Blending Fuel Gas to Optimize use of Off-Spec Natural Gas

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ABSTRACT

The completion of a pipeline to bring natural gas directly from gas wells to power plants in the Odessa, Texas, area was announced in June 2010. The natural gas being supplied is from the Permian Basin Yates Formation. The Yates Formation gas is an off-spec gas with a high concentration of Nitrogen. The fundamental objective is to use this low Btu, high Nitrogen gas as a low cost fuel. Scrubbing the gas to remove the Nitrogen makes it too costly to use as a fuel. However, if this gas could be blended with higher Btu spec gas typically supplied to power plants, it would meet the objective of providing a lower cost fuel while volumetrically reducing the Nitrogen content of the final mixture.

The project objective was to design and install a blending station(s) utilizing either Btu or Wobbe Index as the basis to blend the gases such that the resulting fuel would be a lower cost alternative, and meet GE's firing requirements for the GE Frame 7001 FA Gas Turbines and environmental emissions limits. An analyzer that could determine the composition of the natural gas in near real time mode was employed. The analyzer outputs, as well as other instrumentation, were brought into the plant's DCS for operator monitoring and control of the gas blending stations.

INTRODUCTION

The objective of this paper is to present a project to provide a lower fuel cost alternative, while meeting the firing requirements of the GE Frame 7001 FA Gas Turbines (GT) and environmental emissions limits. Before discussing the project, we will discuss the source of the low cost fuel and review a few important plant statistics. Details of the project will be discussed, such as, the requirements and restrictions of blended fuel gas, blending methodologies, Wobbe Index, the selected gas composition analyzer, general project piping layout overview, blending stations, and control methodology. This will be followed by a results summary.

BACKGROUND

THE ALTERNATIVE FUEL SOURCE

Several years ago, four forward thinking companies came together forming a partnership to provide a cheaper source of fuel for generating electricity in West Texas. A 62 mile pipeline has been constructed to supply off-spec well gas that is high in nitrogen direct from Permian Basin wells to the Odessa-Ector Power Plant operated by PSEG-Texas and to Quail Run Energy Center near Odessa operated by Navasota Energy.

The off-spec well gas is prevalent throughout the Yates formation, especially in the Permian Basin's Gains, Andrews, and Ector counties. The off-spec well gas is produced at a depth of about 3,000ft, but has been considered too costly because it had to be "scrubbed" to remove the diluent, Nitrogen, before being transported. There are over 200 old wells drilled to a deeper oil formation at a depth of approximately 4,800 ft. These wells can be worked over to produce gas from the Yates formation.

GE has confirmed that the high-nitrogen well gas could be used as a fuel gas in their gas turbines on a blended basis. This means that the off-spec gas could now be transported without the prior need to remove the Nitrogen at the well head. This would significantly reduce the cost of fuel gas to the plants.

THE PLANT STATISTICS

The Odessa-Ector Power Plant began operation in 2001. The plant is rated at 1,000 MW electrical and is composed of two combined-cycle, 2 on 1 GT / HRSG / ST trains. Each combination includes two GE Frame 7001FA Gas Turbines (GT) with dry low-NOx burners. Each GT is rated at 150 MW and has an associated Heat Recovery Steam Generator (HRSG) with a duct burner. A 200 MW GE Steam Turbine (ST) is common to each pair of GT/HRSGs. The plant presently fires pipeline quality (Hi Btu) gas rated at an average of 1,000 – 1,025 Btu/scf provided from two sources. The mixture passes through a knock-out separator in the gas yard before being sent to the plant via a common header. The gas mixture is pre-heated to 300^{o} F prior to being fired in the gas turbines.

The plant central control system is an Ovation Distributed Control System (DCS) supplied by Emerson Process Management. The DCS is integrated with the Combustion and Steam Turbine Mark 5e controllers, supplied by GE with the equipment, for the purpose of remote start/stop of the turbines, monitoring of data, and collecting historical data in a historian. There is no gas metering or fuel composition analysis at the gas yard and no fuel composition analysis at any of the units.

THE PROJECT

DESIGN CRITERIA

To fully appreciate the scope of the project, the design parameters must first be discussed:

A gas sample of the Low Btu gas from the Yates Formation has the following fractional analysis:

Table 1 – Yates Formation Sample Fractional Analysis

COMPONENT	MOL %
Nitrogen	**28.33**
Carbon Dioxide	0.05
Methane	56.78
Ethane	8.88
Propane	3.84
Iso-Butane	0.36
N-Butane	1.02
Iso-Pentane	0.20
N-Pentane	0.26
Hexanes	0.28
TOTAL	100.00

Calculated Specific Gravity = 0.789

Btu / cu ft (@14.65 psia, 60^{o} F) =

Calculated Gross Wet = 888

Calculated Gross Dry = 904

Table 2 specifies the allowable limits for the fuel properties and constituents for GE gas Turbines.

Table 2 – Fuel Gas Specification

FUEL PROPERTIES	MAX	MIN
Gas Fuel Pressure	Varies with unit and combustor type	Varies with unit and combustor type
Gas Fuel Temperature, °F		
Lower Heating Value, Btu/scf	None	100-300
Modified Wobbe Index (MWI)		
- Absolute Limits	54	40
- Range Within Limits	+5%	-5%
Flammability Ratio		2.2:1
Constituent Limits, mole %		
Methane	100	85
Ethane	15	0
Propane	15	0
Butane + higher paraffins (C4+)	5	0
Hydrogen	Trace	0
Carbon Monoxide	Trace	0
Oxygen	Trace	0
Total Inerts (N_2+CO_2+Ar)	**15**	0
Aromatics (Benzene, Toluene etc.)		0
Sulfur		0

GAS TURBINE LIMITS

The GE Frame 7001FA Gas turbines are unable to burn 100% Low BTU. In addition to the potential of generating excessive NO_x emissions, fuel gases with large percentages of inert gases such as Nitrogen will have a ratio of rich-to-lean flammability limits less than that of natural gas. Low flammability ratios may cause the GT to experience problems maintaining stable combustion over the full operating range of the turbine. Therefore, a gas blending system is required to ratio the two sources of gas to prevent combustion instability and the generation of excessive NO_x emissions. The intent is to burn as much of the Low Btu gas as possible since it is available at a more attractive price than Hi Btu gas.

By calculation, we know the blended gas streams ratio could be a high as 50/50. As indicated in the Fractional Analysis table above, the Yates formation well gas is 28% Nitrogen and the Hi Btu gas contains approximately 2% Nitrogen. If the gas is blended 50/50, the total Nitrogen content would be 15%. This is the maximum Nitrogen limit recommended by GE for the 7 FA Turbines. Table 2 specifies GE's allowable limits for fuel properties and constituents. This then sets the upper limits for the design project.

METHODS OF LIMITING NITROGEN INTRODUCTION

Although the ultimate goal is to use as much of the Low Btu gas as possible, we must control the amount of Nitrogen introduced to the GTs. It is simply a matter of controlling the blending of two fuel gas streams. It is easier to blend based on hydrocarbon content than inert gas content because it is relatively easy to determine the Btu content. Our investigation found that several analyzers were available that could provide real-time or near real-time analysis for hydrocarbons. One analyzer we investigated could provide real-time analog outputs for Btu as well as for Wobbe Index.

Strangely enough, the British Thermal Unit (Btu) is rarely used in Great Britain anymore, where it is considered a non-metric measurement. Even in countries which use the Btu as a standard measurement, there is some disagreement over the formula used to derive it. The thermal energy needed to raise water one degree Fahrenheit can depend on the original temperature and pressure. Therefore, it is possible to get several different definitions of a Btu from different sources. In the US, a Btu is generally defined as the amount of heat required to raise the temperature of one (1) pound (0.454 kg) of liquid water by 1 °F (0.556 °C) at a constant pressure of one atmosphere.

The heat of combustion, also known as heating value or calorific value of a fuel, is the amount of energy generated by the complete combustion of a unit mass of fuel. The US system of measurement uses British Thermal Units (Btu) per pound or Btu per standard cubic foot when expressed on a volume basis. The heating value of a gas fuel may be determined experimentally using a calorimeter in which fuel is burned in the presence of air at constant pressure. The products are allowed to cool to the initial temperature and a measurement is made of the energy released during complete combustion. All fuels that contain hydrogen release water vapor as a product of combustion, which is subsequently condensed in the calorimeter. The resulting measurement of the heat released is the higher heating value (HHV), also known as the gross heating value, and includes the heat of vaporization of water. The lower heating value (LHV), also known as the net heating value, is calculated by subtracting the heat of vaporization of water from the measured HHV and assumes that all products of combustion including water remain in the gaseous phase. Both the HHV and LHV may also be calculated from the gas compositional analysis using the procedure described in ASTM D 3588.

This is important to understand because the caloric value or the higher heating value is used in the calculation of Wobbe Numbers (Wobbe Index). Goffredo Wobbe, an Italian physicist, observed in 1927:

- Given constant pressure and orifice size, the heat output of a burner is proportional to the flow volume per time
- The flow velocity through a given orifice size at constant pressure is proportional to the specific gravity of the gas

- The calorific value or heating value, of a gas is proportional to its specific gravity.

Wobbe developed a numerical index that provided that if two fuel gases have identical Wobbe numbers, they will deliver the same amount of heat.

The Wobbe Number can be defined by

$$\mathbf{WI = CV / \sqrt{SG}}$$

Where: WI = Wobbe Index number (Although expressed in Btu/scf or MJ/Sm3 (mega joules per standard cubic meter), WI is generally expressed without units to limit confusion with heating value units.)

CV = Caloric Value (Higher Heating Value)

SG = Specific Gravity

Gas turbines do not operate with condensing exhaust systems and it is a common practice for the gas turbine industry to utilize the LHV when calculating the overall cycle thermal efficiency. Therefore, GE uses a modified version of the Wobbe Index.

GE's calculations use a Modified Wobbe Index (MWI):

$$\mathbf{MWI = LHV / \sqrt{SGgas * Tgas}}$$

This is equivalent to:

$$\mathbf{MWI = LHV / \sqrt{(MWgas / 28.96) * Tgas}}$$

Where: LHV = Lower Heating Value of the Fuel Gas (Btu/scf)

SGgas = Specific Gravity of the Fuel Gas relative to Air

MWgas = Molecular Weight of the Fuel Gas

Tgas= Absolute Temperature of the Fuel Gas (º Rankine)

28.96 = Molecular Weight of Dry Air

It is clear that since the Wobbe Index is an indicator of the interchangeability of fuel gases; it can be used to control blending of fuel gases. Since the Wobbe Index and the Btu value of fuel gases make similar curves, either could be used to control blending of fuel gases; thereby, controlling the amount of Nitrogen in the blended fuel.

Alternatively, the classic flow control method could also be used, whereby, the Low Btu gas could be placed on flow control at a selected flow rate less than 50% of the needed fuel flow rate and the Hi Btu gas supply placed on pressure control. This is the simplest method of controlling the blend, but certainly not the optimum.

SINGLE BLENDING STATION VS. INDIVIDUAL GT BLENDING STATIONS

The project evaluated two methods of blending, those being a single blending system at the plant gas yard or individual blending systems at each unit. A neighboring plant that has a different version of GE combustion turbines utilizes a single blending station and feeds the blended gas to their gas turbines and HRSG duct burners. However, the Odessa-Ector power plant chose multiple blending systems because they intended to burn the blended gas only in the gas turbines and felt the additional operability offset the cost of the additional blending stations.

The benefits from utilizing multiple blending systems:

- The GTs, although designed to the same specifications and considered identical, have individual operating characteristics that may require the blend to be unit specific.
- Operational availability of all units is of utmost importance. The operation of any of the units may be limited by its combustion or NO_x characteristics. Individual blending would allow any limiting of the blend mix to affect only that unit without imposing the same limit on the other units.
- A central blending system represents a single point of failure that could require all units to revert to Hi Btu gas, curtailing use of the low cost Low Btu gas.
- A multiple blend system offers the ability to tune each unit and its blend depending upon changing unit characteristics, fowling, or de-rating due to some process problem (i.e., turbine vibration, generator limiting, unit specific BOP problems, HRSG related problems, etc.). Self-tuning or Neural Network may even be utilized later to maximize unit flexibility and operability.

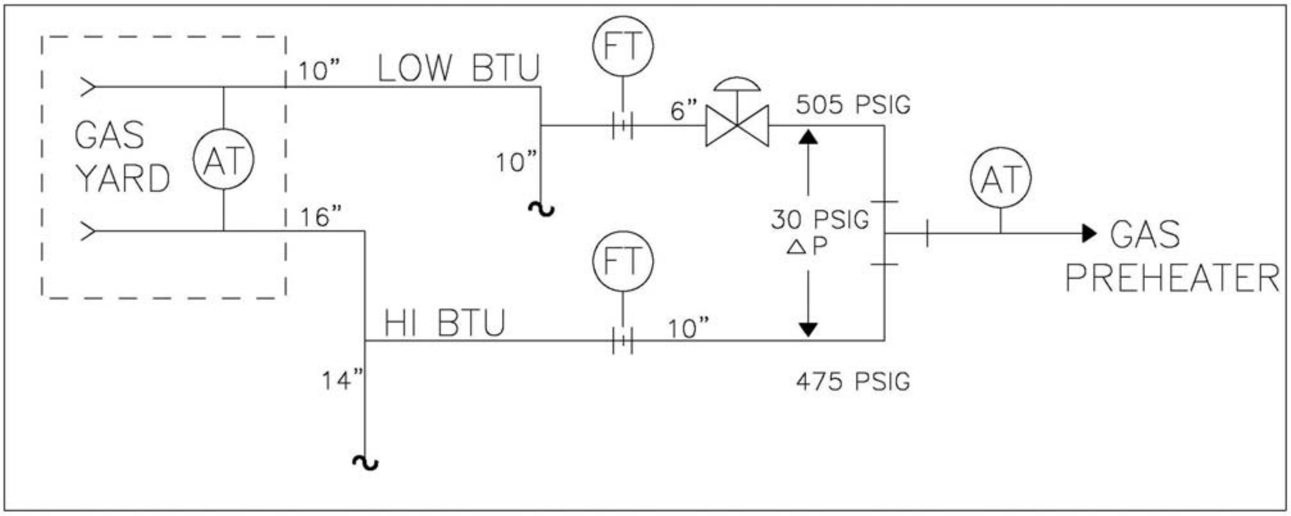
BLENDING SYSTEM DESIGN

The primary reason for success of a good blending system is the selection of a good gas analyzer that can provide the outputs required in real-time. Other characteristics considered were analog outputs for Wobbe Index and Btu, low maintenance requirements, and the analyzer could easily be integrated into the plant in hazardous areas. For this application, the COSA 9600 Btu Analyzer was chosen. This analyzer provides the following features important to this project:

- Analyzer features fast response time and high accuracy
- Provides analog outputs for both Btu and Wobbe Index
- Contains no moving parts, hence low maintenance requirements
- Flameless, the gas/air mixture is burnt catalytically in an oven that utilizes a zirconium oxide Oxygen sensor in the oven
- Can be purged for use in Class 1 Division 1 or Class 1 Division 2 locations as defined in the National Electrical Code (NEC) ANSI/NFPA 70.
- Capable of analyzing multiple streams, thus reducing the number of analyzers required
- Accepts sample gas from a Genie Probe Regulator, whose features are:
    - Provides a representative gas sample
    - Removes all entrained liquids in a sample gas
    - Protects analyzers against liquid damage
    - Probe housing can be installed in a pressurized line
    - Housing includes a foot valve in its base so the probe can be inserted in a pressurized line

In addition to a fuel gas analyzer at each gas turbine blending station, the overall design includes a fuel gas analyzer at the gas yard. The gas analyzer utilized in the gas yard is the dual stream version, eliminating the need for multiple analyzers. The Hi Btu and Low Btu gas supply samples are switched to the analyzer. This analyzer is used to provide a feed forward signal to the blending stations. The analyzers at the discharge of the blending stations are used to bias the blending station for the proper blended gas introduced to the gas turbine. These analyzers provide data to the DCS to control the flow of Low Btu gas. The blending station control logic resides in the plant DCS.

Figure 3 – Blending System Flow Diagram



The actual blending of the gases is accomplished in a "T" downstream of the Low Btu flow control valve. See Figure 3. In order to properly mix the fuel gases, a 30 psi minimum differential is maintained between the two gas supplies at the blending stations. The DCS sends a pressure set point to a PLC at the gas yard to control the Low Btu gas pressure at the blending station 30 psi higher than the High Btu gas pressure. See Figure 4. The blending stations are rather simple and do not require a valve in the Hi Btu fuel gas lines at the blending stations. These blending stations do not require an elaborate skid arrangement and can be fabricated in the field utilizing pre-fabricated spool pieces to maximize the use of existing fuel gas piping.

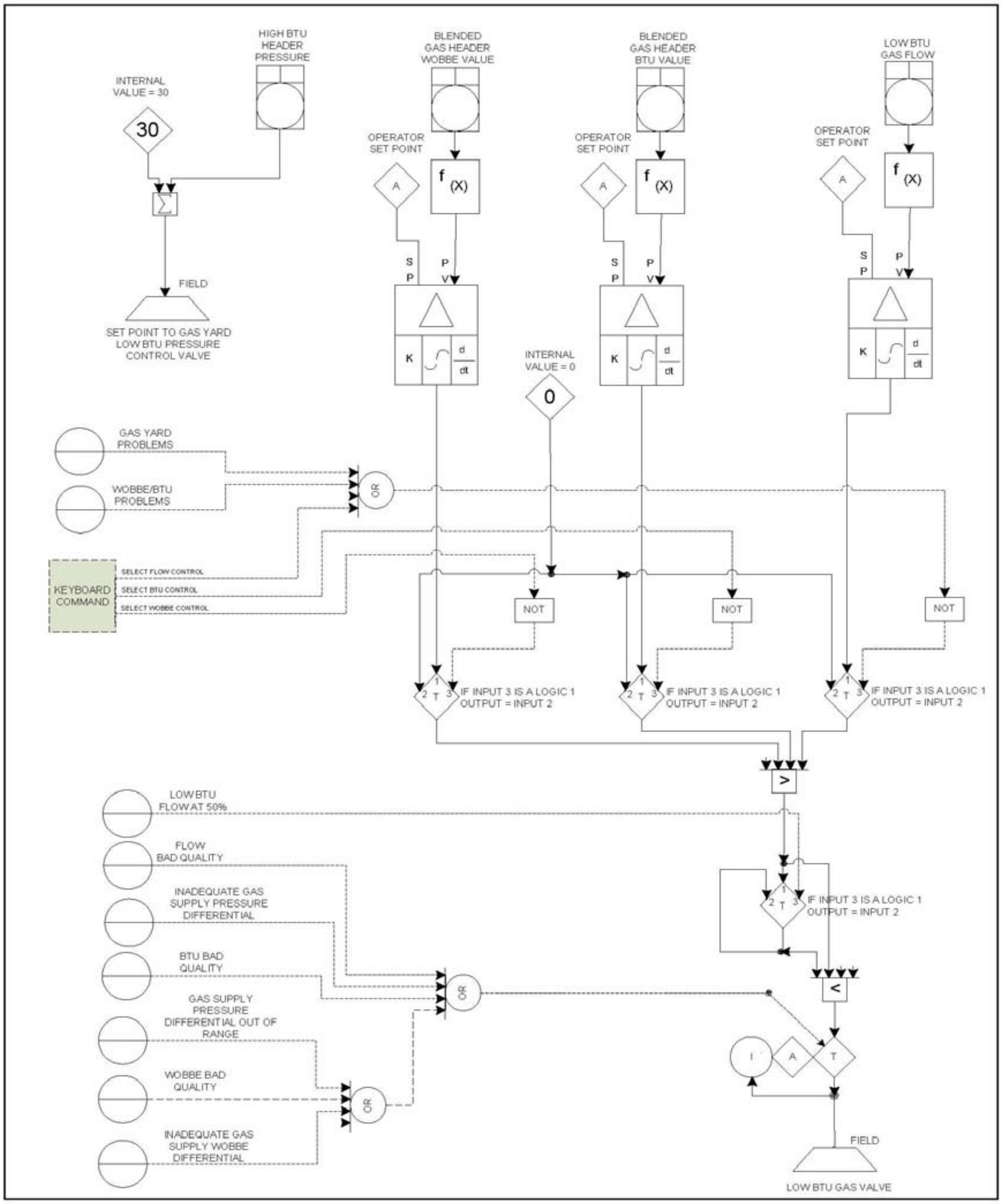
PROGRAMMING

Fuel gases with large percentages of an inert gas such as Nitrogen will have a ratio of rich-to-lean flammability limits less than that of natural gas. Flammability ratios of less than 2.2 to 1 based on volume at standard conditions (14.696 psia and 59°F), may experience problems maintaining stable combustion over the full operating range of the combustion turbine. Combustion turbines can operate with fuel gases having a very wide range of heating values, but the amount of variation that a specific fuel system design can accommodate is limited, usually ± 5%. The fuel nozzles are designed to operate within a fixed range of pressure ratios and changes in heating values are accommodated by increasing or decreasing the fuel nozzle area or the fuel gas temperature. Since changing the fuel nozzle area is difficult, the temperature of the fuel gas is generally changed to accommodate significant changes in the heating values. The combustion turbine control system provides a signal to the DCS indicating poor combustion characteristics. Since, the intent is for the blending station to be capable of introducing as much of the low cost Low Btu gas as possible to the gas turbine, the DCS first decreases the fuel gas temperature to improve combustion before reducing the amount of the Low Btu fuel.

We know that the maximum limit of the Low Btu fuel gas is a 50% ratio, but the minimum limit (low flow) is set by blending system characteristics. To ensure trouble free start-ups, plant Operations prefers to start the gas turbines on Hi Btu fuel gas. Once the unit is online and operating reliability; at a given load, the Operator places the blending station in service.

The success of the blending station depends on the quality of the analyzer signals. If the blending station analyzer fails, the blending control is automatically, or by Operator action, placed on flow control and the Hi Btu gas remains on pressure control. If the gas yard analyzer fails, the station is automatically placed on flow control (Low Btu gas) and pressure control (Hi Btu gas).

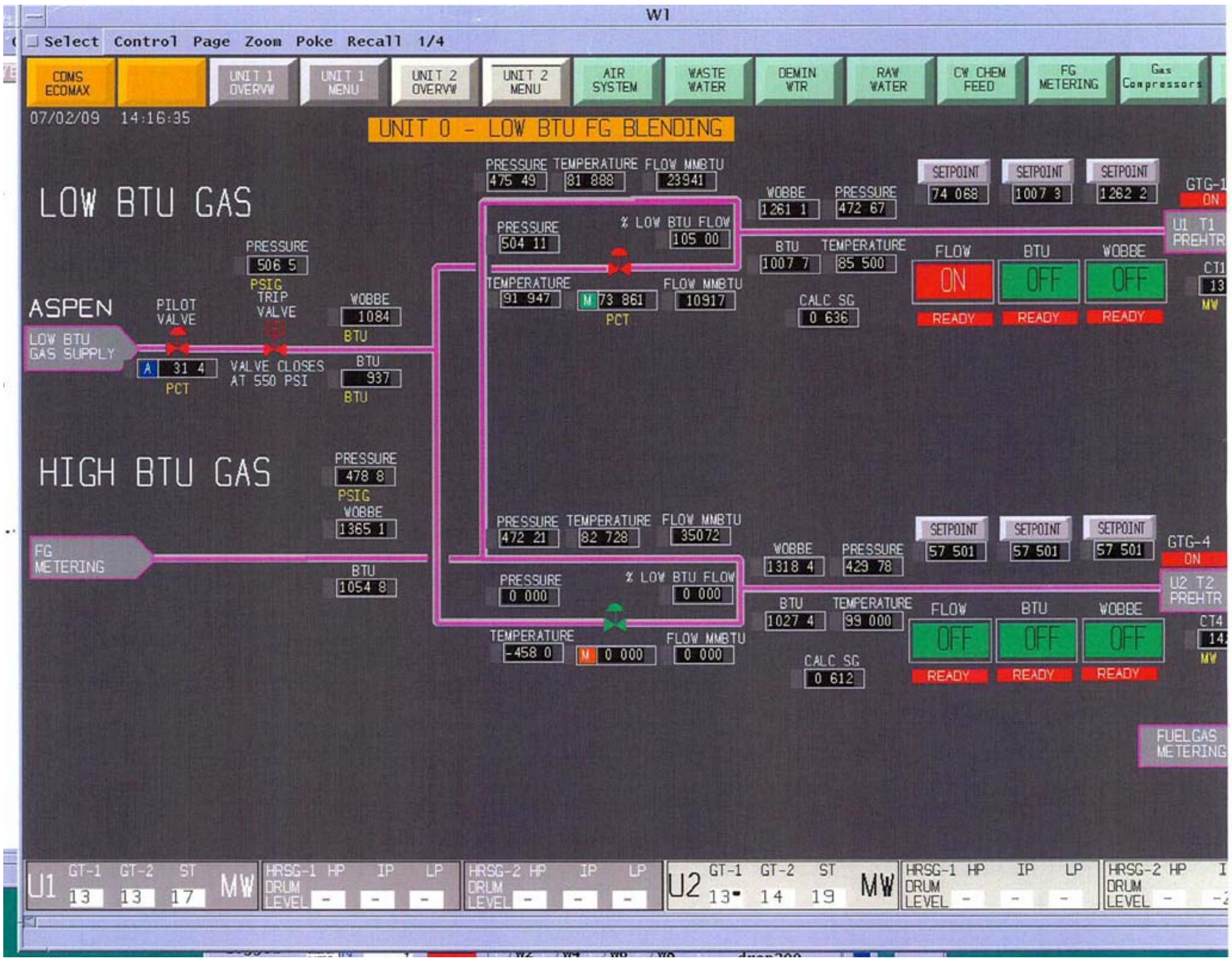
Figure 4 – Key Elements Functional Control Diagram



The blending station logic configuration is programmed into the plant DCS. There is a small Allen Bradley PLC in the gas yard that the DCS interfaces with for data gathering and controlling the gas yard. The Control Room Operator HMI is used for Operator monitoring and control of the Blending Stations.

Graphics were developed to provide the Operator a visual presentation of all the data related to the blending stations. The graphic shown below depicts only two of the four gas turbine units. The other two were added in the second phase of the project. See Figure 5.

Figure 5 – Example of Blending System Graphic



RESULTS

Our research of the Wobbe Index indicated that the preferred blending control mode should be based on the Wobbe Index. However, there did not appear to be any distinct advantage in using the Wobbe

Index over the heating value or Btu. Since both Btu and Wobbe Index outputs are available from the gas analyzers, the logic configuration was developed such that the Operator could select either Btu or Wobbe Index as the basis for controlling fuel gas blending. This would allow the plant to determine which method gave them the best control of the blending stations.

During the start-up phase of the project, both methods of controlling the blending stations were tested. There were no significant differences found between controlling based on Btu or Wobbe Index. Because the Wobbe Index is incremented in finer divisions, one would expect that finer blending control could be obtained, but for this application, very fine adjustments to the blending ratio are not necessary. The Low Btu gas on flow control is the default blending control method. This method was also tested, both as an Operator selected operational mode and as a default control mode when one of the analyzers fails.

The plant is currently operating on flow control mode, selected by the Operator, because the Low Btu gas supplier cannot yet provide enough gas to justify blending based on Btu or Wobbe Index.

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