# INDUSTRIAL PRESSURE CONTROL

**A REGULATOR STATION DESIGN FOR NATURAL GAS PRESSURE CONTROL TO SIMPLE CYCLE AND COMBINED CYCLE COMBUSTION TURBINE ENGINE POWER PLANTS**
**(Revised 2013)**

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## INTRODUCTION

Regulator station designs for pressure control to large Power Plants have always presented unique challenges that differ from standard pipeline pressure control applications. A large Combustion Turbine Power Plant load with little buffering between the regulators and the Turbine Engines requires a different approach to station design. The design approach becomes even more complicated if the Power Plant also has additional small auxiliary requirements such as duct burners, waste heat recovery boilers, building heat requirements, etc. In this paper, the focus will be on a regulator station design philosophy for Simple Cycle and Advanced Combined Cycle Combustion Turbine (CT) Power Plants that meet the load requirements for power plant operation as well as for ancillary equipment.

Since the 1990's, there has been a rapid increase in electricity demand in the United States without any sign of leveling off. The propagation of electronic technology, manufacturing, and computers are some of the driving forces fueling this increase in electricity usage. Also, as we move forward into the near future, the rise in electric automobile usage will only amplify this demand. This increased need for power coupled with a heightened awareness of environmental concerns has altered the landscape of power production.

Two major changes have come about in the last 20 years in the industry of electricity production.

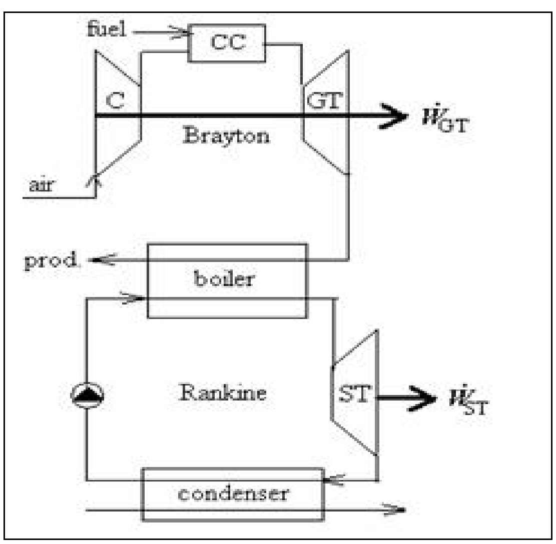
1. New plant construction has increased dramatically in the past 20 years and almost all are Natural Gas Fired Combustion Turbine Engine Technology. Prior to the vast emergence of turbine engine technology, most of the electric generating power plants in the US were Coal and Natural Gas Fired Steam Plants.
2. The move to the Natural Gas Fired Combustion Turbine Engine Technology has also given us growth in Power Plant Size from approximately 200 MW in the 1950's up to 2500 MW in the year 2010. Coal and Oil fired steam plants have also shifted to natural gas as a fuel source, and upgraded their facilities to include Simple Cycle and Combined Cycle Combustion Turbine Engine technology.

There are many reasons for these changes, but most importantly, natural gas is the simplest and cleanest of all fossil fuels to fire power plants. The new construction and existing plant upgrades have forced the Gas Industry to change the way we look at regulator station designs that feed these plants.

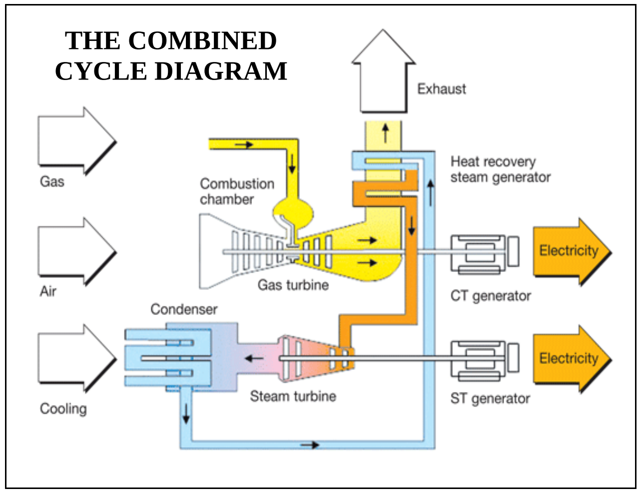
# WHAT IS A SIMPLE CYCLE AND A COMBINED-CYCLE PLANT?

**Simple Cycle** – A Simple Cycle Combustion Turbine Power Plant consists of one Thermodynamic Cycle that converts heat into Mechanical Energy which drives an Electrical Generator and the waste heat is exhausted to the atmosphere. The Thermodynamic Cycle is the Brayton Cycle (the Natural Gas Turbine).

**Combined Cycle** - A Combined Cycle Combustion Turbine Power Plant consists of two Thermodynamic Cycles that convert heat into Mechanical Energy which drives Electrical Generators. The two Thermodynamic Cycles are the Brayton Cycle (the Natural Gas Turbine) and the Rankine Cycle (the Steam Turbine). The Combined Cycle plant consists of one or more gas turbine units generating electric power, with the hot exhaust gasses discharged into waste heat recovery boilers. Steam is generated in the waste heat recovery boilers (also known as **H**eat **R**ecovery **S**team **G**enerators, or **HRSG's**) to turn a Steam Turbine Generator. In this way, the heat from the Gas Turbines is used for Steam Generation and therefore a greater proportion of the Gas Turbine fuel is used in Net Electric Generation which increases the overall thermal effiency or ***Plant Net Efficiency***. The ***Plant Net Efficiency*** is calculated by dividing the Net Output (kW) by the Heat Input (BTU/hr).




**THE TWO THERMODYNAMIC CYCLES**




# POWER PLANT TYPES

Power plant types fall into three general categories: Peak-Load, Base-Load, and Medium-Load generating units. Recently, there have been some changes to these basic classifications as we get better at the business of Electricity Generation. These minor changes are due to the increase of Combustion Turbine packages that are now in service.

**Peak-Load Generating Units** operate only during peak electrical loads and are typically 50-200MW in capacity or less. They have a high fuel cost and relatively low efficiency due to being a Simple Cycle Design. They respond the quickest to electrical load changing requirements. Generally this is a small gas fired combustion turbine jet engine.

**Medium-Load Generating Units** are typically 200-500 MW in capacity. Their efficiency is greater than the Peak-Load units. They have quick electrical load change capabilities and can be ramped up to meet escalating electric demand. Generally, these are simple cycle combustion turbine engines that are approximately 50MW capacity and are operated in banks of 4 units. The operator can utilize from one turbine to all of the units available to meet the required electrical demand. It is normal for these Medium-Load Units to be located at a base load plant for wide range of electricity delivery requirements.

**Base-Load Steam Generating Units** operate at full load for as long as possible. They are typically 500-2500MW in capacity and have a low fuel cost and medium efficiency. Base Load Steam Plants have poor load changing capability and do not respond quickly to load demands. Generally, these plants are Natural Gas, or Coal fired high performance steam plants and they are usually operated for months at a time.

**Base-Load Combined Cycle Generating Units** can operate for short durations or extended periods of time. They are usually built in 500MW "Blocks" that consist of two Gas Turbines, two Heat Recovery Steam Generators, and one Steam Turbine commonly referred as a "Two by One" configuration. Multiple blocks can be placed at the same location thus increasing the capacity of that particular plant. The most prevalent sizes are 500MW and 1000MW plants, but can be larger. These plants normally will operate for long periods of time to the meet the Base-Load requirements for the given area with one plant under **AGC** operation. **AGC** stands for **A**utomatic **G**eneration **C**ontrol. The plant that is on AGC Control is in a sense "trimming" the electrical output of many plants to maintain a steady tight electrical delivery to the grid. These AGC plants are constantly changing their MW output in real time as the grid fluxuates to the demand.

Each category of power plant has certain performance characteristics that must be addressed in the design of the Regulator Station. Different equipment and size of plant also affect the design. Steam Plants have lower pressure set-points and long run times. Small Turbine Engines require different inlet pressures and have different response specifications that Large Turbine Engines. On some Small Turbine Engine Banks, the pressure must be adjustable depending on how many units are on line. All these different criteria will affect the final design of the Regulator station.

*The designs we will focus on in this paper are primarily used on the **Base-Load Combined Cycle Generating Units** and the **Medium-Load Simple Cycle Generating Units**.* These Simple Cycle and Combined Cycle Combustion Turbines are categorized as Base-Load or Medium load units but exhibit many characteristics of all three categories of power plants.

- They respond quickly to electrical load changes and can operate on short notice for Peak-Loading requirements.
- They exhibit the characteristics of a Medium-Load unit by running as a simple cycle with a reduced MW output.
- They can operate for long durations of time in a Combined Cycle configuration, which requires a large stable gas delivery system.
- When under **AGC** control, the plant is constantly changing MW output to maintain electric grid stability thus there is a constantly changing Natural Gas Load.

These new power plants are a "hybrid" of all three categories. New construction and plant upgrades using the new CT technology has caused stability and speed of response problems when using standard regulator station designs that are supplying the gas to these power plants. The older Regulator Stations were designed for Steam Generators that fed Steam Turbines which operate under totally different operating parameters.

## THE ISSUES AND REQUIREMENTS OF COMBUSTION TURBINES

What is different from feeding Steam Generators to feeding Combustion Turbine engines? What are the operating characteristics of CTs (Combustion Turbines) that would necessitate changes in proven power plant regulator station designs? In order to answer this question, we must look at the issues and requirements of these new CT power plants.

**Fast Speed of Response –**Speed of Response is vital in the design of a regulator station for the Combined Cycle Power Plants. While there are many characteristics that necessitate a fast speed of response, there are three that stand out, *Pipe Diameter, Distance to the Plant, and CT Response Time.*

As power plant retrofits occur, the size of the plant usually gets larger, but the pipe diameter <u>may</u> stay the same. What used to be oversized pipe built for future expansion is now at capacity. Also, regulator stations that deliver gas to these CT power plants are usually located from 50 to 2500 feet from the turbine engines. When minimum pipe diameter and minimal distance from regulator station to power plant are present, the system is classified as a "***Short System***". These "short systems" do not allow for the luxury of having a "storage bottle" that would act to dampen any sudden changes in gas flow rate.

In addition to the "short system" envelope of operation, CT power plants have the characteristic of nearly instantaneous transition from one operation point to another, like a high performance race car. They have the ability to start-up quickly, maintain a warm-up or idle, and then quickly ramp up to full speed or Base-Load (100% synchronization to grid). If under AGC Control, a CT is constantly moved from one operating point to another to maintain stability of the Grid, and that happens quickly. CT's also can shut down or trip off-line almost instantaneously. Plants with Multiple CTs may be at different operating points of start-up, ramping to full speed, or shutting down---all at the same time. This differs from traditional Base-Load Gas Fired Steam Plants that do not have fast and frequent gas flow rate changes.

*The "short system" of piping coupled with the Advanced CTs operating characteristics of rapidly changing gas flow rates requires a regulator station to have a **Fast Speed of Response**.*

**Tight Control** - Most new CT power plant designs do not have any additional pressure reduction after the regulator station and prior to the fuel gas heaters. Tight Control is always a desirable characteristic in Station Design, but for CT's it is more than just "desirable", it is a necessity.

Combustion Turbines have a *High/Low Pressure Trip Point* that will shut down the unit if the pressure falls outside these parameters. This is to ensure proper unit operation and prevent equipment damage. These trip points can be as close as 20-30 psi above and below the station set-point. This bandwidth of trip points is narrower than the traditional 50-100 psi delivery pressure range that is further reduced to 5 psi at the burner tips of a Base-Load Steam Plants. *The ability to maintain Tight Control in the event of a system trip and not bring other turbines off line is critical the overall operation of the plant.* The typical delivery pressure from the regulator station to the older conventional CTs is approximately 250-300 psig. In the Combined Cycle Systems, we typically see delivery pressures around 450-485 psig. In the new high efficiency Simple Cycle systems, pressures are around 650 psig. The higher you get, the harder it is to maintain tight control if there is an upset.

*This requires a regulator station to have a **Fast Speed of Response** <u>with</u> **Tight Control**.*

**Stable Steady State Control -** Combustion Turbine Engine efficiency is affected by fluctuations in the gas delivery pressure. Poor turbine efficiency affects the overall Plant Net Effiency which translates to lost dollars for the operators.

Combustion Turbine Power Plants exhibit two characteristics related to gas flow rate. They experience ***High Frequency-Low Volume*** changes in gas flow rate as well as ***Low Frequency-High Volume*** changes in gas flow rate – all at the same time.

The *High Frequency-Low Volume* changes are a characteristic of single or multiple CTs running at steady-state operation or when under AGC Control. Combustion Turbine engines rotate at a very high RPM (2500 – 10,500 rpm) and small gas flow rate changes happen quickly and frequently. The *Low Frequency-High Volume* changes are a characteristic of a single or multiple CTs coming on line or going off line. Large gas flow rate changes also occur during ramp up and down, or when a turbine trips off line.

Multiple CTs running at varying points of operation plus any small auxiliary flow rate requirements such as Duct Burners or Auxiliary Boilers, makes this a difficult application. The highly variable gas flow rate characteristic of the new CTs calls for a regulator station that has the ability to deliver gas without pressure swings.

*This requires a regulator station to have a **Fast Speed of Response** <u>with</u> **Tight Control** <u>and</u> **Stable Steady-State Control.***

**Bubble tight valve shut-off –** The ability to have a bubble tight valve shut-off is a requirement of any dead-end system. Under a complete plant shutdown there can be no leakage of the regulator station. Any leakage would result in plant relief valves venting off gas due to overpressure. This can cause environmental and safety concerns. This requires an ANSI Class VI shut-off monitor valve and/or a Trip Stop Valve.

**Reliable Control System** – Reliability in regulator station operation is the cornerstone of Advanced Combustion Turbine power plants. Plant operation and efficiency is affected by the performance of the regulator station. Inability of the control valves to maintain the required pressure and gas flow rate directly affects the plant operation efficiency. The robustness of the design is also important as most CT power plants have frequent run cycles based upon contract requirements for their electricity production. CT power plants are in essence Base-Load generating units that have frequent duty cycles. This is in contrast to typical high performance steam turbine Base-Load plants operating at full load as long as possible during the year (lower duty cycle).

**Simple Control System Logic** – Simple control system logic is a want for any engineer, technician, or plant operator. As the equipment or process becomes more complex, the control system increases in complexity. Ideally, a single-stage pressure cut to the power plant instead of a double-stage pressure cut will simplify the design. Simplicity in station design and equipment will aid in understanding the control logic.
All of these issues and requirements for Combustion Turbine Power Plants are familiar to us.

- Fast Speed Of Response
- Tight Control
- Stable Steady-State Control
- Bubble Tight Valve Shut-Off
- Reliable Control System
- Simple Controls

These are the basic staples of regulator station designs. Knowing all the issues and requirements for Advanced CT Power Plants, the question that we must ask ourselves is:
Q: Why can't we use existing station designs that have already proven themselves on steam plants and small turbine applications? What is different?
A: The difference is that the ability of these new CTs to operate as a "hybrid" of all three power plant types requires a regulator station that incorporates ALL the needs of the newer CT power plants in one simple cost effective design.

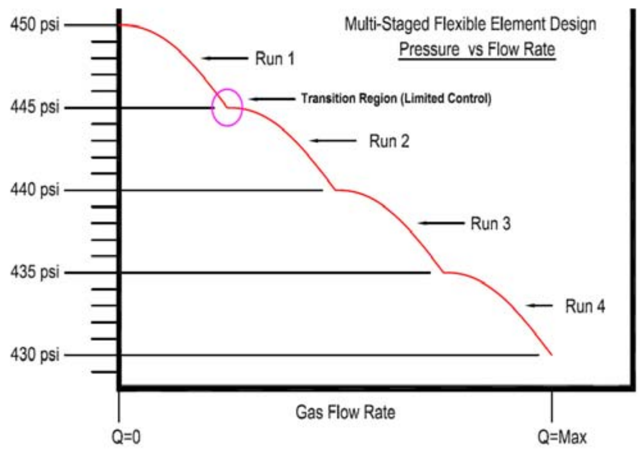
Existing designs that were primarily used on Steam Generators feeding Steam Turbines only address some of the needs of the new CTs systems.

## CURRENT DESIGNS

There are many designs in use for gas feeds to power plants. Described below are two designs that are most common in the field that feed Medium-Load and Base-Load power plants today. Where do these current designs miss the mark if used to feed the new Advanced CT power plants?

### Multi-Staged Flexible Element Design

The first design seen is the cascading multiple-staged flexible element type. This station design is usually two or more runs of flexible element type regulators. These pressure reducing regulators are the proportional type with a bandwidth or “droop” of approximately five (5) psig from closed to full open. This means that as the flow through the regulator increases, the delivery pressure will decrease. The set point of each run is set approximately 5 psi different from each other in descending order.




For example, if the first run has a lock-up pressure of 450 psi when closed and 445 psi at full open, the next run will be closed at 445 and 440 at full open…and so on. Each additional run will continue this decreasing pressure trend. In this station design, as the plant gas flow increases, the first regulator run will crack open and continue to “droop" to full open with a 5 psig drop in delivery pressure. As the plant continues to draw more gas, the second run will crack open, and “droop” to full open with an additional 5 psig drop in delivery pressure. Additional runs can be added to meet the required flow rate complete with additional drops in delivery pressure.

This regulator station design usually feeds the Peak-Load or smaller Medium-Load power plants with multiple runs of small regulators. They have the fastest speed of response of all regulator station designs. They have a bubble tight shut-off and are very and simple. This philosophy is difficult to apply to large CT power plants for a few reasons:

**Droop** - Each run has a “droop” of approximately 5 psig. Each additional run will add an additional 5 psig drop from full closed to full open. With an inlet pressure of 550 psig and a delivery pressure of 475 psig, a 750 MW power plant would require a minimum of four (4) runs of 6” worker/monitor pairs. This would be approximately 20 psig of “droop” or more from the power plant start-up to full Base-Load operation. This falling set-point could approach the CT *High/Low Pressure Trip* point, not leaving much room for upsets.

**Fluctuations in Set Point** - As with all flexible element pilot operated designs, the set-point will shift as the station inlet pressure varies. This shift of the operating set-point can impinge on the CT *High/Low Pressure Trip* point as well as create operational issues.

**Transition Regions** - When a CT or multiple CTs are operating at a “transition” region between two runs of regulators, you may have the regulators “fighting” each other and this appears as a fluctuating delivery pressure.

**Differential Pressure Requirement** - Flexible element regulators require a minimum pressure differential of approximately 50 psig to operate effectively and maintain steady flow rate. This limits the operational envelope of this type of regulator station.

**Noise** - Flexible element regulators can be noisy when operated at capacity. Standard Noise limitations may be exceeded and there is no noise trim currently available to mitigate the noise to acceptable levels.

The Multiple Staged Flexible Element regulator design has many favorable characteristics and in some instances is used for Medium-Load and Base-Load plants that are operating new Advanced Combustion Turbine engines, but most Power Plants will opt for control valves for tighter control and long term maintenance issues. The issues of “droop”, fluctuations in set point due to inlet pressure changes, and the differential pressure requirement are problematic for this application. Potential noise and reliability is another issue. Most new CT Base-Load power plants are 500 MW or larger and this design may not address all the issues and requirements for larger plants.

## Low Flow/High Flow Design


The second type of regulator station design used for power plants is a Low-Flow run in parallel with a High-Flow run. This design typically has a 2” globe valve Low-Flow run and 6”, 8”, or 10” globe valve High-Flow run(s). The controls for all runs are PID controllers and positioners. The 2” Low-Flow run supplies the gas load for all the small or low volume applications. When the Low-Flow run reaches capacity and is 100% open, a High-Flow run takes over (at a slightly lower set-point) and provides the main feed for the power plant.

This design has a fast speed of response, bubble tight shut-off, and is very reliable and simple. This design works well with Medium-Load and Base-Load Steam Plants where there is a secondary pressure reduction at the burner tips and very few fluctuations in gas flow rate. When this design is used to feed the advanced CT power plants, it has trouble maintaining the desired station set-point for two primary reasons:

1. **The Use of One Control Valve**- *The Low-Flow/High-Flow design has trouble maintaining he set-point pressure for the advanced CT power plants because the only valve in play after start-up is the High-Flow run control valve.*

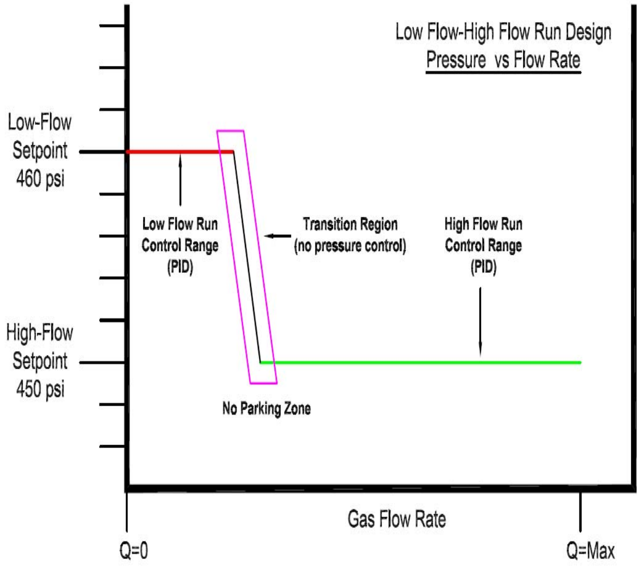
Remember, CT power plants exhibit two characteristics related to gas flow rate, *High Frequency-Low Volume* changes and *Low Frequency-High Volume* changes in gas flow rate – all at the same time. When the Low-Flow control valve is wide open, it does not provide any control capability to the system. Once the 2” control valve opens fully it is just like a piece of pipe! Now the High-Flow control valve is tasked with satisfying all the demands in gas flow rate, *both large and small* for Combustion Turbine Power Plants.

This was OK when we were delivering gas to a boiler which takes a very steady load. But, when feeding a Combustion Turbine, we are asking a large control valve to cover both ends of the spectrum. The *High Frequency-Low Volume* changes in gas flow are very difficult to accomplish with a large valve for obvious reasons. Large Mass and Inertia, oversized for small load changes, and Lag time issues just to name a few. If the system is tuned to try to mitigate these issues, we now have problems providing *Low Frequency-High Volume* changes in gas loads due to overshooting.

It is nearly impossible to tune the large valve PID loop for the turndown required to meet both conditions of steady-state gas flow demands **and** the large step rate gas flow demands of the newer CT power plants--especially when the regulator station is located close to the CTs. You end up with a system that can only partially satisfy both conditions with pressure swings at steady state operation and during large step rate changes. These pressure swings can be reduced, but not eliminated, by using electronic PID controls instead of pneumatic PID due to the speed advantage These fluctuations also can also be reduced, but not eliminated, by including a second-stage pressure cut which increases station cost and complexity.

2. **Transition Regions**-*There is a Point Of Transition between the Low Flow Valve and the High Flow Valve where there is no control available.*

Combustion Turbine engines sometimes will go from start-up to an intermediate operating point and maintain this position for some time while other plant equipment comes on line (usually the steam drum). These intermediate operating points can occur at the Point Of Transition between the Low-Flow and the High-Flow run.




Couple this with a plant that is operating under AGC control, and there are many instances where the plant needs to operate at the Point Of Transition region between the two control valves. If operated here, there is a lack of control or instability in the station set-point. If the operators adjust the set-points between the runs close to each other, there is "fighting" between the regulators at the transition region. If there is a large gap between the set-points of the runs, neither regulator is in control at the cross-over point of operation. In either case, there is instability in the gas delivery pressure at the Point Of Transition region and CTs cannot operate there for extended periods of time.

## THE TRIM RUN-MAIN RUN COMBUSTION TURBINE ENGINE DESIGN PHILOSOPHY

After looking at the two most used current designs, it is clear that the problems presented by CT power plants require a different approach to regulator station design for these applications. The challenge to this application is to provide a system that has:

- Essentially infinite turndown to meet the small gas flow rate changes and the demands of ancillary equipment
- Allow for smooth start-up of the combustion turbines at relatively low flow rates, and yet provide enough high capacity for multiple turbine power plants at 100% Base-Load operation
- The control valve system must have exceptional speed of response because of the close proximity to the CTs and the near-instantaneous transition capability of the CT's. This speed of response cannot come at the expense of maintaining stable steady-state control
- Stable Steady State Control. This is especially critical when under AGC control and when commissioning new CT power plants. Fluctuating inlet pressure to the CTs could cause a unit or multiple units to trip off line. Also, Turbine Efficiency is reduced when the pressure is not stable.

**Trim Run/Main Run Design** - This design is based upon a dual run philosophy and has been used successfully for approximately 15 years as of this writing. There are three major equipment configurations of this design. Each configuration has many small design details that make the system perform; details such as Valve Trim Styles, Actuator Bench Sets, PID Settings, etc. These small design details are selected based upon plant size, distance to plant, pressures, flow rates, etc. These details will not be discussed since this is a general presentation of the design philosophy.

There are **three** main configurations of this design and they are:

- **Globe Valve / Flexible Element** – As the picture shows below, this design has a Main Run Globe Valve worker and Ball Valve Monitor. The Trim Run has a Flexible Element worker/monitor set. **(See the P&ID on the following pages for detail - Fig 1)**.

- **Ball Valve / Globe Valve** – As the picture shows below, this design has a Main Run Ball Valve worker and monitor set and the Trim Run has a Globe Valve worker and monitor set. **(See the P&ID on the following pages - Fig 2)**

- **Globe Valve / Globe Valve –** As the picture shows below, this design has a Main Run Globe Valve Worker with Ball Valve Monitor. The Trim Run has a Globe Valve worker and ball or globe valve monitor set. **(See the P&ID on the following pages for detail - Fig 3)**.

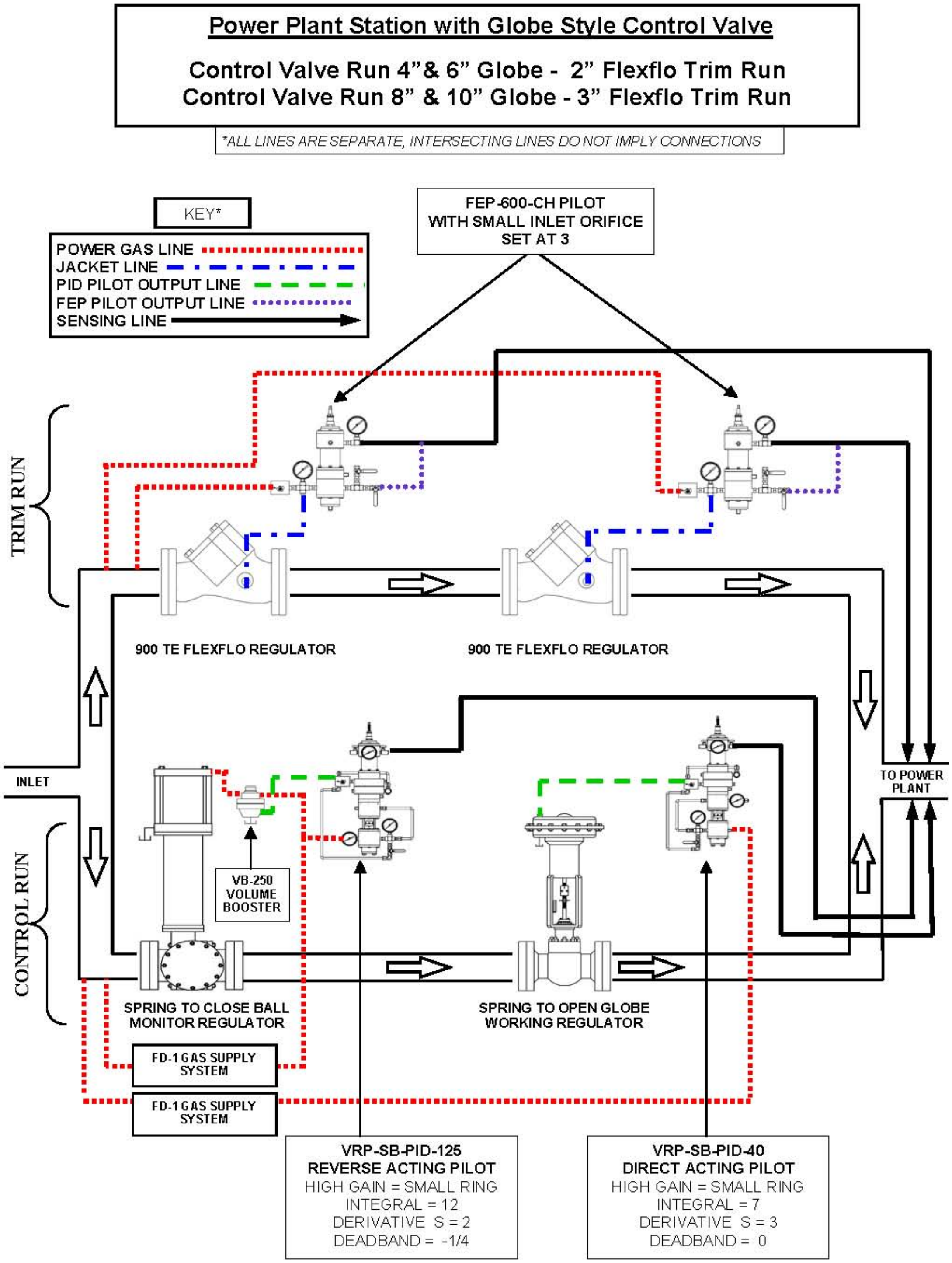

Power Plant Station with Globe Style Control Valve
Control Valve Run 4"& 6" Globe - 2" Flexflo Trim Run
Control Valve Run 8" & 10" Globe - 3" Flexflo Trim Run
*ALL LINES ARE SEPARATE, INTERSECTING LINES DO NOT IMPLY CONNECTIONS
KEY*
POWER GAS LINE
JACKET LINE
PID PILOT OUTPUT LINE
FEP PILOT OUTPUT LINE
SENSING LINE
FEP-600-CH PILOT
WITH SMALL INLET ORIFICE
SET AT 3
TRIM RUN
900 TE FLEXFLO REGULATOR
900 TE FLEXFLO REGULATOR
INLET
TO POWER
PLANT
CONTROL RUN
VB-250
VOLUME
BOOSTER
SPRING TO CLOSE BALL
MONITOR REGULATOR
SPRING TO OPEN GLOBE
WORKING REGULATOR
FD-1 GAS SUPPLY
SYSTEM
FD-1 GAS SUPPLY
SYSTEM
VRP-SB-PID-125
REVERSE ACTING PILOT
HIGH GAIN = SMALL RING
INTEGRAL = 12
DERIVATIVE S = 2
DEADBAND = -1/4
VRP-SB-PID-40
DIRECT ACTING PILOT
HIGH GAIN = SMALL RING
INTEGRAL = 7
DERIVATIVE S = 3
DEADBAND = 0

Fig. 1

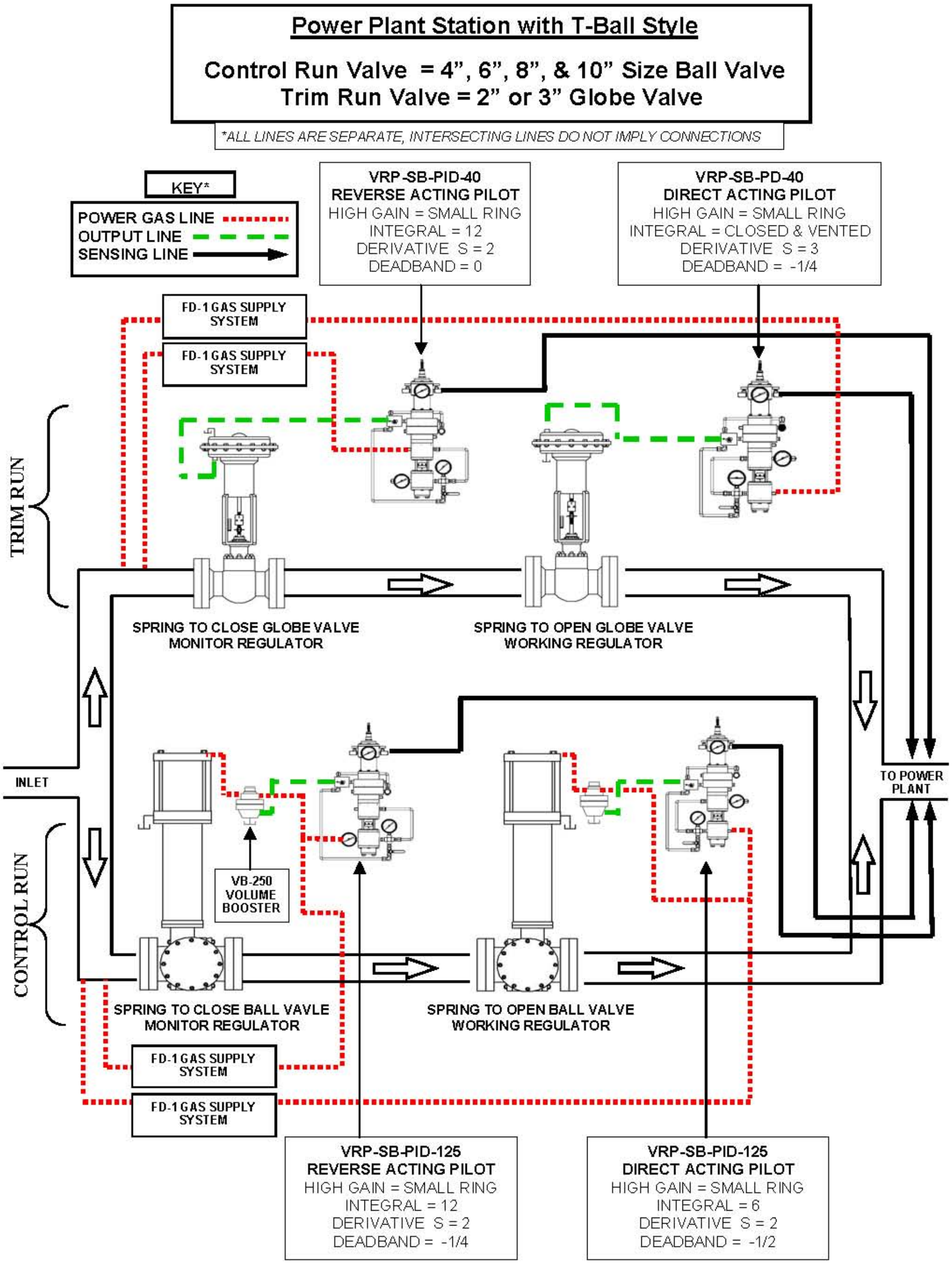
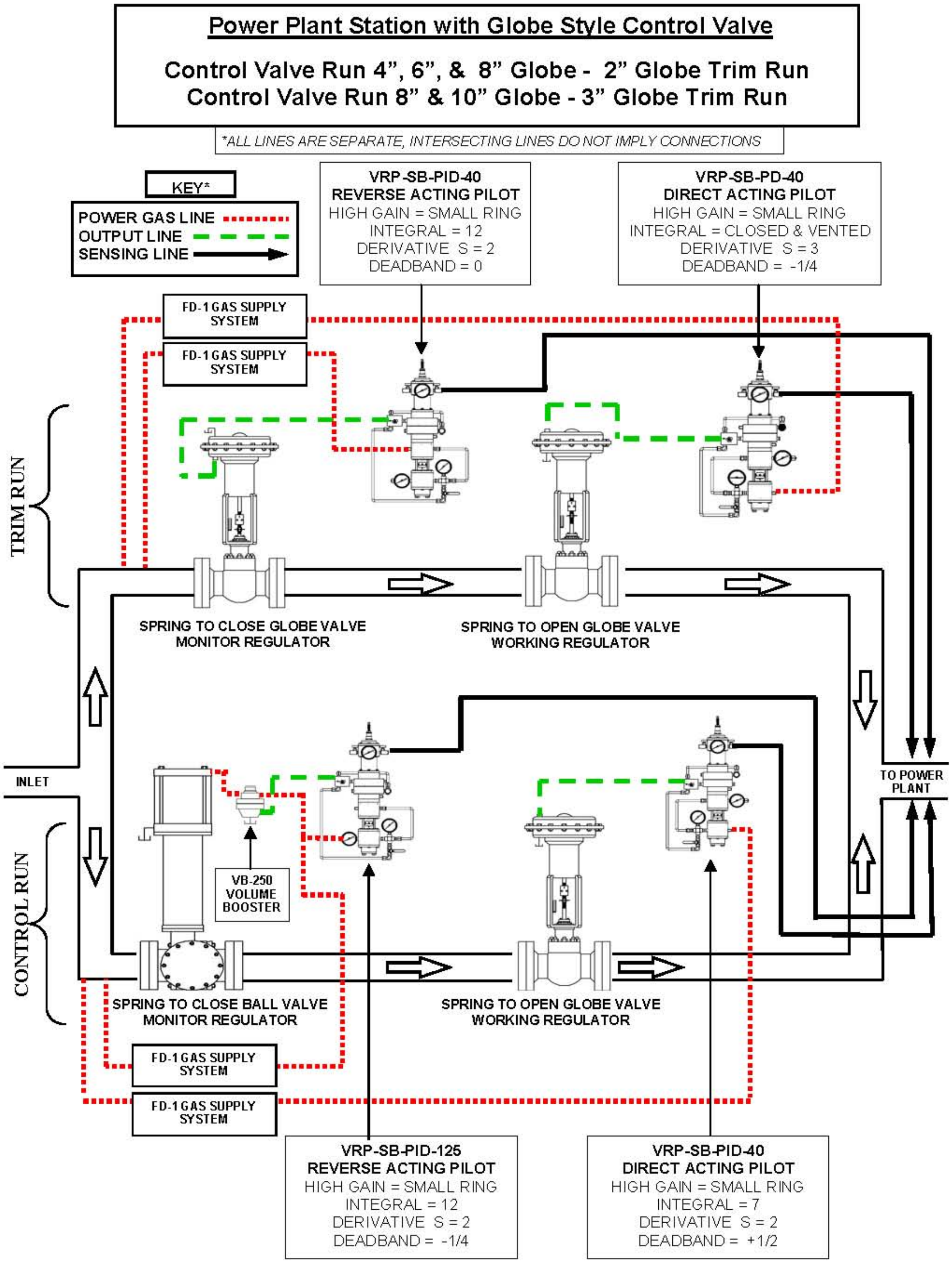

Power Plant Station with T-Ball Style
Control Run Valve = 4", 6", 8", & 10" Size Ball Valve
Trim Run Valve = 2" or 3" Globe Valve
*ALL LINES ARE SEPARATE, INTERSECTING LINES DO NOT IMPLY CONNECTIONS
KEY*
POWER GAS LINE
OUTPUT LINE
SENSING LINE
VRP-SB-PID-40
REVERSE ACTING PILOT
HIGH GAIN = SMALL RING
INTEGRAL = 12
DERIVATIVE S = 2
DEADBAND = 0
VRP-SB-PD-40
DIRECT ACTING PILOT
HIGH GAIN = SMALL RING
INTEGRAL = CLOSED & VENTED
DERIVATIVE S = 3
DEADBAND = -1/4
FD-1 GAS SUPPLY SYSTEM
FD-1 GAS SUPPLY SYSTEM
TRIM RUN
SPRING TO CLOSE GLOBE VALVE
MONITOR REGULATOR
SPRING TO OPEN GLOBE VALVE
WORKING REGULATOR
INLET
TO POWER PLANT
VB-250
VOLUME
BOOSTER
CONTROL RUN
SPRING TO CLOSE BALL VAVLE
MONITOR REGULATOR
SPRING TO OPEN BALL VALVE
WORKING REGULATOR
FD-1 GAS SUPPLY SYSTEM
FD-1 GAS SUPPLY SYSTEM
VRP-SB-PID-125
REVERSE ACTING PILOT
HIGH GAIN = SMALL RING
INTEGRAL = 12
DERIVATIVE S = 2
DEADBAND = -1/4
VRP-SB-PID-125
DIRECT ACTING PILOT
HIGH GAIN = SMALL RING
INTEGRAL = 6
DERIVATIVE S = 2
DEADBAND = -1/2

**Fig. 2**



Power Plant Station with Globe Style Control Valve
Control Valve Run 4", 6", & 8" Globe - 2" Globe Trim Run
Control Valve Run 8" & 10" Globe - 3" Globe Trim Run
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HIGH GAIN = SMALL RING
INTEGRAL = 7
DERIVATIVE S = 2
DEADBAND = +1/2


**Fig. 3**

At first glance, these three designs look like the Low Flow/High Flow design, but the difference is that this dual parallel run operates and controls--*at the same time, not independently*. The two regulator runs work together as a team to provide the necessary control and turndown required to meet the varying gas load needs for these Turbine Engine Power Plants. From Start-Up to Base-Load operation this design delivers reliable stable gas pressure, including the needs of ancillary equipment - from duct burners to water heaters, and all points in between.

**The Set Up**

This design meets all the needs of new CT power plants primarily because the Trim Run valve is **always** in operation providing needed control at the same time as the Main Run valve. Remember, in the Low Flow/High Flow design, the Low Flow run completely opens before the High flow run begins to operate and in effect becomes a piece of pipe. ***In this design, we don't want the Trim Run to ever go fully open under normal conditions; we want it to be the lead in control at all times. The main run is the supporting function in this design.***

The question is -- how do you get the two runs to operate simultaneously without the trim run going full open? How do you get the two runs to work together without "fighting" each other? The answer is that the Trim Run worker operates as a Proportional + Derivative (PD) regulator and the Main run worker operates as a Proportional + Derivative + Integral (PID) regulator. They work together without interfering with each other. The Trim Run is a small High Gain Control Valve system that has the ability to provide ***High Frequency - Low Volume*** changes in gas load. The Main Run is a large High Gain Control Valve system that will provide the ***Low Frequency - High Volume*** changes in gas load. When the two runs work simultaneously, they can supply all the gas load needs of the CT power plant, both large and small. The Trim Run is a much faster reacting control valve than the Main Run valve. It is the "leading" function in this design, meaning it reacts to system demands first. The ability to be quicker than the Main Run means that the Trim Run is actually in control at all times. The purpose of the Main Run is now relegated to providing gross gas load changes for the system, no matter how many turbines are online.

**How does it Work?**

We know that a proportional regulator has a drop in downstream pressure as flow rate increases. This is the "proportional band" or "droop" of the regulator. Keep in mind, the proportional band is defined as the change in control pressure required to stroke the control valve from full closed to full open. Since the Trim Run worker is a Proportional + Derivative regulator, it will open in proportion to increased flow rate, and as it opens, there is a pressure drop from setpoint. Conversely, if the flow rate decreases, the valve closes, and there is a corresponding increase in pressure. We take advantage of the "droop" of the Trim Run regulator in the operation of the system.

The idea is that we want the Trim Run to operate at between 30-70% open at all times, thus staying in control. When the Trim Run Valve is at 50% open, (in the middle of its proportional band), this position is at the station set-point. **The 50% open position of the Trim Run Valve corresponds to the regulator station pressure set-point, the same set-point as the Main Run.** When the power plant is starting up, the Trim Run opens and feeds gas until it reaches its 50% position, which corresponds to the station set-point or delivery pressure. This 50% position of the Trim Run is the Crossover point where the Main Run starts to open. (See Fig. 4)

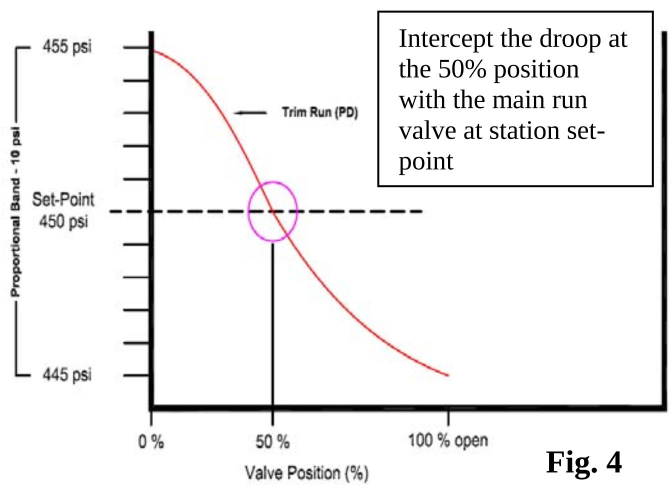



**Fig. 4**

As the Power Plant draws more gas, the Trim Run attempts to provide more flow and "droops" below the station set-point. When this happens, the Main Run starts to open providing the gross gas load requirement and the trim backs off to its basic 50% position. Since the Main Run is a PID controlled run (the "I" function or Integral portion is responsible for eliminating any proportional band offset), it will maintain a defined set-point with a very small, if any, dead band. When the Power Plant is on line and is operating at steady-state, the regulator station will experience *High Frequency-Low Volume* changes in gas load. Under these conditions, the Trim Run has ample speed and capacity above and below its 50% position to satisfy those small gas load changes when they are within the Main Run operational dead band. (See Fig.5)

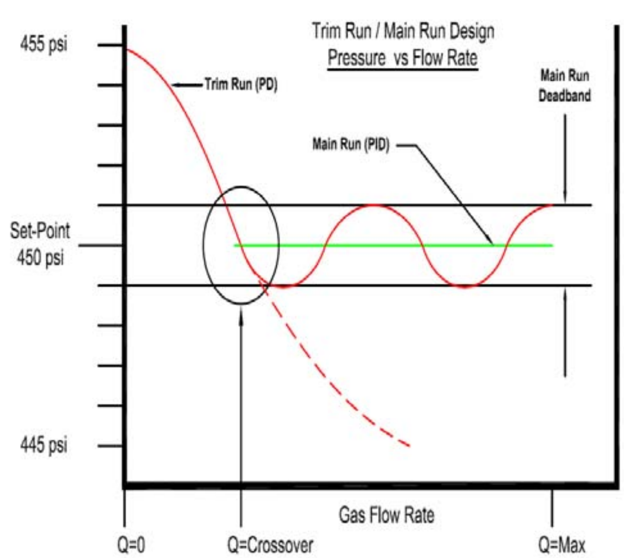



**Fig. 5**

When additional CTs come online and there is an increase in the required gas load, the regulator station will experience a *Low Frequency-High Volume* change in gas load and the Trim Run will attempt to satisfy the gas load change. The Trim Run set-point will drop as the Trim valve opens to satisfy the load change and the station set-point will drift outside the Main Run dead band. At this point, the PID controlled Main Run valve repositions itself, thus satisfying the large load change in gas flow rate and re-establishing its set-point. When the Main Run valve completes this change, the Trim Run moves back to approximately its 50% open position, and the Main Run valve has a new position. **In effect, the Main Run is providing all the gross gas load requirements at set-point pressure, and the quicker Trim Run maintains the fine control no matter how many CTs come on line (see Fig 6).** The Trim Run will operate between 30-70% open under normal operation with 50% as its target position for the station set-point. This identical process will take place in the opposite direction if there is a large decrease in gas flow rate demand.

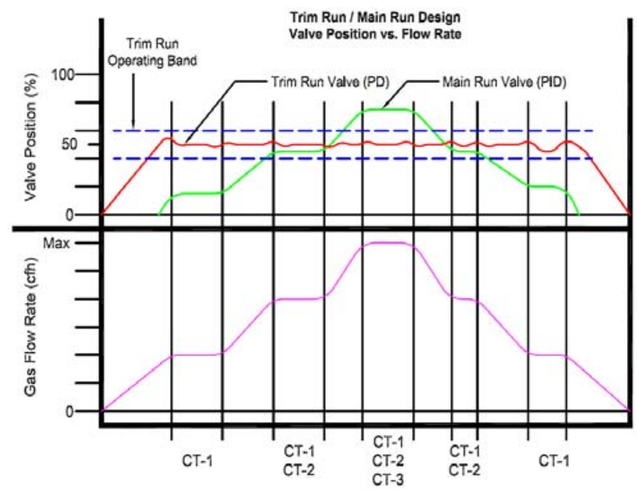
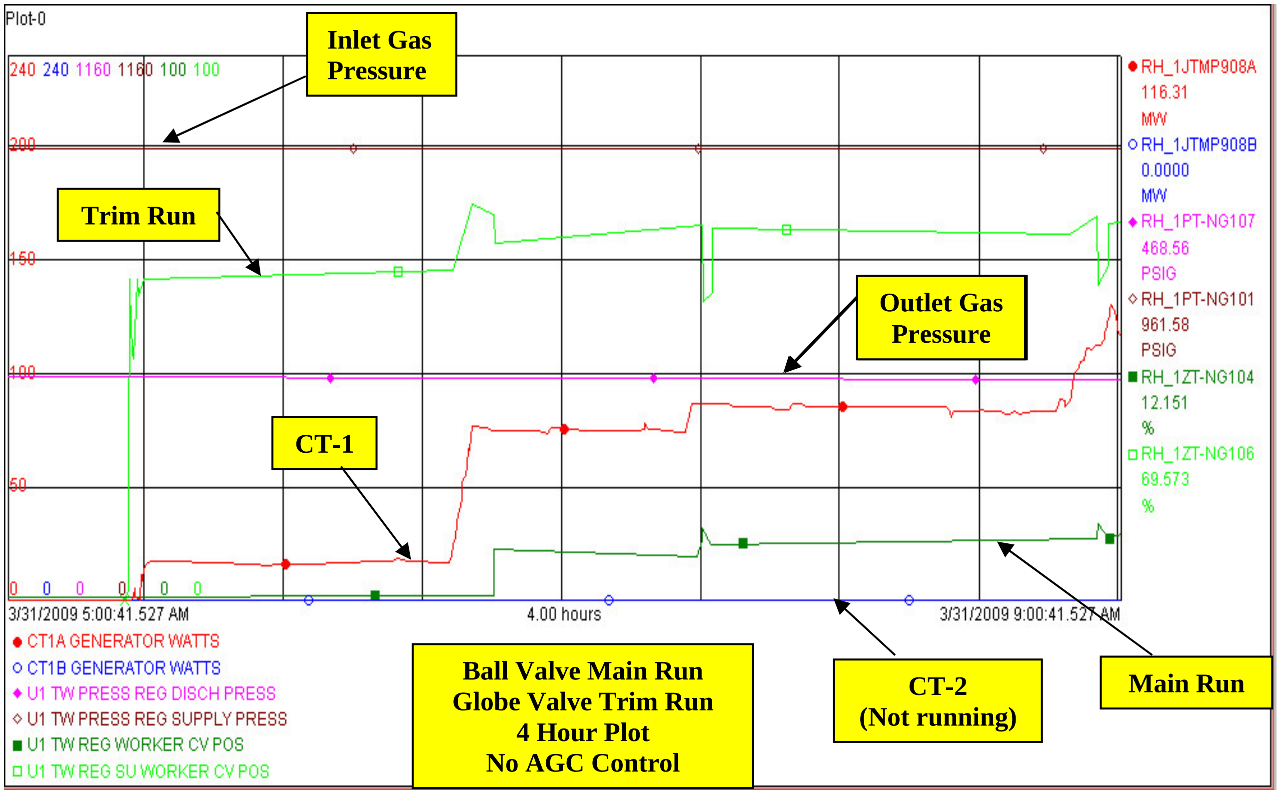
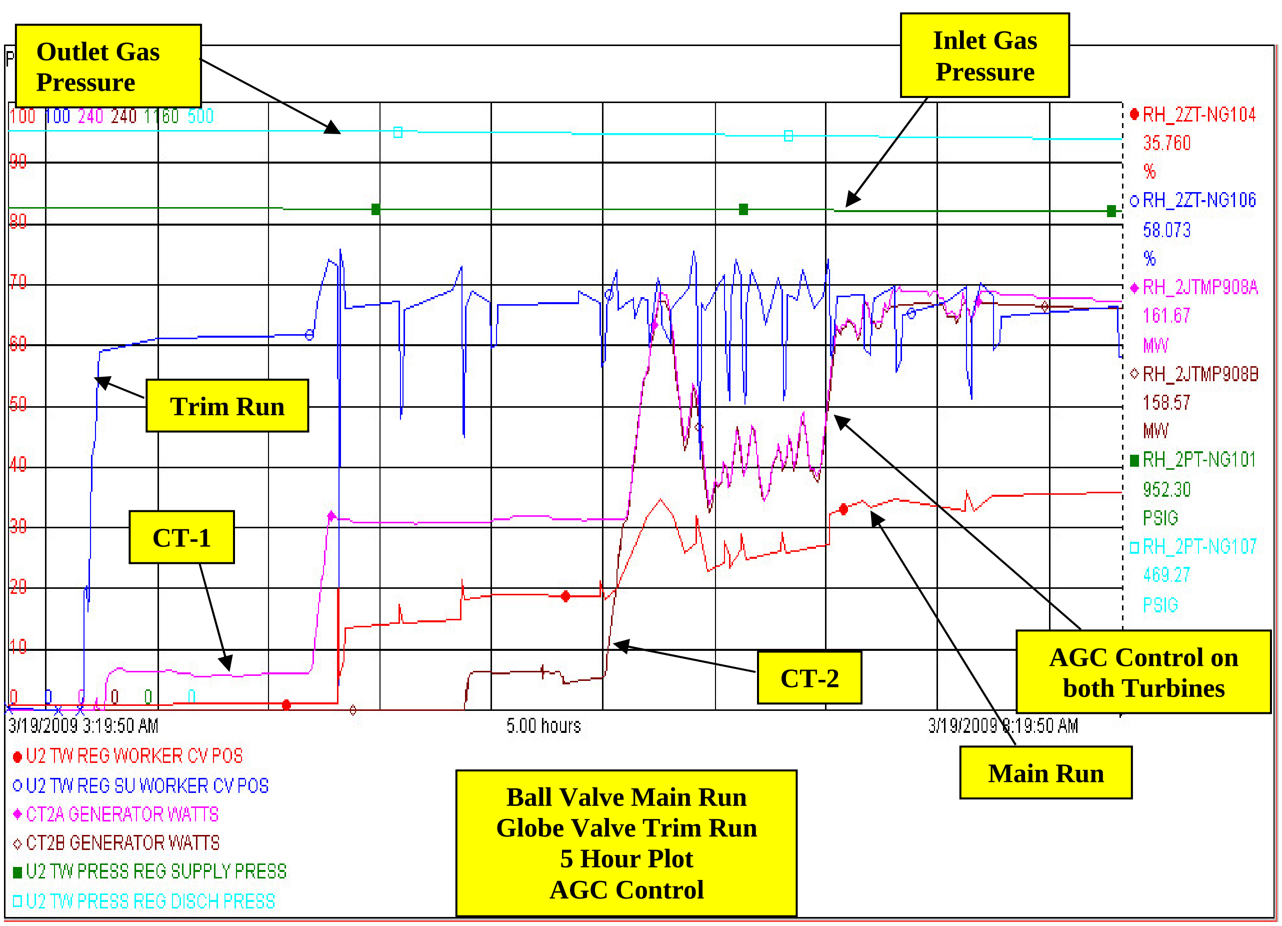


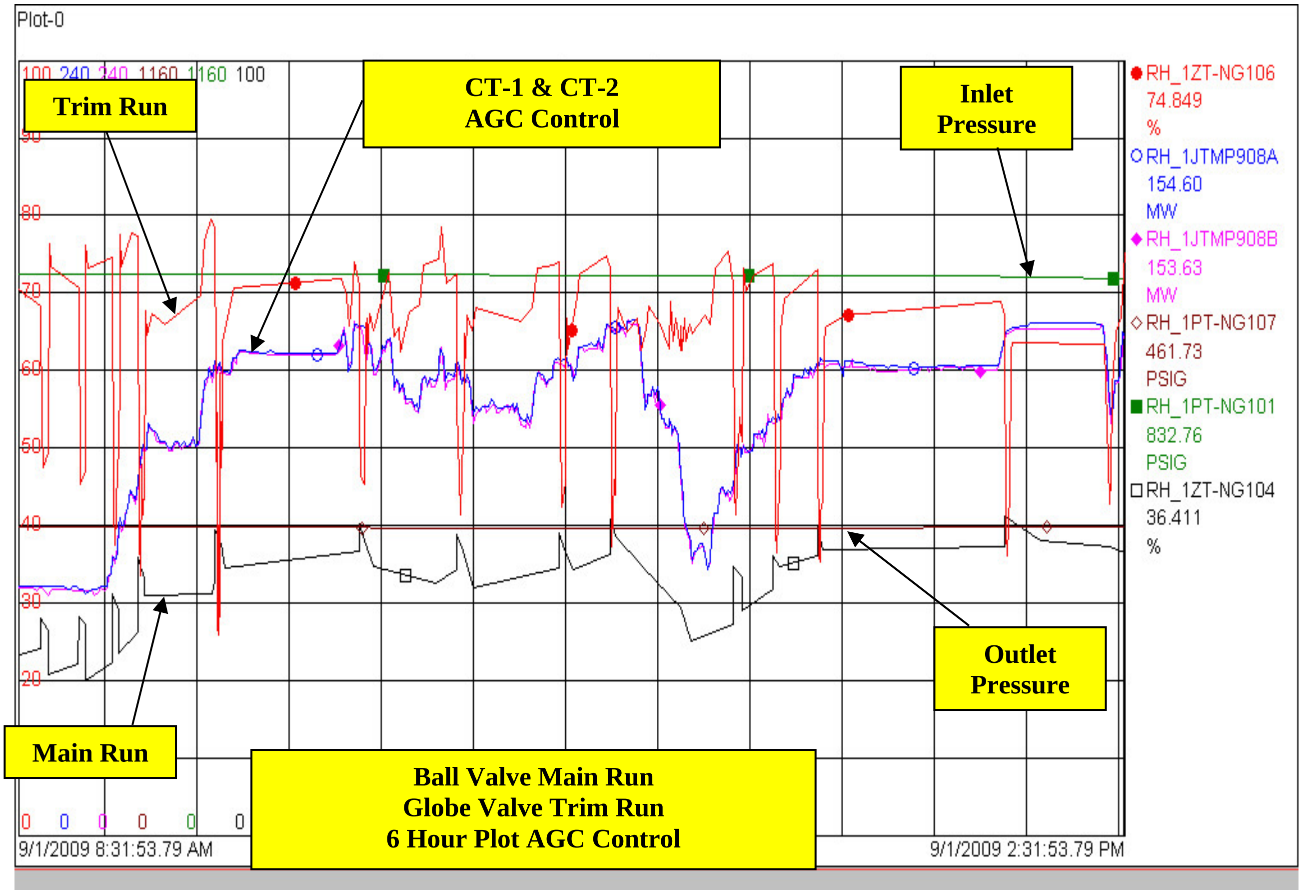

**Fig. 6**

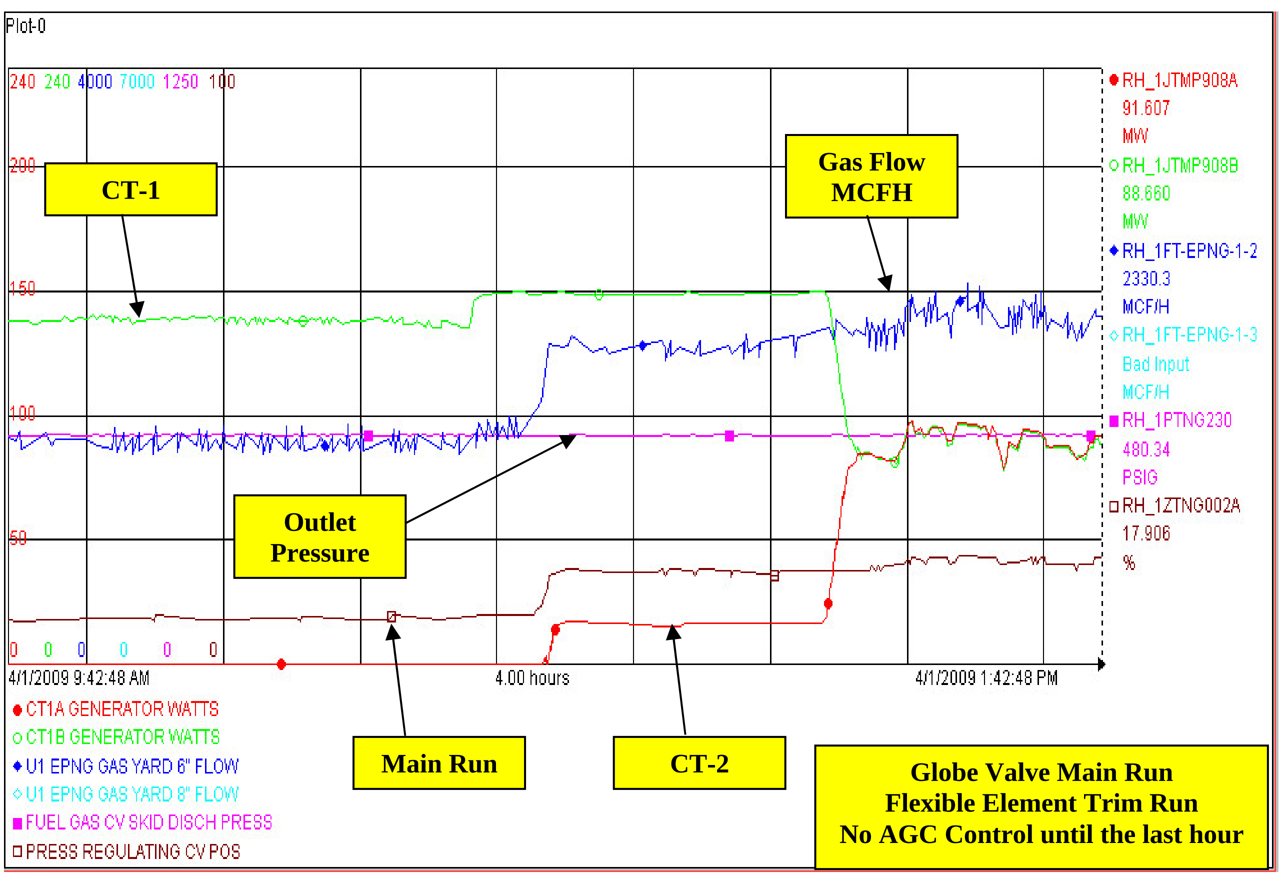
It is this ability to satisfy both large and small gas load requirements at the same time and maintain control that makes this design the right choice for CT power plants. By having both runs in control and having the Trim Run as the "leading" function, the station will have a **Fast Speed of Response** coupled with a **Tight Control** capability and a **Stable Steady State** delivery pressure, under all operational conditions.

**Listed below are actual Plots from two different designs where you can see the valve movement of both the Trim Run and the Main Run. You also can see the inlet pressure and the fluxuations in the load of the CT's. Against all of this the outlet gas pressure is stable under all these conditions.**


Plot-0
Inlet Gas Pressure
Trim Run
Outlet Gas Pressure
CT-1
240 240 1160 1160 100 100
200
150
100
50
0 0 0 0 0 0
3/31/2009 5:00:41.527 AM
4.00 hours
3/31/2009 9:00:41.527 AM
RH_1JTMP908A 116.31 MW
RH_1JTMP908B 0.0000 MW
RH_1PT-NG107 468.56 PSIG
RH_1PT-NG101 961.58 PSIG
RH_1ZT-NG104 12.151 %
RH_1ZT-NG106 69.573 %
CT1A GENERATOR WATTS
CT1B GENERATOR WATTS
U1 TW PRESS REG DISCH PRESS
U1 TW PRESS REG SUPPLY PRESS
U1 TW REG WORKER CV POS
U1 TW REG SU WORKER CV POS
Ball Valve Main Run
Globe Valve Trim Run
4 Hour Plot
No AGC Control
CT-2
(Not running)
Main Run


Outlet Gas Pressure
Inlet Gas Pressure
100 100 240 240 1160 500
90
80
70
60
50
40
30
20
10
0 0 0 0 0 0
Trim Run
CT-1
CT-2
AGC Control on both Turbines
3/19/2009 3:19:50 AM
5.00 hours
3/19/2009 8:19:50 AM
RH_2ZT-NG104 35.760 %
RH_2ZT-NG106 58.073 %
RH_2JTMP908A 161.67 MW
RH_2JTMP908B 158.57 MW
RH_2PT-NG101 952.30 PSIG
RH_2PT-NG107 469.27 PSIG
U2 TW REG WORKER CV POS
U2 TW REG SU WORKER CV POS
CT2A GENERATOR WATTS
CT2B GENERATOR WATTS
U2 TW PRESS REG SUPPLY PRESS
U2 TW PRESS REG DISCH PRESS
Main Run
Ball Valve Main Run
Globe Valve Trim Run
5 Hour Plot
AGC Control


Plot-0
100 240 240 1160 1160 100
Trim Run
CT-1 & CT-2
AGC Control
Inlet
Pressure
RH_1ZT-NG106
74.849
%
RH_1JTMP908A
154.60
MW
RH_1JTMP908B
153.63
MW
RH_1PT-NG107
461.73
PSIG
RH_1PT-NG101
832.76
PSIG
RH_1ZT-NG104
36.411
%
90
80
70
60
50
40
30
20
Outlet
Pressure
Main Run
Ball Valve Main Run
Globe Valve Trim Run
6 Hour Plot AGC Control
0 0 0 0 0 0
9/1/2009 8:31:53.79 AM
9/1/2009 2:31:53.79 PM


Plot-0
240 240 4000 7000 1250 100
RH_1JTMP908A
91.607
MW
RH_1JTMP908B
88.660
MW
RH_1FT-EPNG-1-2
2330.3
MCF/H
RH_1FT-EPNG-1-3
Bad Input
MCF/H
RH_1PTNG230
480.34
PSIG
RH_1ZTNG002A
17.906
%
200
CT-1
Gas Flow
MCFH
150
100
50
Outlet
Pressure
0 0 0 0 0 0
4/1/2009 9:42:48 AM
4.00 hours
4/1/2009 1:42:48 PM
CT1A GENERATOR WATTS
CT1B GENERATOR WATTS
U1 EPNG GAS YARD 6" FLOW
U1 EPNG GAS YARD 8" FLOW
FUEL GAS CV SKID DISCH PRESS
PRESS REGULATING CV POS
Main Run
CT-2
Globe Valve Main Run
Flexible Element Trim Run
No AGC Control until the last hour

**Monitor Regulators**

The monitor regulators primary function in this design is to protect the power plant from an overpressure occurrence. The Main Run monitors, on all three configurations are all ball valve regulators but could be globe valve if the worker is a globe valve. The main run monitor will have different PID loop control settings that the worker regulator. These control settings will be faster reacting to catch a worker failure without over pressuring the line. Since the monitor remains in the full open position, the closing speed is maximized to prevent an overpressure occurrence. If the monitor is fully closed, the opening speed is minimized to prevent overpressure occurrence. The downside to this faster reacting setting is a slight pressure swing when the Main Run monitor regulator is in control. The monitor regulator set-point is approximately 10-15 psig greater than the worker regulator.

The Trim Run monitor regulator is set up as a duplicate Trim Run regulator if it is the "Boot Style" design. This is because it is the fastest of all regulators and in the event of a Trim Run worker failure it has the speed to "catch" the overpressure without loss of control. If the Trim Run design monitor regulator is the Globe Valve type, the controls on this monitor are full PID controls, not PD control. PID control is required on the monitor to avoid interference with the working regulator. The monitor regulator set-point of both Trim Run designs is usually the same as the Main Run monitor regulator.

## CONCLUSION

The Trim Run/Main Run design addresses the issues most prominent in Simple Cycle and Combined Cycle Combustion Turbine power plants that also have ancillary gas load requirements. Having a PID controlled Main Run coupled with a PD controlled Trim Run allows the two to work together without interference. The Main Run Regulator provides the gross gas load requirements while the small regulator acts as a trimmer to absorb any overshoots or bumps. The end result is a system with near infinite turndown, fast speed of response, tight control, and steady-state stability. The control system logic is simple and reliable. Outside of small Peaker Plants, no matter the size of the plant, the system will still be a dual run - only the size of the control valve changes. The overall result of utilizing this Main Run/Trim run design is that the pressure to the power plant is stable at all points of operation and the plant can operate at its peak efficiency with minimal downtime.

## REFERENCES

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Wikipedia – Combined Cycle Plants