAMP RATE TO MAXIMUM</td>
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<td>FS_KSU_TC</td>
<td>1.000</td>
<td>sec</td>
<td>SEC64</td>
<td>STARTUP FSR TIME CONST DURING LOWER</td>
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<tr>
<td>FS_KSU_WU</td>
<td>19.5000</td>
<td>%</td>
<td>PCT</td>
<td>WARMUP FSR</td>
</tr>
</tbody>
</table>
Fuel Control Principles

Fuel Flow is proportional to:

- Bypass Valve Position
- Fuel Pump Speed

\[ FFN = f \left( \% \text{FSR} \right) \times \left( \% \text{TNH} \right) \]
Liquid Fuel Flow

- **TNH** measured 0 to 100 % speed
- **FFN** measured in frequency
  (measure speed of flow divider)
- **FSR** measured 0 to 100 percent
  of Bypass Valve (full open to closed)

\[ FFN = f(\%FSR) \times (\%TNH) \]
Liquid Fuel Flow Principles

- Fuel Pump is driven by Turbine through Accessory Gear Box (% TNH)
- By-pass Valve Position is controlled by Speedtronic™ Panel (% FSR)
- Flow divider speed is proportional to fuel flow (FFN, gal/min)
Liquid Fuel Control Fundamentals

\[ FFN = f(\%FSR) \times (\%TNH) \]

- FFN > 70.7 cps/gpm

\%FSR > < FFN < \%TNH
Liquid Fuel Bypass Valve

Servovalve 65FP > Bypass Valve
Flow Divider

Speed Pickup (77FN-1)
Flow Divider
Speed Pickups (77FN-2, 3)
Flow Divider Characteristic:

60-tooth wheel
4600 cps = 65 gallons/min

Therefore, 70.7 cps per 1.0 gpm
Liquid Fuel Flow Calibration
(from GE Control Specifications, ISO conditions)

Fuel Flow = \( \cdot 0085 \times (%FSR) \times (%TNH) \)

1. Assume for “firing” fuel:
   \( %FSR = 14 \)
   \( %TNH = 16 \)

   Firing Fuel = \( \cdot 0085 \times 14 \times 19 \)

   Firing Fuel Flow Rate = 1.90 gpm
Fuel Flow = \(0.0085 \times \%\text{FSR} \times \%\text{TNH}\)

2. Assume for “full speed/no load” fuel:
   \(\%\text{FSR} = 14\)
   \(\%\text{TNH} = 100\)

Firing Fuel = \(0.0085 \times 14 \times 100\)

FSNL Flow Rate = 12.0 gpm
Liquid Fuel Flow Calibration
(GE Control Specs, ISO conditions)

Fuel Flow = .0085 (%FSR) (%TNH)

3. Assume for Base Load Operation:
   %FSR = 66.6
   %TNH = 100
   Firing Fuel = .0085 (66.6) (100)

Base Load Flow Rate = 57.2 gpm
Gas Fuel
Control Principles
Gas Stop Speed/Ratio & Control Valve
Gas Fuel Pressure Gages
Gas Stop Speed/Ratio ($SRV$) & Gas Control Valve ($GCV$)
P2 Pressure Transmitter
(96FG)

P2, Pressure Transducer > >
Gas Stop Speed/Ratio (SRV) & Control Valve (GCV)
Speed/Ratio Valve Calibration
(from GE Control Specifications)

\[ P2 = \text{Speed Ratio (} \% \text{ TNH} \text{)} - \text{Preset} \]

\[ P2 = 0.49 (\% \text{TNH}) - 0.50 \quad \text{P2 in DC volts} \]
**Speed/Ratio Valve Calibration**

\[ P2 = Speed \text{ Ratio (} \% \text{ TNH} \text{)} - \text{Preset} \]

*96FG transducer calibration*

\[ 0 \text{ to } 5.0 \text{ DC volts} = 0 \text{ to } 300 \text{ psig} \]

\[ P2 = 2.95 (\%\text{TNH}) - 30 \text{ in psig} \]
**Speed/Ratio Valve Calibration**

*from GE Control Specifications*

\[ P_2 = 2.95 \times \text{%TNH} - 30 \text{ in psig} \]

**At 100% shaft speed**

\[ P_2 = 265 \text{psig, constant} \]
Inlet Guide Vane
Control Principles
Variable Inlet Guide Vanes

(VIGV)
IGV Actuator & Position Indicator
IGV Control Fundamentals

Servovalve 90TV
IGV Control
(Control air flow into compressor)

Servovalve 90TV

20TV

RVDT

< IGV Modulating >

< IGV Modulating >
Summary of Control Principles
Summary of Control Systems
(System calling for “least” fuel controls FSR)
Protection Systems
Four Primary Protections:

✅ Overspeed
✅ Overttemperature
✅ Loss of Flame
✅ Vibration
Four Primary Protections (typical settings):

- **Electronic Overspeed**: 110 % TNH
- **Mechanical Overspeed**: 112% TNH
- **Overttemperature**: (~ 1000 °F)
- **Loss of Flame**
- **Vibration**: (1 inch/second, 5 mils peak-peak)
Triple Modular Redundant (TMR)
(Speedtronic™ Mark IV & V)

Logic “0” or “1”
2/3 Voting
Many Secondary Protections including:

- Low Lube Oil Pressure
- High Lube Oil Header Temperature
- Low Hydraulic Pressure
- Generator Lockouts
- Customer Added Protections
- Other, as required
Protection Systems
(High-pressure Hydraulics)

L 4 “trips” >

25 psig

1200 psig
Protection Systems
(20 FG energize to run, de-energize to trip)

< L 4 “trips”

1200 psig

Solenoid Valve Deenergizes!
If operating on Liquid Fuel:

when stop valve closes,
the bypass valves goes to
“full recirculation.”
Protection Systems

(If a trip occurs, BPV goes to 100% fuel recirculation)

Stop Valve Closes

Flow Divider Stops
If operating on Gas Fuel:

when stop valve closes, gas control valve also closes immediately.
Protection Systems

(If a trip occurs, both valves close)
Inlet Guide Vanes:

When a trip occurs, IGV go toward the “closed” position immediately to prevent compressor surge.
Protection Systems
(If a trip occurs, IGV Close)
Summary
(Control & Protection Systems)

- Shaft Speed Control
- Shaft Acceleration Control
- Overspeed Protection

- Exhaust Temperature
- Rate of change of Temperature
- Overtemperature Protection

- Vibration
- Loss of Flame
- All Other Protective Devices
The End

Thank you for your attention!
Questions ?