# 19th SYMPOSIUM ON INDUSTRIAL APPLICATIONS OF GAS TURBINES

## Introduction to Gas Turbine Fuel Control

by

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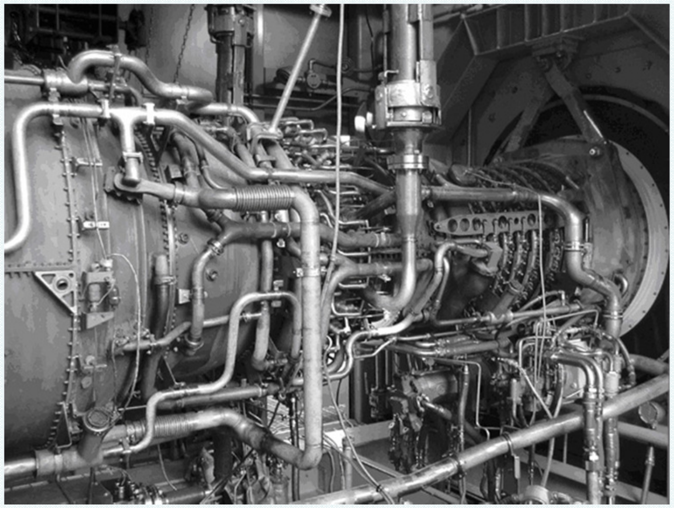
# Session outline

- Turbine control and control types
- Control instrumentation
- Fuel control logic



# Types of Control Programs

- The Control Units can be supplied individually or combined:
  - PCU (Package Control Unit)
  - FCU (Fuel Control Unit)
  - ACU (AntiSurge Control Unit) & RCU (Reciprocating Compressor Unit)
- Each Control Unit operates as an independent program. FCU, ACU, RCU are enabled by the PCU when supplied as a complete package or by an external system when supplied as stands-alone systems.

*Package control*

# Turbine Fuel Control Unit

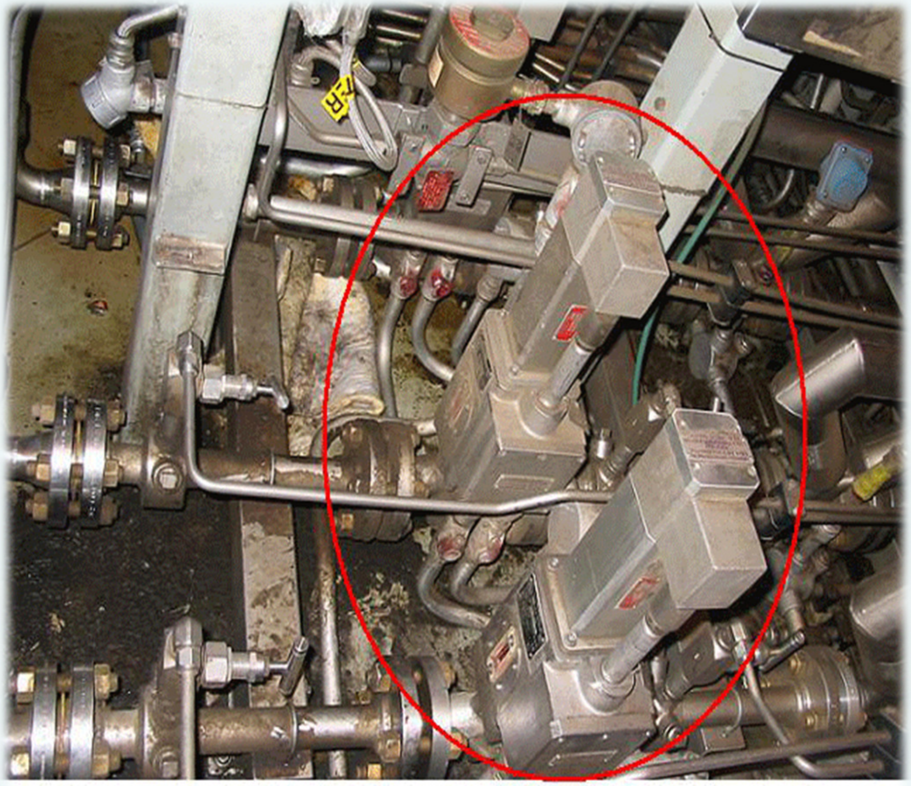
Fuel control system requirements are to safely & reliably

- Control turbine start sequence to idle
- During operation keep turbine within physical limitations
  - Temperature Limits (TE)
  - Speed Limits (N1, N2, N3)
  - Power Limits (turbine and driven equipment)
  - Stall Limit (compressor stall, CDP)
- Control the turbine during transient maneuvers
  - Acceleration Limit (over-speed, over-temperature)
  - Deceleration Limit (flameout)
  - Must minimize overshooting the target condition/setpoint
- Control the turbine air system
  - BOV and variable geometry

# Turbine Fuel Control Unit

Turbine Fuel Control is accomplished by:

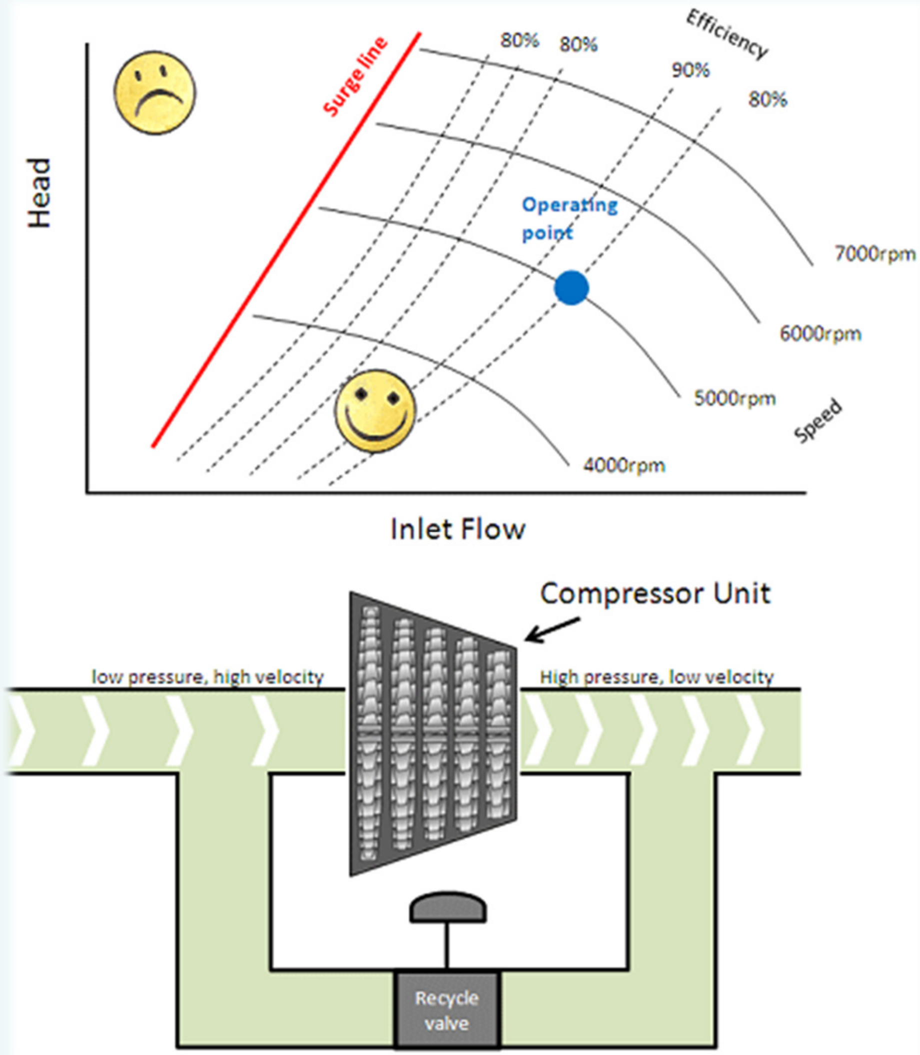
- Fuel flow control
  - Varying fuel flow to the engine using a throttle valve
  - HSS valves to chop fuel to the engine in an emergency shut down
  - Valve position feedback signal to TCS
- Airflow control
  - Manipulating air flow through the engine using variable geometry (IGV, VSV)
  - On some engines, the variable geometry is controlled by the control system
  - On other engines it is done mechanically, on-engine (open-loop no feedback)
  - BOV – starting and handling valves
- Air flow control to improve operability of engine off-design point
  - move away from any surge condition



Fuel control valves

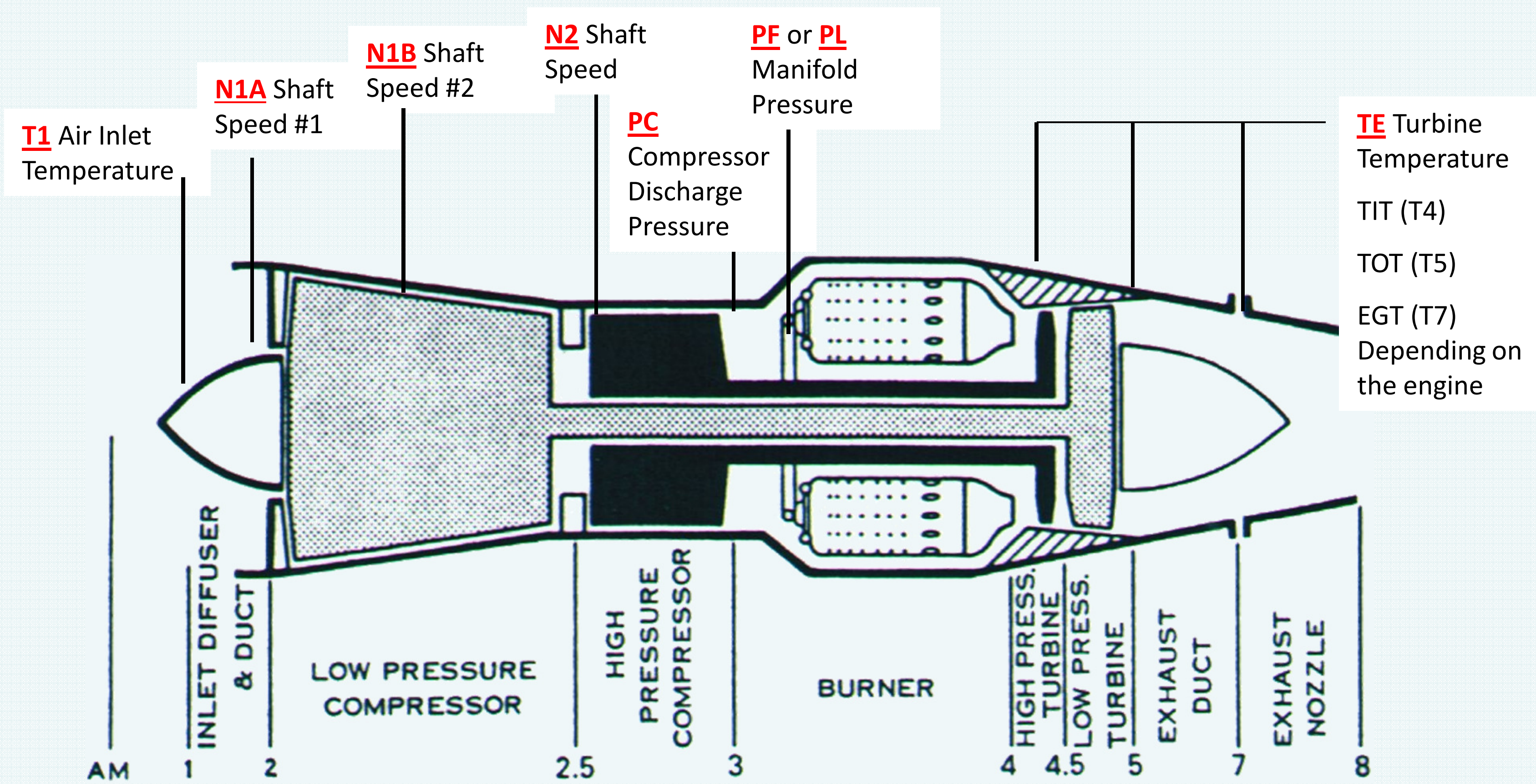
# Compressor Anti-Surge Control

- Compressor Surge control
  - Low pressure/high velocity converted to high pressure/low velocity gas
  - The compressors need to be protected against surge
  - Use the recycle valve to control operating point
- Disabled until the Load Sequence
- Enabled by asserting “KALOAD”
- Ensures Compressor Flow remains high enough to prevent surge.
- Surge line, control line and alarm line

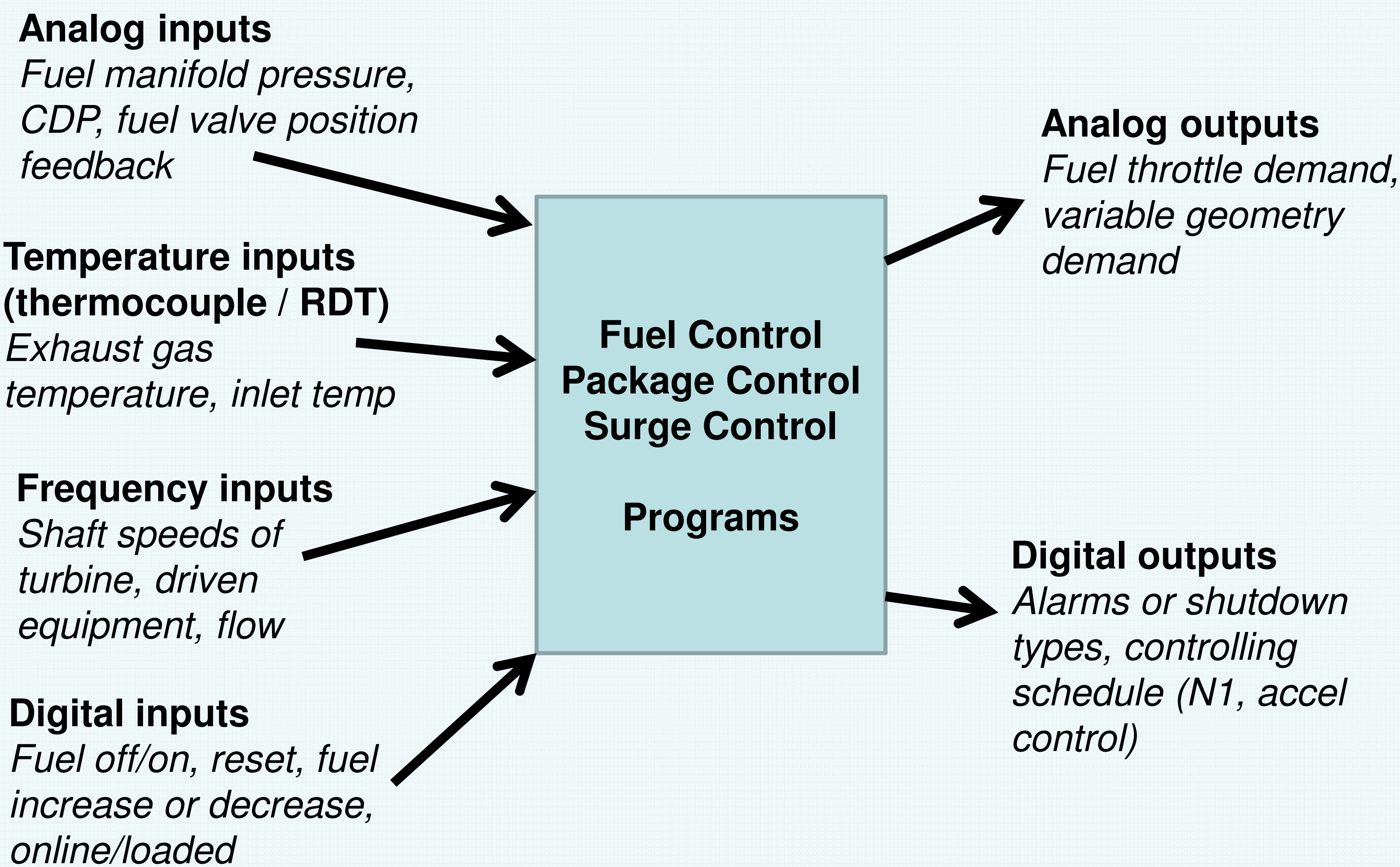


# Fuel Control Instrumentation

## Gas Turbine Stage Definitions – TARCO Variation



# Fuel Control Instrumentation



# Signal Selection

- The TCS control philosophy is to  protect the machine and when possible prevent spurious trips. This results in the highest availability possible for the selected design configuration.
  - Best to have 2 or more signals for critical control parameters
- Digital signals
  - Faulted if the hardware senses a fault or if they inputs do not agree (one off & one on)
- Analog signals
  - If not faulted, can use one of 2 voting options: high signal or low signal selects
  - If one of the channels is faulted then the non-faulted channel is selected
  - Is considered faulted if channel is outside fault limits, hardware system detects a fault  and/or channel deviates from the sensed value by both
- Some examples are:
  - Speed pick-ups the highest of the signals is used for control
  - Inlet air temperature RTD's the lowest of the signals is used for control
  - Individual thermocouples are used for deviation alarming only, highest of the average signals is used for control

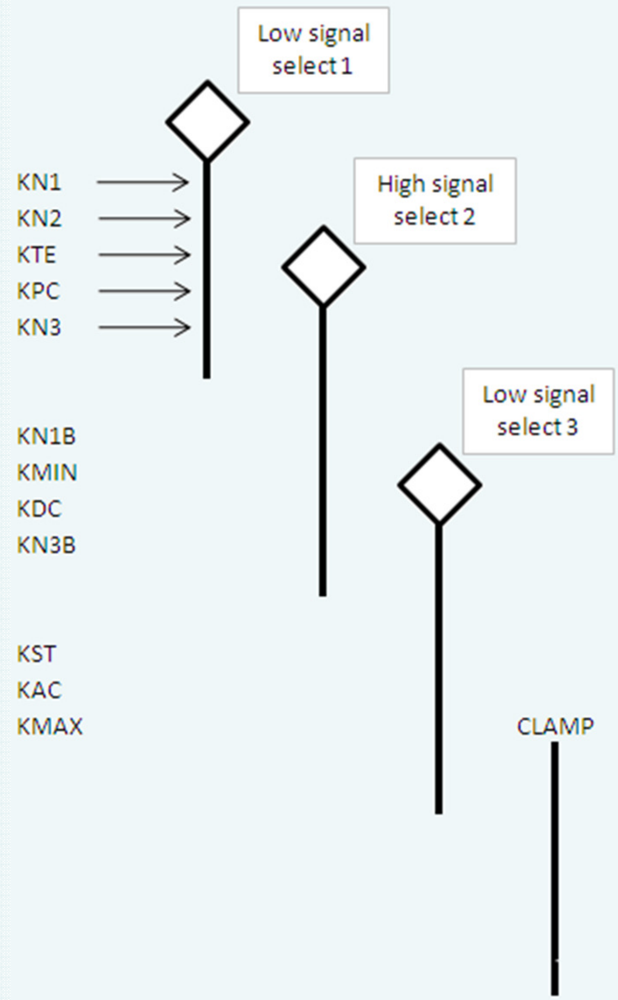
# Fuel Control Logic

There are many controllers that interact. At any given time, only one controller will actually control the fuel valve position:

- KN1 Compressor Speed Control
- KN2 HP Compressor Speed Control
- KTE Temperature Control
- KPC Compressor Pressure Limiting
- KN3 Power Turbine Speed Control

- KN1B Compressor Speed Bottom Control
- KMIN Minimum Fuel Limiting
- KDC Deceleration Limiting
- KN3B Power Turbine Speed Bottom Control

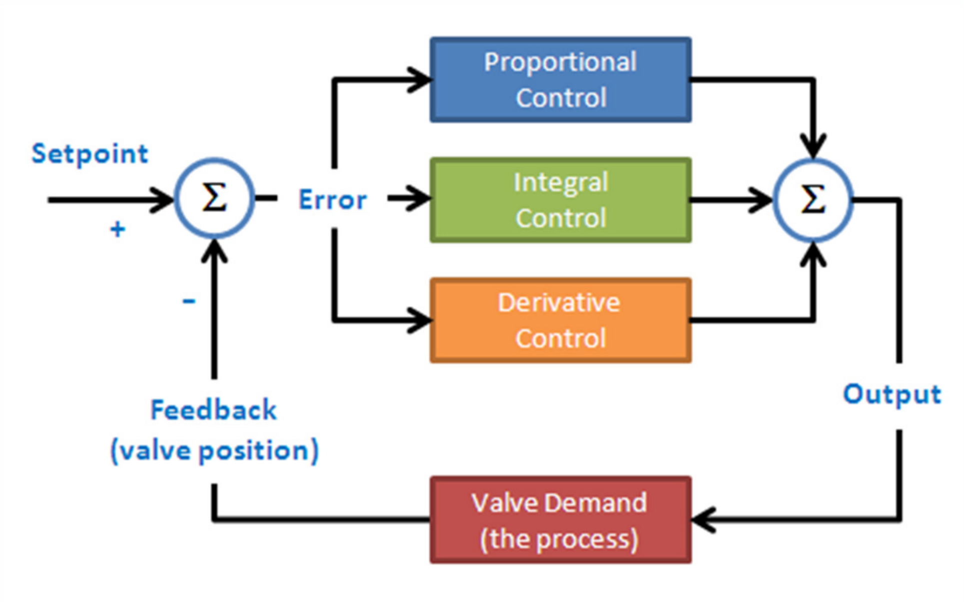
- KST Starting Fuel Ramp
- KAC Acceleration Limiting
- KMAX Maximum Fuel Limiting




Various controllers go through a low, high and low signal selector gate, only the 'winning' signal passes through to give the final valve demand position

# PID Control Loops

- Almost all of the controllers consist of PID-type control loops to move the fuel valve to it's setpoint. There are 3 components:
  - P –Proportional term is proportional to the error. If there is no error the output is zero, which means there is usually an offset which is smaller with bigger gains
  - I – Integral term grows bigger if the error is positive, and shrinks if the error is negative. It grows or shrinks more quickly if the error is bigger
  - D – Derivative term is only there if the error is changing. The derivative term can be there even if you are a long way from setpoint




- For some controls not all P-I-D components are used

# Limits & Air Temperature Effect

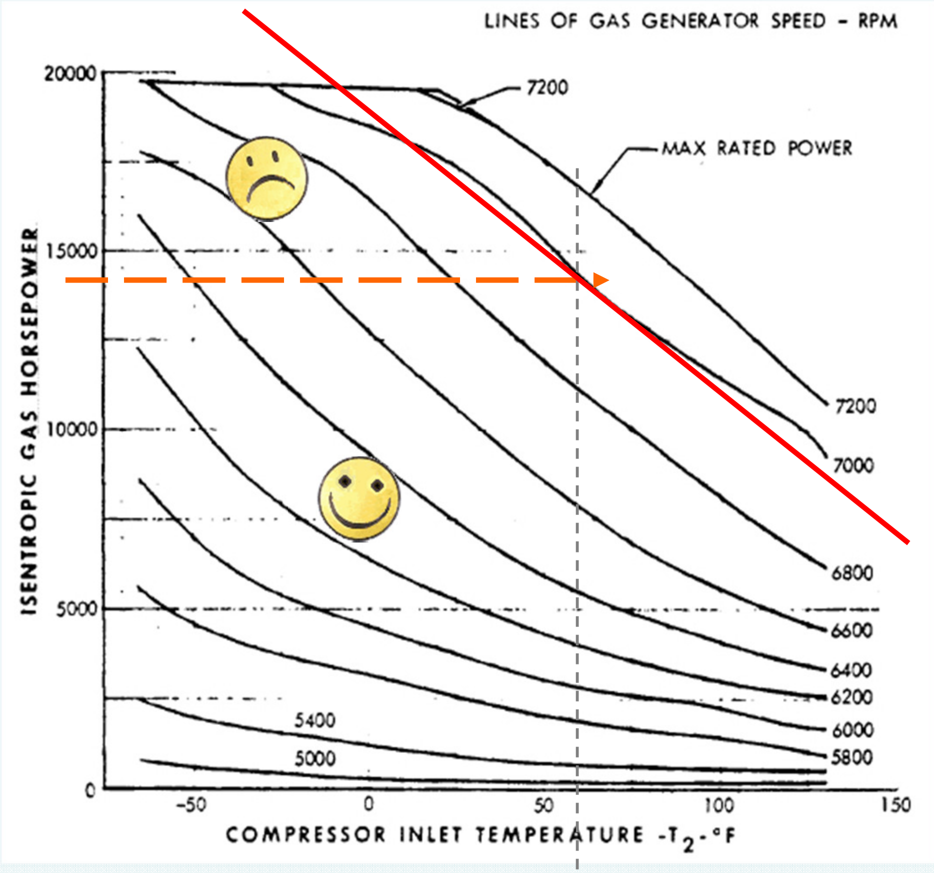
- Output Power decreases dramatically with increasing air temperature – Operations concern

Conversely

- Output Power increases dramatically with decreasing air temperature – Concern about power rating of driven equipment

Example

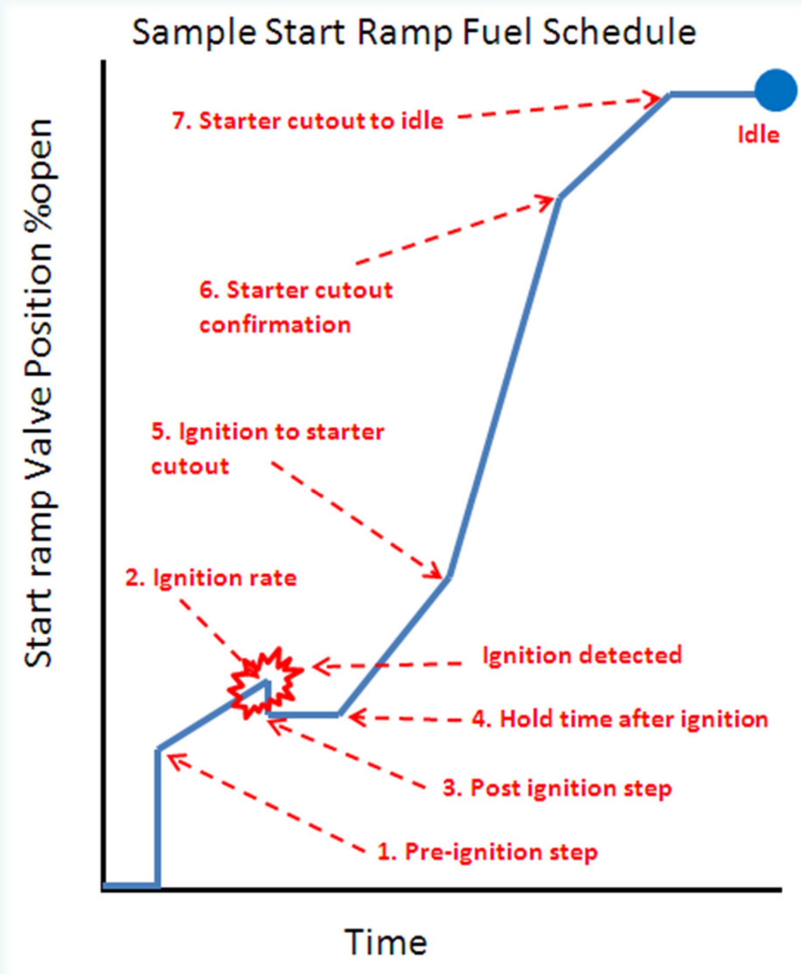
- Assume the orange dashed line represents the maximum power rating of the driven equipment
- As the air temperature falls below 55 deg F, the turbine can produce more power than the driven equipment can handle
- Fuel Control must watch out for this by limiting engine speed at lower temperatures



Turbine Average Performance

# ST, Start Fuel Ramp

- Controls fuel flow to the engine during
- Prevents over-fuelling
- Fuel flow is strictly controlled
- PID – style control is not used
- Starter and lube oil are controller via package control

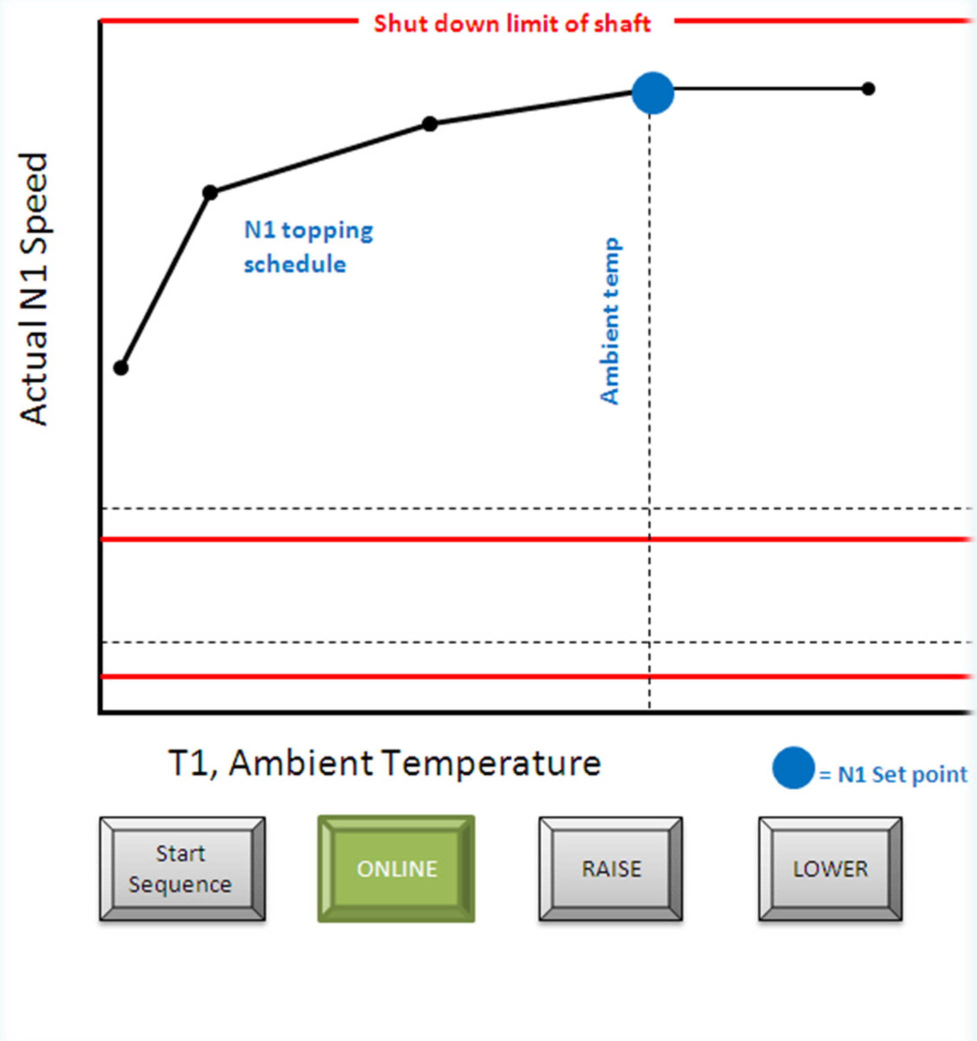


# N1, Compressor Speed Controller

- "Ambient Biasing" ensures engine power output does not exceed rating of driven equipment or the engine itself.
- N1 Speed is reduced at lower temperatures, reducing mass air flow and therefore, power output.

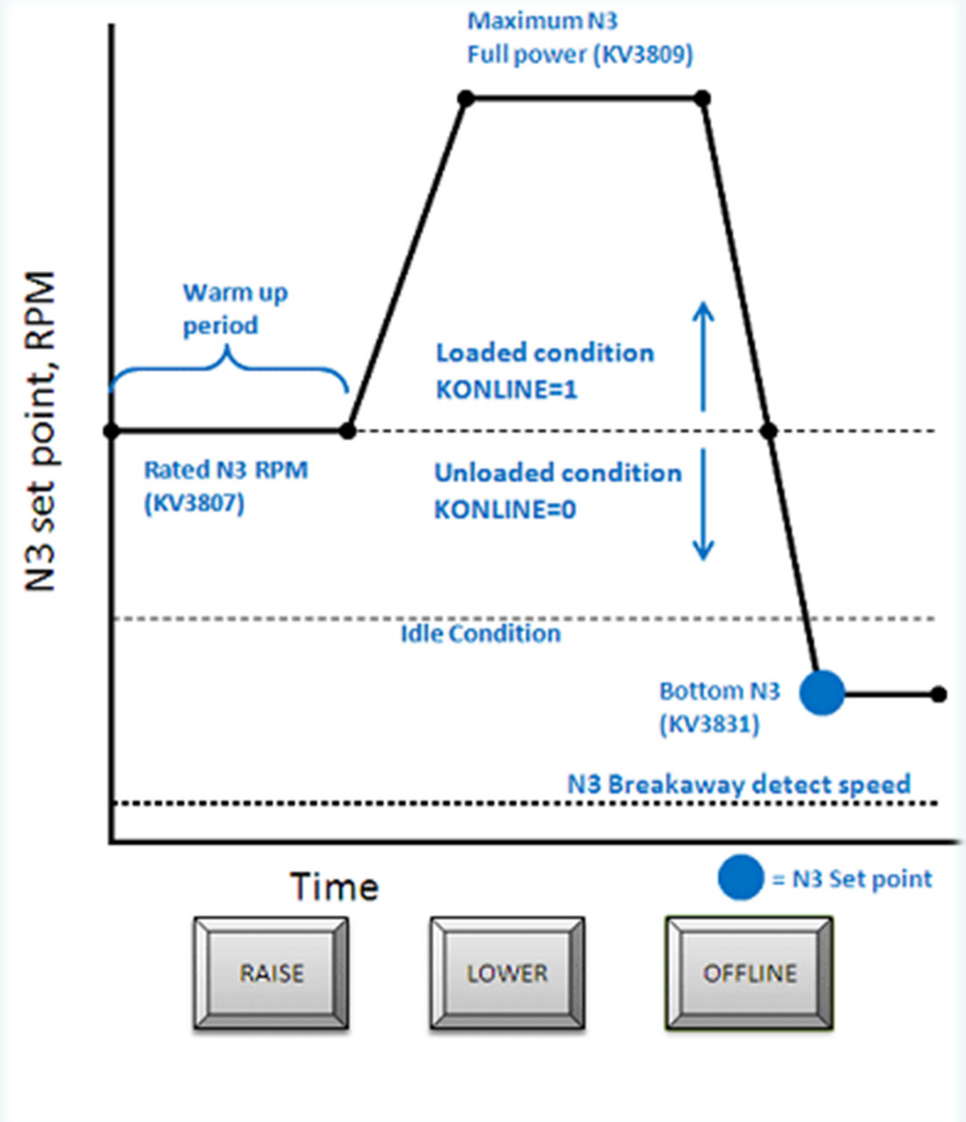
Also, N1B bottom controller

- N1 Bottom control ensures that the engine speed does not fall below the minimum allowable
- Prevents underspeed and flameout



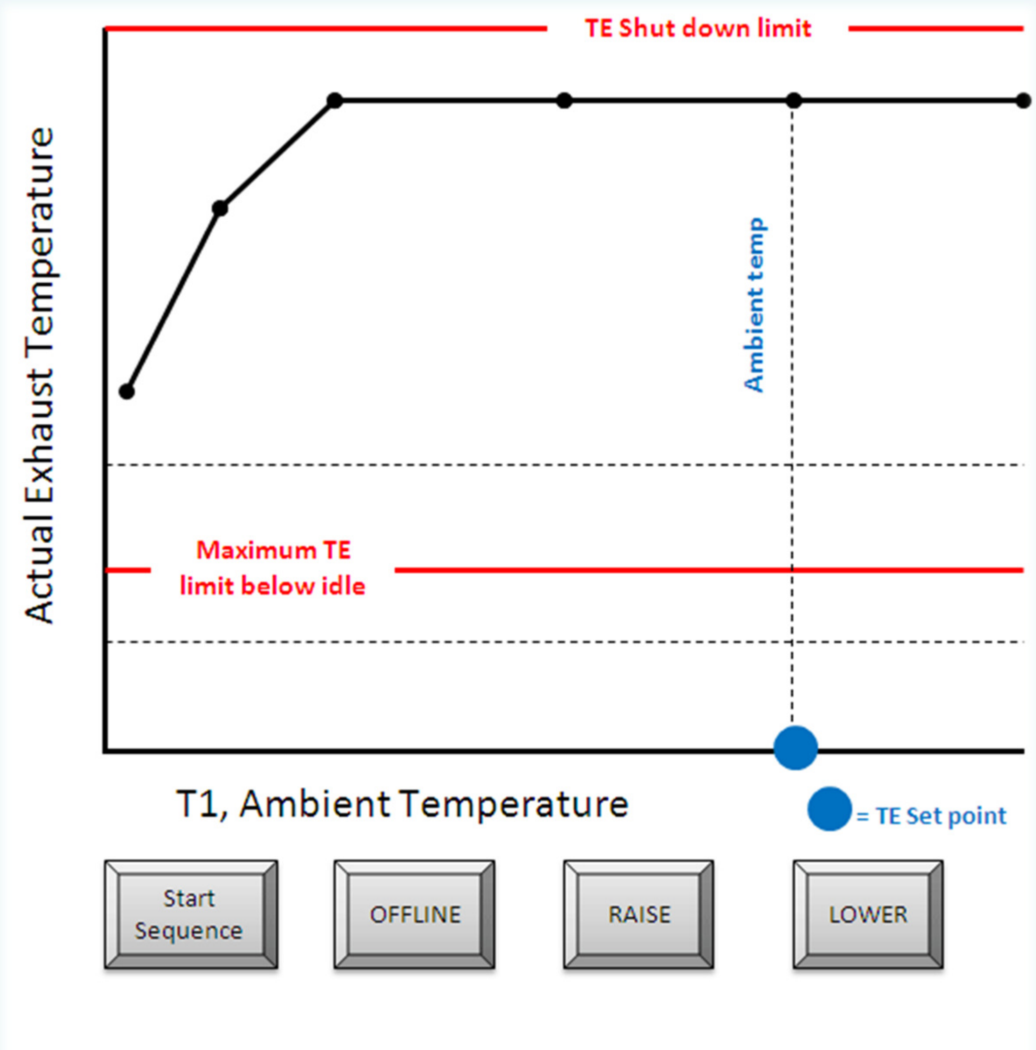
# N3, Power Turbine Speed Controller

- Controls N3 speed to the desired setpoint
- N3 setpoint is controlled by "Raise/Lower" commands
- PT bottom speed controller
  - N3 Bottom control ensures that the PT speed does not fall below the minimum allowable
  - Prevents PT underspeed
- N3 breakaway control initiated if PT has not started rotating



# TE, Temperature Topping Controller

- This controller has two purposes:
  - Limit exit temperature to maintain the hot gas path components.
  - Backup to the N1 ambient biasing to limit output power, although on hotter days it is usually the limiting schedule
- For start sequence, SD limit for over-temp
- SD / trip limit in effect above idle



# CDP, Compressor Pressure Controller

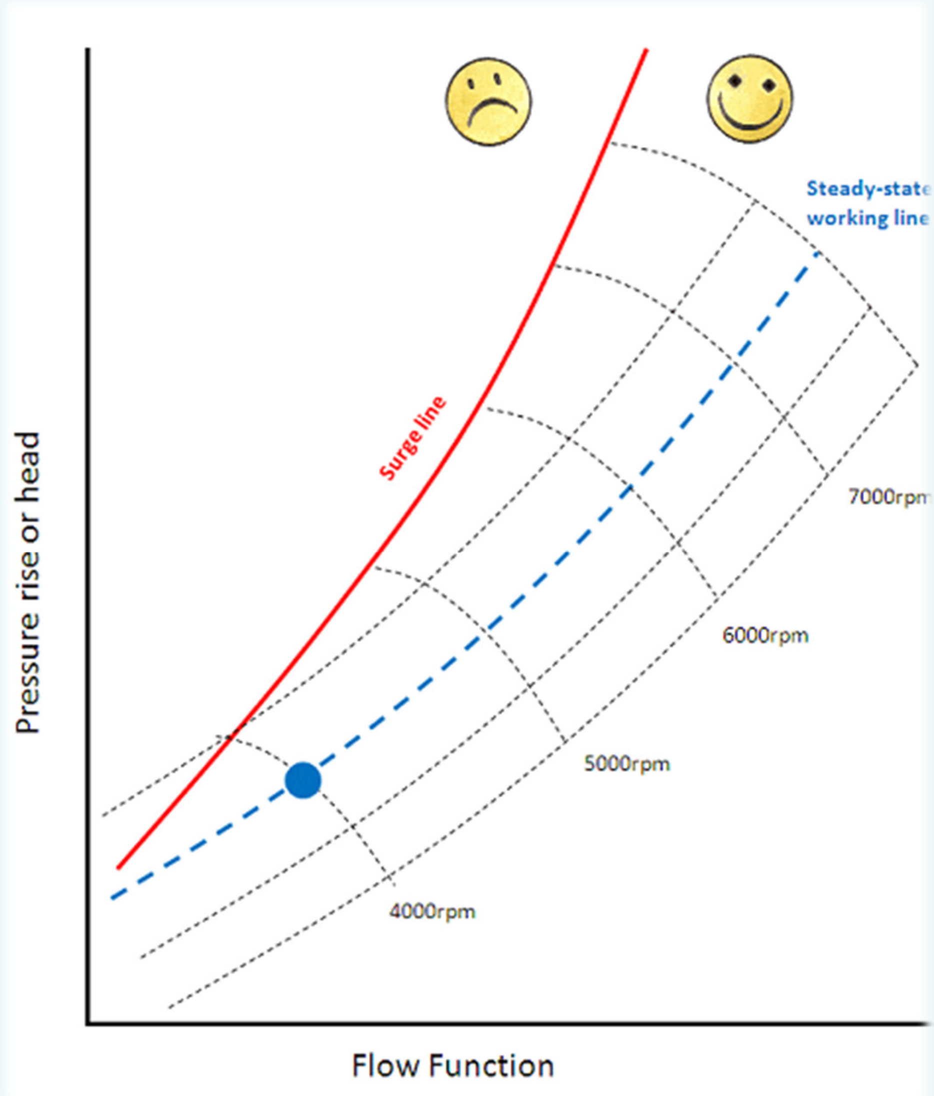
- The PC (Compressor Discharge Pressure) Setpoint is not scheduled.  It is a single KVAL.

- If the PC tries to increase above KV3611, the PC controller will act to reduce fuel demand.

- PC is related to engine power output so this controller can be used as a backup to N1 and TE ambient biasing to ensure that the turbine power output does not exceed the rating of itself of the driven equipment.

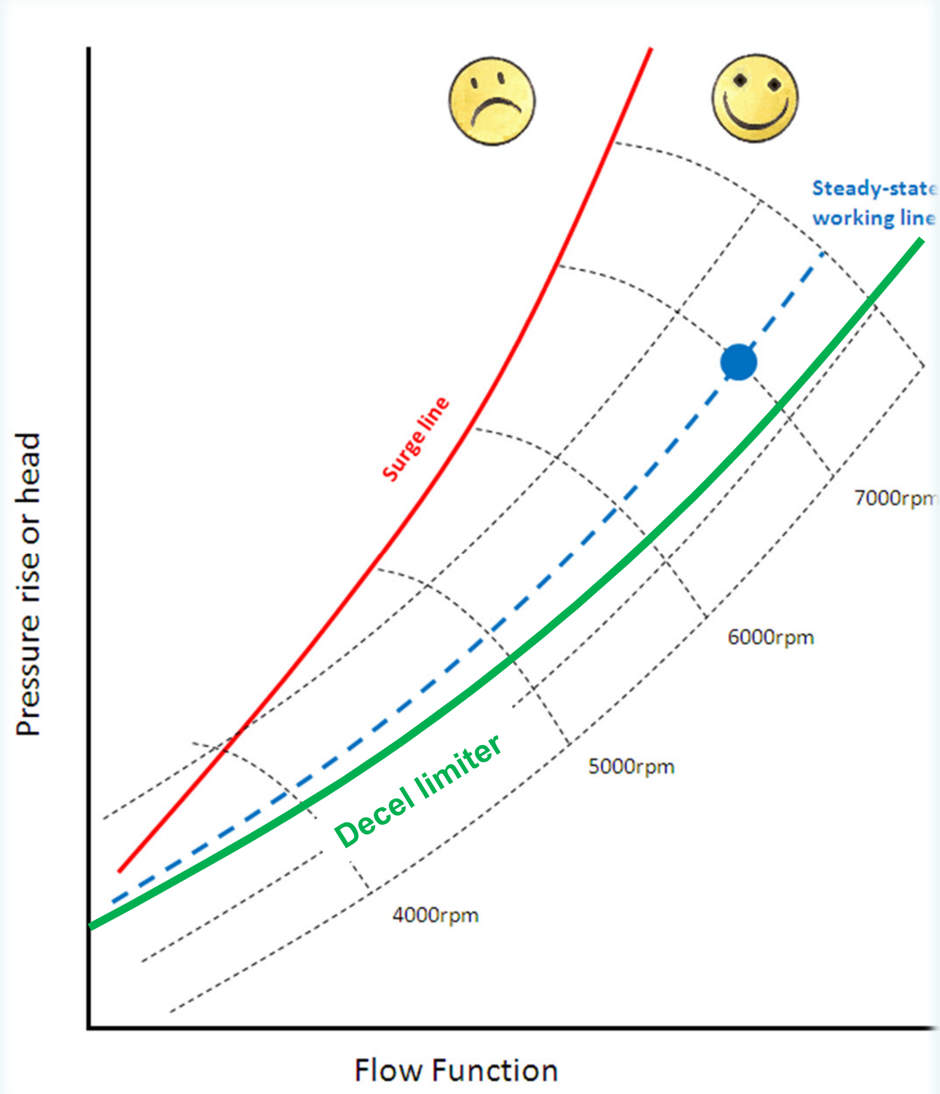
# AC, Acceleration Controller

- Accel limit should not normally occur on a pipeline application
- Prevents over-fuelling the gas turbine during fast load acceptance
  - Protects hot gas path components
  - Over-speed/temperature
  - Potential HP comp surge
- For any given compressor discharge pressure, the fuel valve is not allowed to open more than allowed by the Acceleration Schedule.



# DC, Deceleration Controller

- For normal operation, the gas turbine should not hit the decel limit
- Prevents under-fuelling the turbine during fast load rejection
  - Protects against flameout
  - Potential LP comp surge
- Manifold Pressure is used to estimate fuel flow vs valve position



# Max & Min Fuel Limiting

- Maximum fuel limiter
  - The MAX fuel Limiter acts as a maximum clamp on the fuel valve demand.
  - If any controller tries to open the fuel valve more than the MAX limit, it is clamped at the MAX limit
  - Acts as a backup to the Acceleration controller to prevent over-fuelling during fast load acceptance
- Minimum fuel limiter
  - The MIN fuel Limiter acts as a minimum clamp on the fuel valve demand
  - If any controller tries to close the fuel valve more than the MIN limit, it is clamped at the MIN limit
  - Acts as a backup to the deceleration controller to prevent under-fuelling during fast load rejection
  - There are two MIN setpoints for the liquid fuel valve and two for the gas fuel valve: one at idle and one for loaded

# KW, Generator Max Power Output

- The KW Max Controller is usually only in effect during initial loading of a generator.
- The main purpose is to provide a means of controlling how fast the generator takes load after the breaker closes
- It can also be used to limit generator power output when running but usually TE, PC, or N1 will have control before the KW max controller.