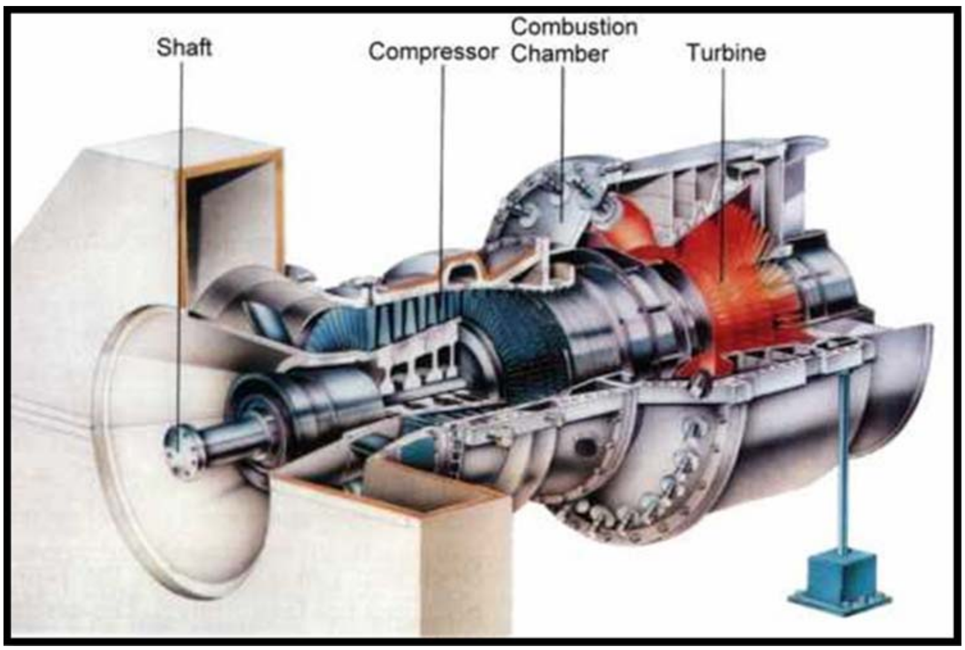
Gas Turbine Basics

Instrument Unit



PAKARAB FERTILIZERS LIMITED MULTAN

UTY-08 (Rev. 1)

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Gas Turbine Basics

Instrument Unit

Preamble

Gas turbine is an important part of Co-Generation plant here at Pakarab Fertilizers Multan. There are total three gas turbines at Co-Gen plant. Each turbine is attached with a generator to produce electricity. That is why they are collectively called as Gas Turbine Generator (GTG). These three GTG's collectively fulfill the power demand of the whole complex and colony as well. Gas turbine is a very complex machine and it involves extremely sophisticated interlocking. In this module we shall learn about gas turbine basics and related instrumentation. Graphics, P&ID's, control drawings, quiz questions and videos would be used for better understanding.

Note:

This is **Revision 1** of 'Gas Turbine Basics' module. Grammatical and technical mistakes are expected and reader is welcomed to get them corrected.

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- P&ID's of GTG
- Start/Stop sequence of GTG
- CD containing:
  - Loop wiring
  - UCP I wiring
  - UCP II wiring
  - GTG Graphics
  - Important Videos
  - Computer based Quiz

1. INTRODUCTION TO A GAS TURBINE

An external view of a GTG

Learning objectives:

- To have a general introduction of different types of turbines and to understand the basic working principle of a Gas Turbine.
  - (A video tutorial is available in the CD)

- To understand the thermodynamic cycle of a Gas Turbine.
  - (Brayton Cycle).

- To identify the following parts of a Gas Turbine.
  - Fuel nozzle
  - Combustion chamber
  - Transition piece
  - Lower turbine casing
  - Exhaust casing
  - Exhaust diffuser
  - Inlet casing and journal bearing no. 1
  - Compressor discharge casing
  - Inlet guide vanes control ring
  - Compressor rotor blades
  - High pressure rotor
  - First stage nozzles
  - First stage nozzles support ring
  - Second stage nozzles
  - Third stage nozzles
  - Inlet plenum

- To learn about five different operational modes of a GTG, locate them in graphics and differentiate them from each other, also to find out the mode being used here at Co-gen plant.
  - OFF mode
  - CRANK mode
  - FIRE mode
  - AUTO mode
  - REMOTE mode

o To understand the following terms and techniques related to load control and know the mode being used here at Co-gen Plant.

- Droop mode
- Isochronous mode
- Isochronous load sharing mode
- Preselected load
- Base load

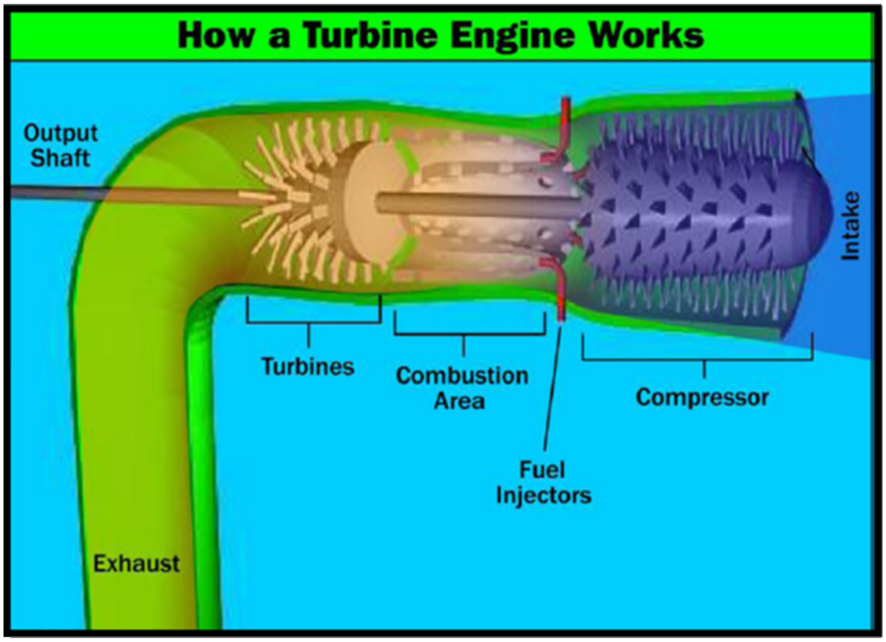
1. Introduction to a Gas Turbine

<u>Different types of a Turbine</u>

There are many different kinds of turbines:

- **Steam turbine:**
  - Most power plants use coal, natural gas, oil or a nuclear reactor to create steam. The steam runs through a huge and carefully designed multi-stage turbine to spin an output shaft that drives the plant's generator.
- **Water turbine:**
  - The turbine used in a hydroelectric plant is completely different from a steam turbine as water is so much denser and slow moving than steam, but water turbines work on the same principle.
- **Wind turbine:**
  - Wind turbine is also known as windmill. It uses wind as its motive force. A wind turbine looks nothing like a steam turbine or a water turbine because wind is slow moving and very light but again principle is the same.
- **Gas turbine:**
  - A gas turbine is an extension of the same concept. In a gas turbine, a pressurized gas spins the turbine. In all modern gas turbine engines, the engine produces its own
    Pressurized gas, and it does this by burning something like propane, natural gas, and kerosene or jet fuel. The heat that comes from burning the fuel expands air, and the high-speed rush of this hot air spins the turbine.

The Gas Turbine Process

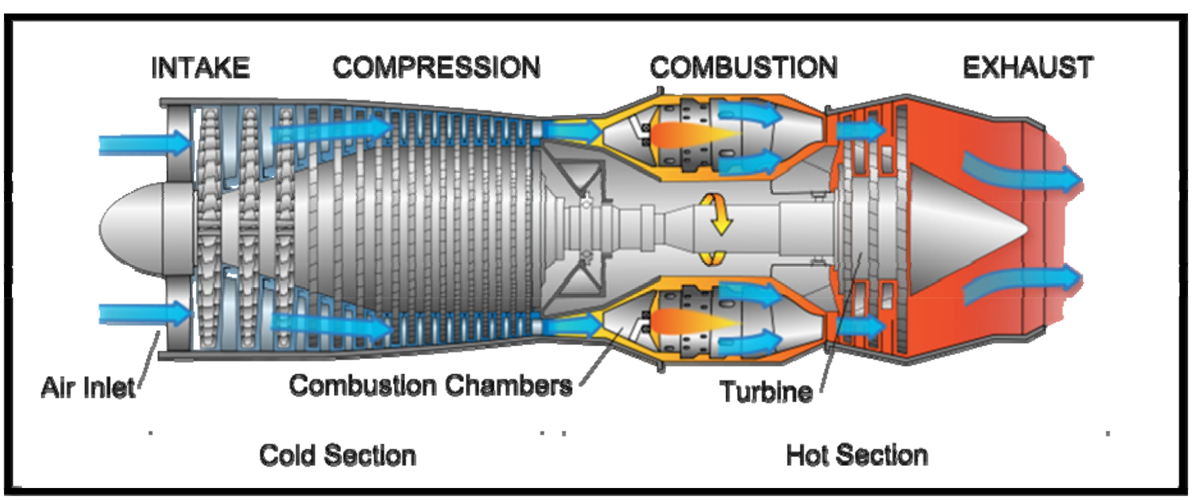


A simple view of how gas turbine works

Gas turbine engines are, theoretically, extremely simple. They have three parts:

- **Compressor** : Compresses the incoming air to high pressure
- **Combustion area** : Burns the fuel and produces high-pressure, high-velocity gas
- **Turbine**: Extracts the energy from the high-pressure, high-velocity gas flowing from the combustion chamber.

Another view of gas turbine is shown below.



1.1 Basic working principle of a gas turbine

(Video tutorial)

A gas turbine works in the following way:

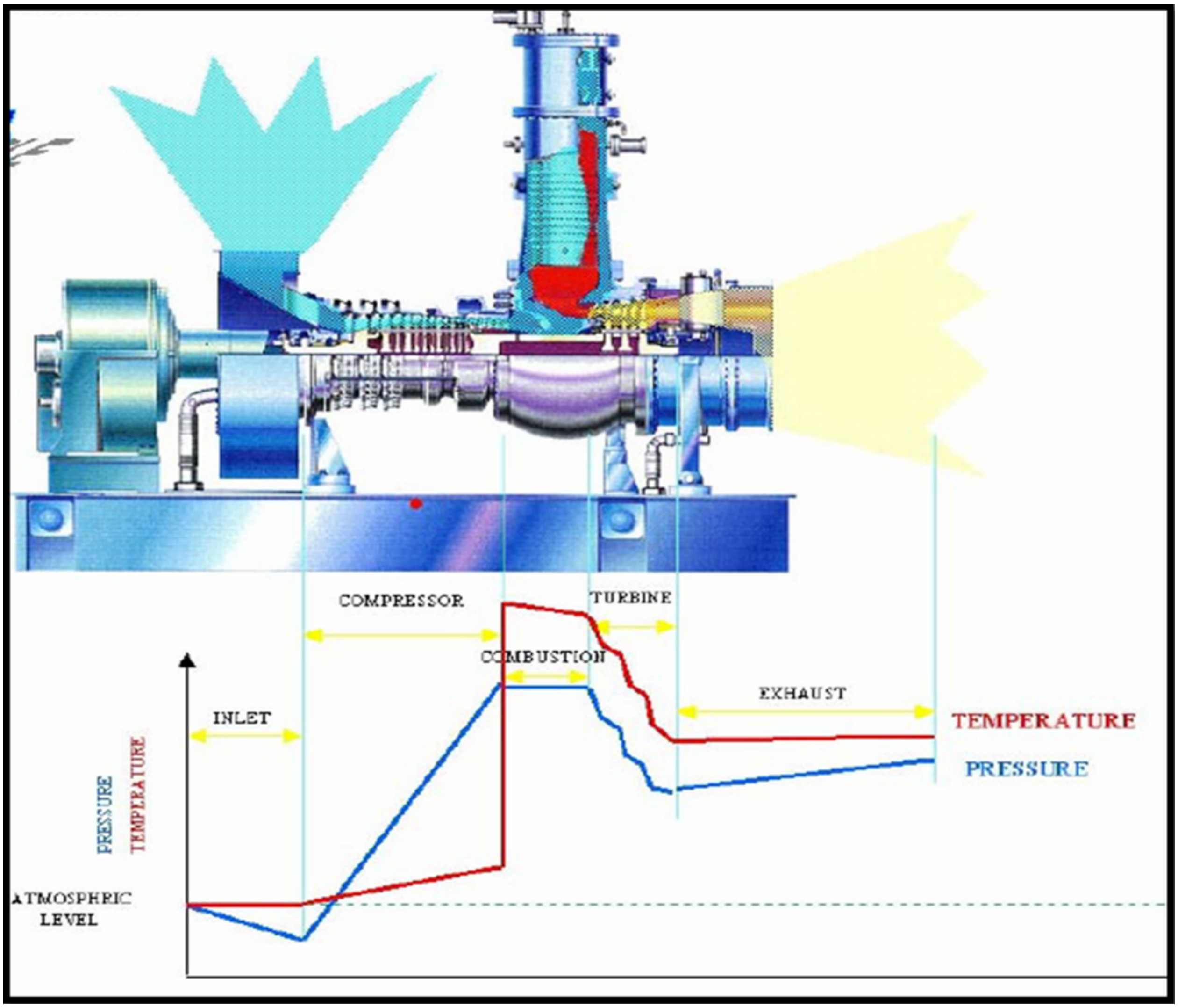
1. It draws in air from the surrounding environment;

2. It compresses it to a higher pressure.

3. It increases the energy level of the compressed air by adding and burning fuel in a combustion chamber.

4. It directs high pressure, high temperature air to the turbine section, which converts thermal energy into mechanical energy that makes the shaft revolve; this serves, on the one hand, to supply useful energy to the driven machine, coupled to the machine by means of a coupling and, on the other hand, to supply energy necessary for air compression, which takes place in a compressor connected directly with the turbine section;

5. It exhausts low pressure, low temperature gases resulting from the abovementioned transformation into the atmosphere.



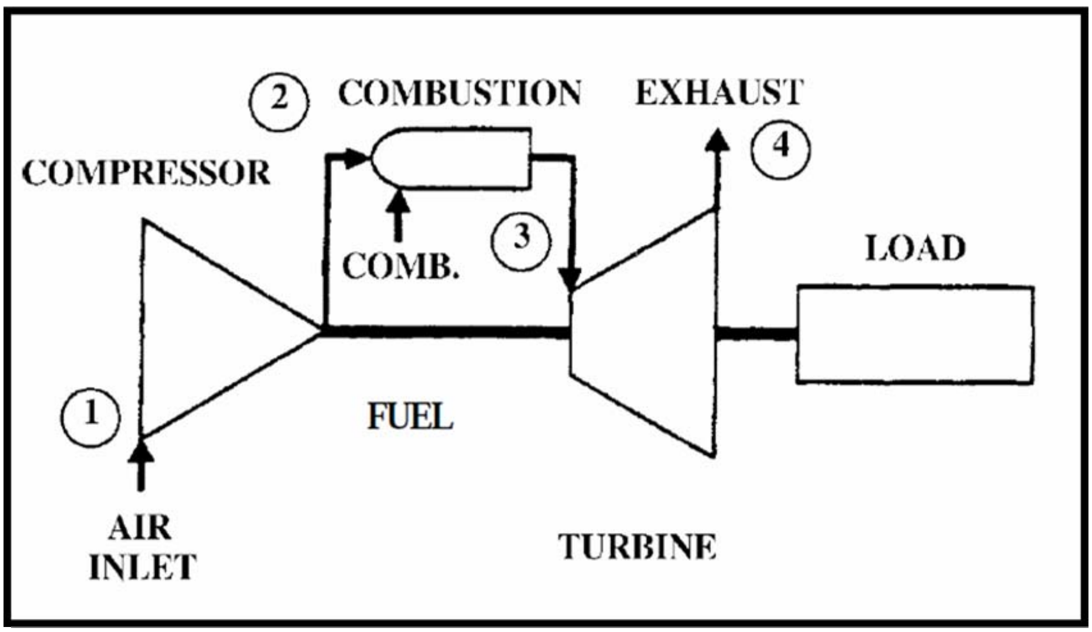
P-T variations at different parts of a gas turbine

Explanation:

The red line indicates temperature variations throughout the cycle while the blue line is for pressure. It is evident from the diagram that combustion is a **constant pressure** process.
Moreover, combustion is a continuous process unlike reciprocating engine. In reciprocating cycle, power is generated in expansion phase
This is only 1/4th of the complete cycle. In gas turbine, combustion continues throughout the cycle.

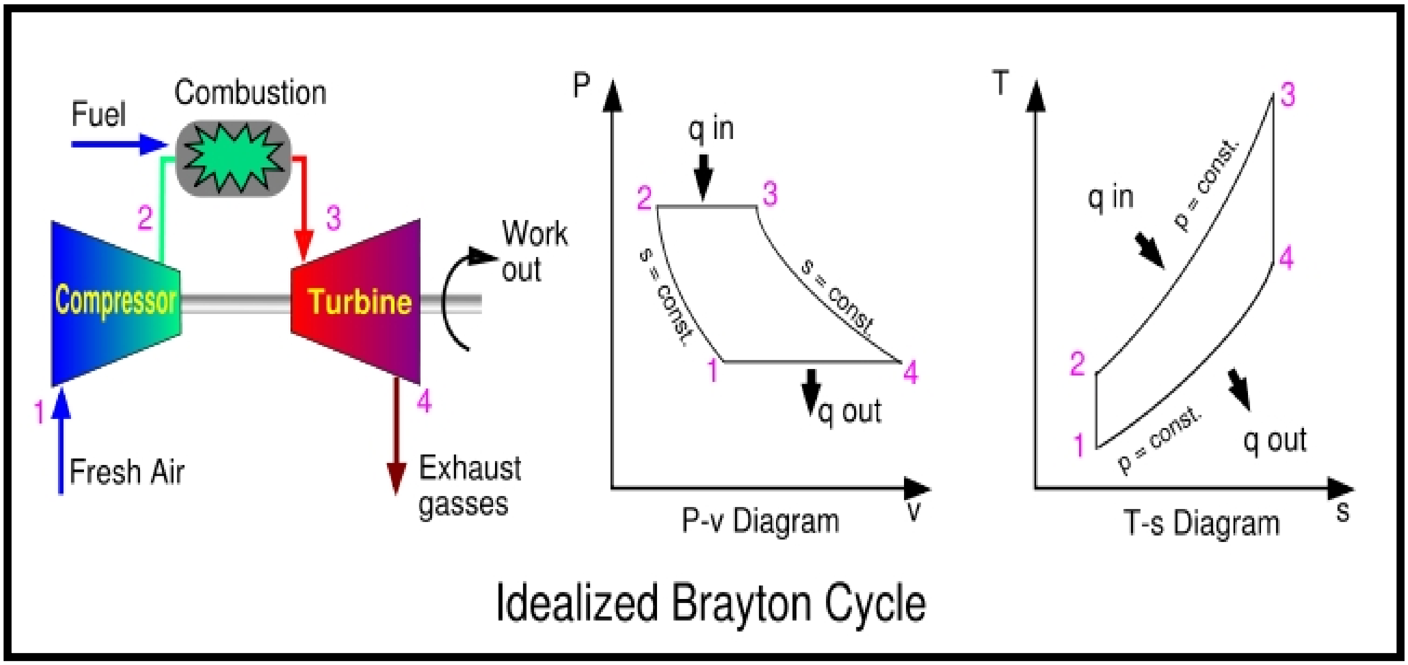
1.2 Brayton cycle: Thermodynamic cycle of a gas turbine

The thermodynamic cycle of a gas turbine is known as the *Brayton cycle*.
Fresh air at ambient conditions is drawn into the **compressor**, where its temperature and pressure are raised. The high-pressure air proceeds into the **combustion** chamber, where the fuel is burned at constant pressure. The resulting high-temperature gases then enter the **turbine**, where they expand to the atmospheric pressure through a row of nozzle vanes. This expansion causes the turbine blade to spin, which then turns a shaft inside a magnetic coil. When the shaft is rotating inside the magnetic coil, electrical current is produced.



ISO CONDITIONS
Ambient temperature (°C) 15
Ambient pressure (mbar) 1013
Relative humidity (%) 60

Over 50% of the energy developed by expansion in the gas turbine is required for the compression by the axial compressor.



Brayton cycle can be understood with the help of the above two graphs.

1. Pressure(**P**) vs. Volume(**V**)
2. Temperature(**T**) vs. Entropy(**S**)

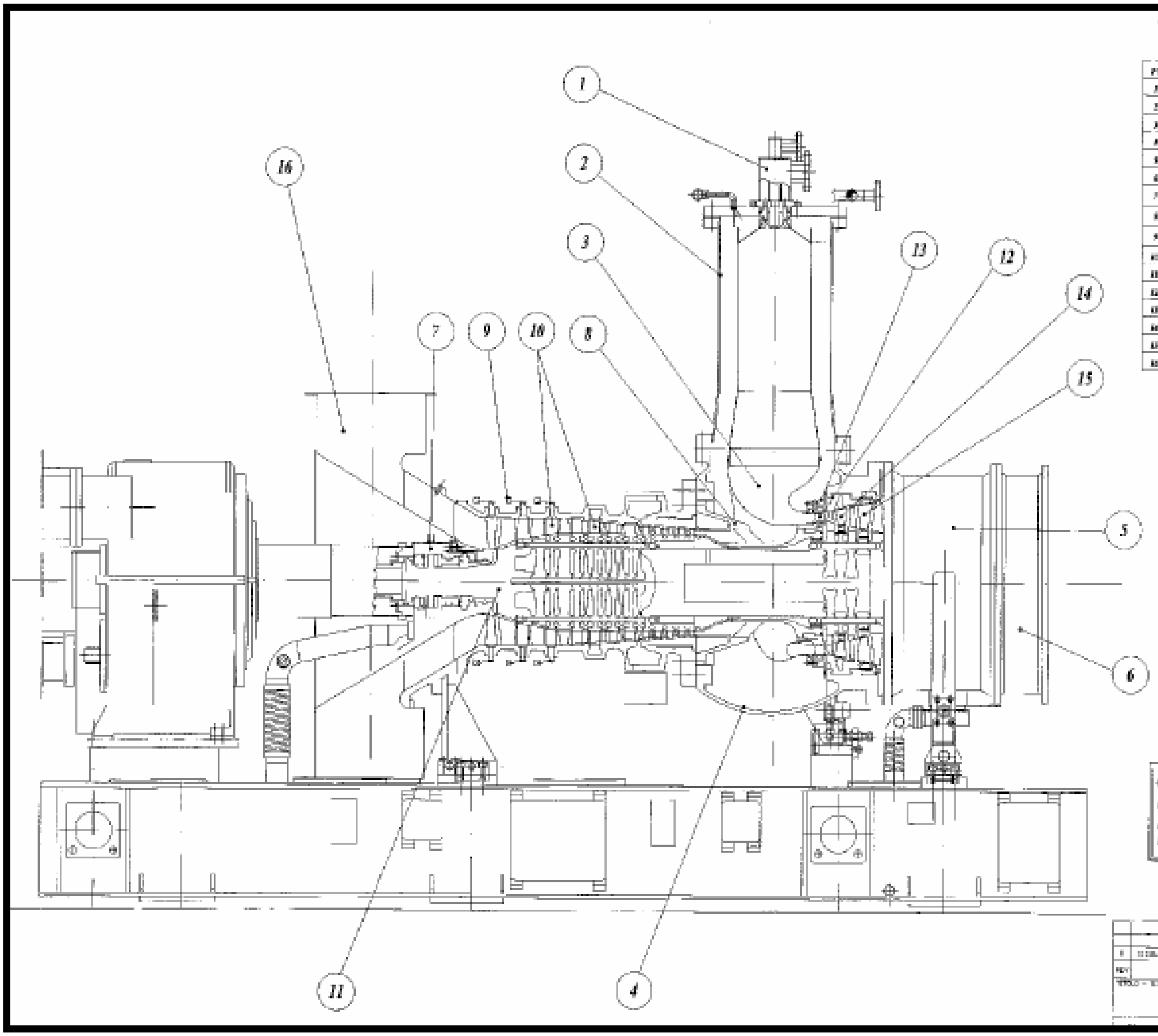
Entropy means: a measure of disorder that exists in a system.
We can see that the entropy in the above graph changes whenever a heat (**q**) is added or subtracted from the system which is basically a disorder in the system.

1.3 Different parts of a gas turbine

A pictorial view of a gas turbine along with its different parts is given below.
The purpose of the following figure is just to give the reader a rough idea about the different parts of a GTG. The list of different parts of GTG is as follows.

i. Fuel nozzle
ii. Combustion chamber
iii. Transition piece
iv. Lower turbine casing
v. Exhaust casing
vi. Exhaust diffuser

vii. Inlet casing and journal bearing no. 1
viii. Compressor discharge casing
ix. Inlet guide vanes control ring
x. Compressor rotor blades
xi. High pressure rotor
xii. First stage nozzles
xiii. First stage nozzles support ring
xiv. Second stage nozzles
xv. Third stage nozzles
xvi. Inlet plenum



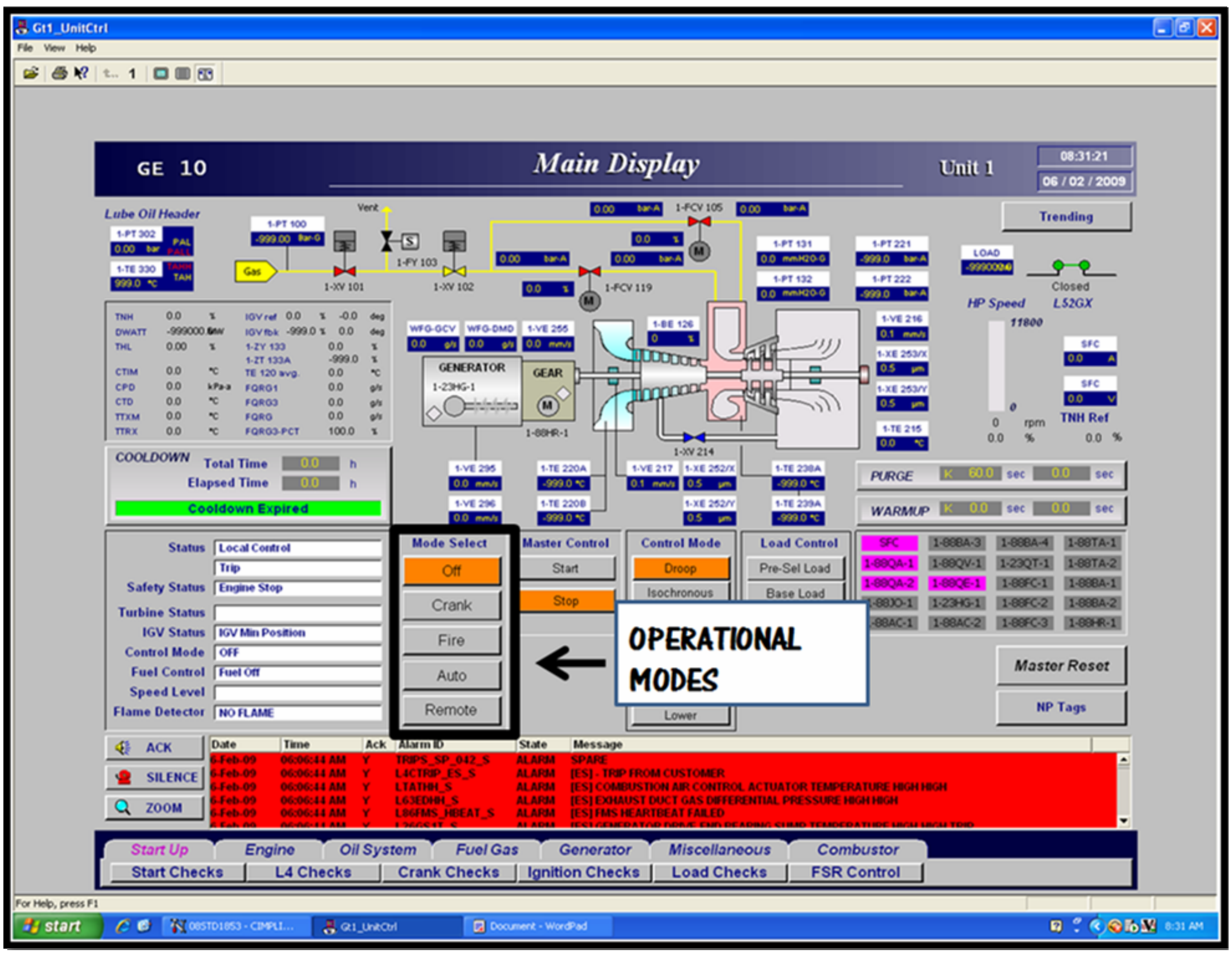
A figure indicating different parts of a GTG

Following videos also show some important parts of a GTG.

a. Load gear, Compressor, Combustor and related instruments.
b. Combustor, Exhaust turbine and Duct

1.4 Operational modes of a gas turbine

Gas turbine has the following modes in which it operates.
GTG is normally run on **AUTO** mode by operation department.



OPERATIONAL MODES

Gas turbine has the following operating modes.

1. OFF
2. CRANK
3. FIRE
4. AUTO
5. REMOTE

Only one mode can be selected or set at any time. Mode selection is allowed only if the relevant permissive conditions are met. Permissive conditions mean the conditions that permit a particular mode to be selected.

1.4.1 OFF mode

OFF mode is automatically set upon system initialization, i.e. UCP (Unit Control Panel) power-up or CPU reset. Off Mode can only be selected by the operator when the GT has come to a complete stop, and all sequences have been completed.
If the master selector is in OFF ,no kind of sequence can be run as the machine is not ready to start and any kind of start command is ignored.

1.4.2 CRANK mode

From the CRANK position it is possible to select one of the following options, displayed on UCP HMI:

a. **Calibration Crank**

This operational mode sets the machine to reach purge speed only and it allows Inlet Guide Vanes (IGV) Calibration. Gas turbine crank speed is achieved at 19% of the rated speed which is almost 2140 r.p.m.

b. **Water wash**

This operational mode sets the machine to reach purge speed only and allows to perform engine off line water wash. Engine water wash is useful in order to remove dust and oil particles from the compressor blades.

c. Normal Operation

This operational mode allows the engine to complete crank phase only, reaching purge/firing speed. All other sequencing phases, following CRANK phase, can be completed changing the Master Selector position.
During the crank mode, purging takes place. Purging means removal of undesirable particles that are present in the Gas turbine. Purging time for a GTG is 60 seconds usually.

1.4.3. FIRE mode

In FIRE mode the ignition phase is allowed, the turbine can lite-off and the sequence stops to warm-up. Warm up time for a GTG is 300 seconds in normal condition.

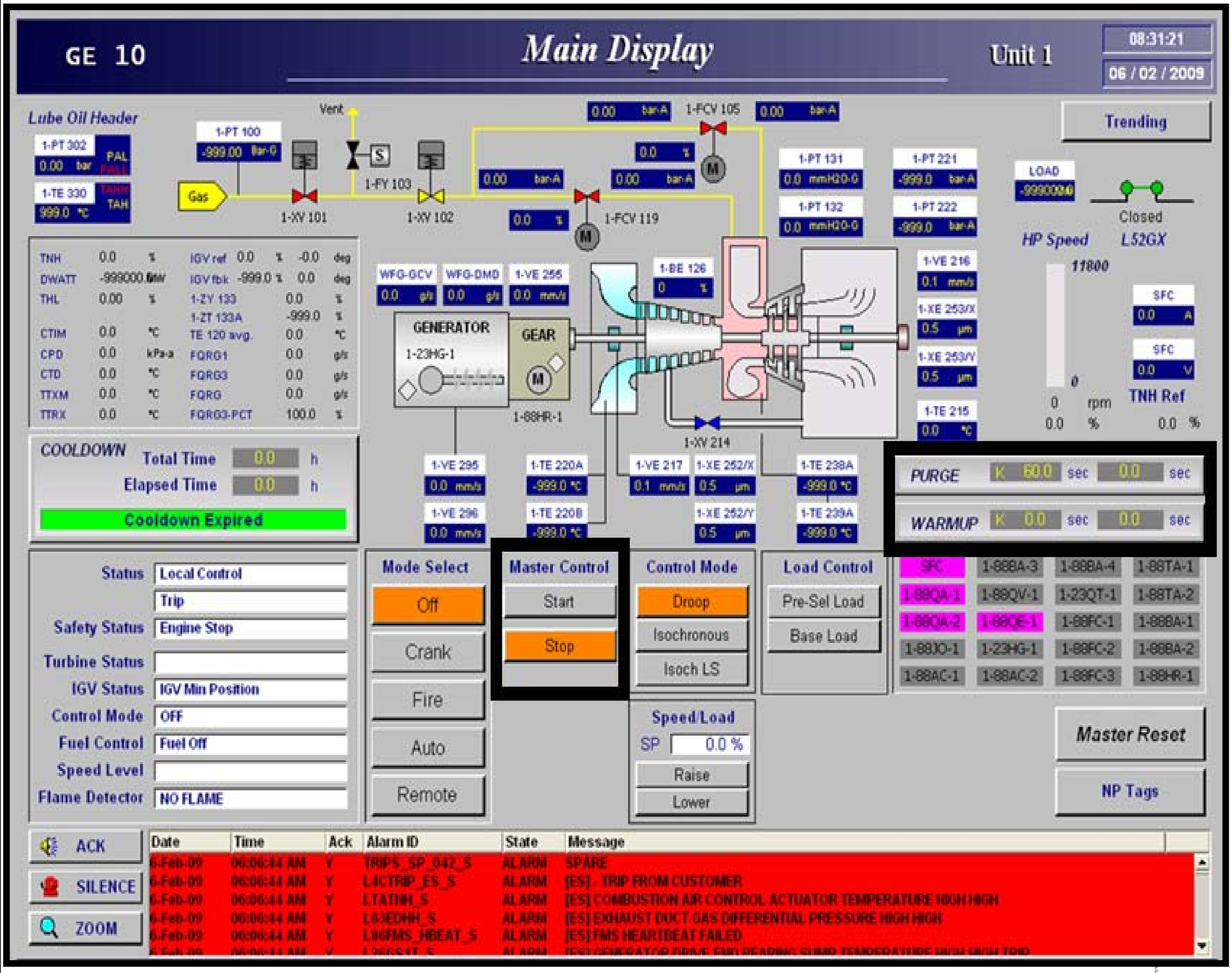
1.4.4. AUTO mode

In AUTO mode the complete start-up procedure can be executed, until unit at synchronization speed. The load is controlled by an external set point.
GTG startup *always* takes place in this mode.

The actual practice at Pakarab fertilizer Co-Gen plant is to press ***start*** button only and the whole GTG startup takes place itself if the startup permissive conditions are met.

After pressing the startup button, the gas turbine compressor starts rolling. When it reaches its 19% of the rated speed i.e; 2140 rpm, purging of the gas turbine starts. Purging continues for 300 seconds. After purging , ignition starts and gas turbine is warmed up for 60 seconds after which the gas turbine speed accelerates to almost 11000 rpm.

In the following figure, the *start* button and *purge* and *warm up* timers have been highlighted for visual verification.



A display highlighting *start button* and *purge* and *warm up* timers

1.4.5. REMOTE mode

REMOTE mode is similar to AUTO, but the start command is given by a remote system (when available) while the stop command is both in remote and in local.

1.5 important terms and techniques:

Load Control Modes

Gas turbine has the following load control modes. Normally the load is controlled at *droop* mode here at Co-Gen plant.

A software selector on HMI allows selecting the Load Control mode:

1. Off/Droop
2. Isochronous
3. Isochronous Load Sharing (Isoch LS)

Once the operational mode is selected, pushing the START button activates the relevant starting sequence.

1.5.1 Droop Mode

Droop means *to move lower*
In the Constant Settable Droop load control mode, a 4% variation of the turbine speed set-point in relation to the system frequency corresponds to a 100% variation of the power supplied to the load; likewise, on the basis of the same speed set-point, a 1% system frequency variation implies a 25% variation of the power supplied to the load. In other words, for each 1% difference between the set-point speed and the

Turbine speed/system frequency a 25% variation of the power supplied to the load is obtained.

1.5.2 Isochronous mode

Isochronous means *with equal frequency.*
In this load control mode the unit is controlled so as to maintain, within the turbine capacity limits, a constant speed (50 Hz), independently on the load.

1.5.3 Isochronous load sharing

In this load control mode the unit is controlled so as to maintain, within the turbine capacity limits, a constant speed (50 Hz) and a constant power output shared between synchronized units.

1.5.4 Preselected load

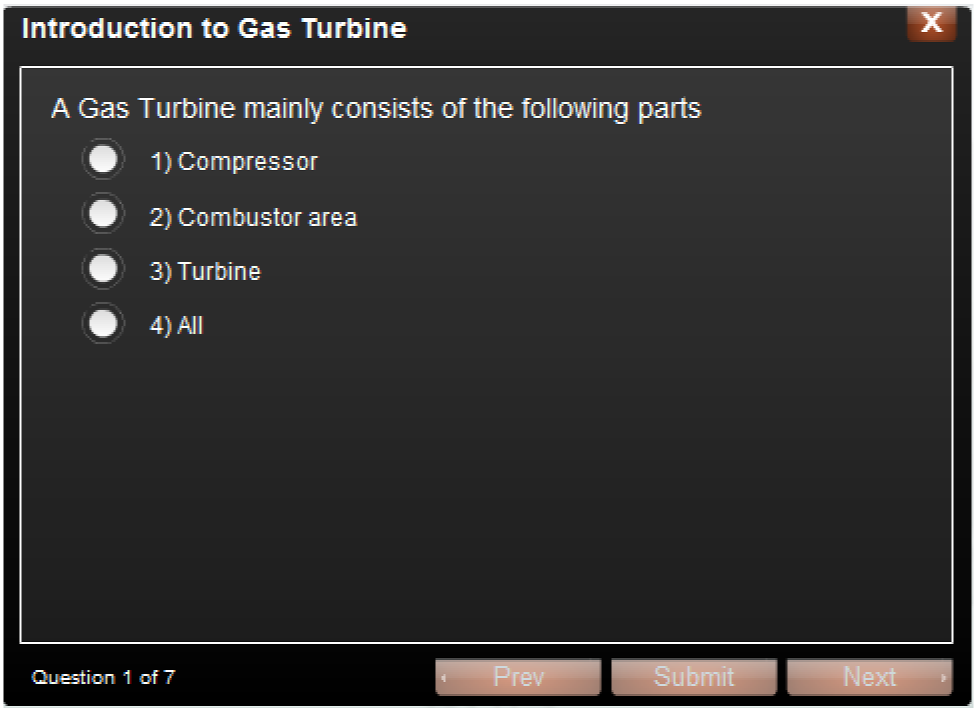
In this load control mode the unit is controlled so as to maintain, within the turbine capacity limits, a constant active power output.

1.5.5 Base load

In this load control mode, the machine runs on temperature control and full load is allowed only in parallel with other machines.

QUIZ:

To take a quiz, click here.



2. GTG Control Architecture

A pictorial view of GTG control architecture cabinets. For a video, click here

Learning objectives:

- To understand the Control Architecture of UCP1 and UCP2 and to locate important hardware present in both the panels as given. Also to understand the basic function of each hardware.

- Unit Control Panel 1:
    - RX3i PLC
    - Versamax IO's
    - HIMatrix
    - Bentley Nevada 1701
    - Dataforth
    - Braun speed module
    - Hub

- Unit Control Panel 2:
    - OSM (**Historian**)
    - HMI
    - Generator Protection
    - Generator Synchronization
    - Versamax

- To understand the function of Historian and learn how to view or copy alarms and trends.

2.1 GTG Control Architecture

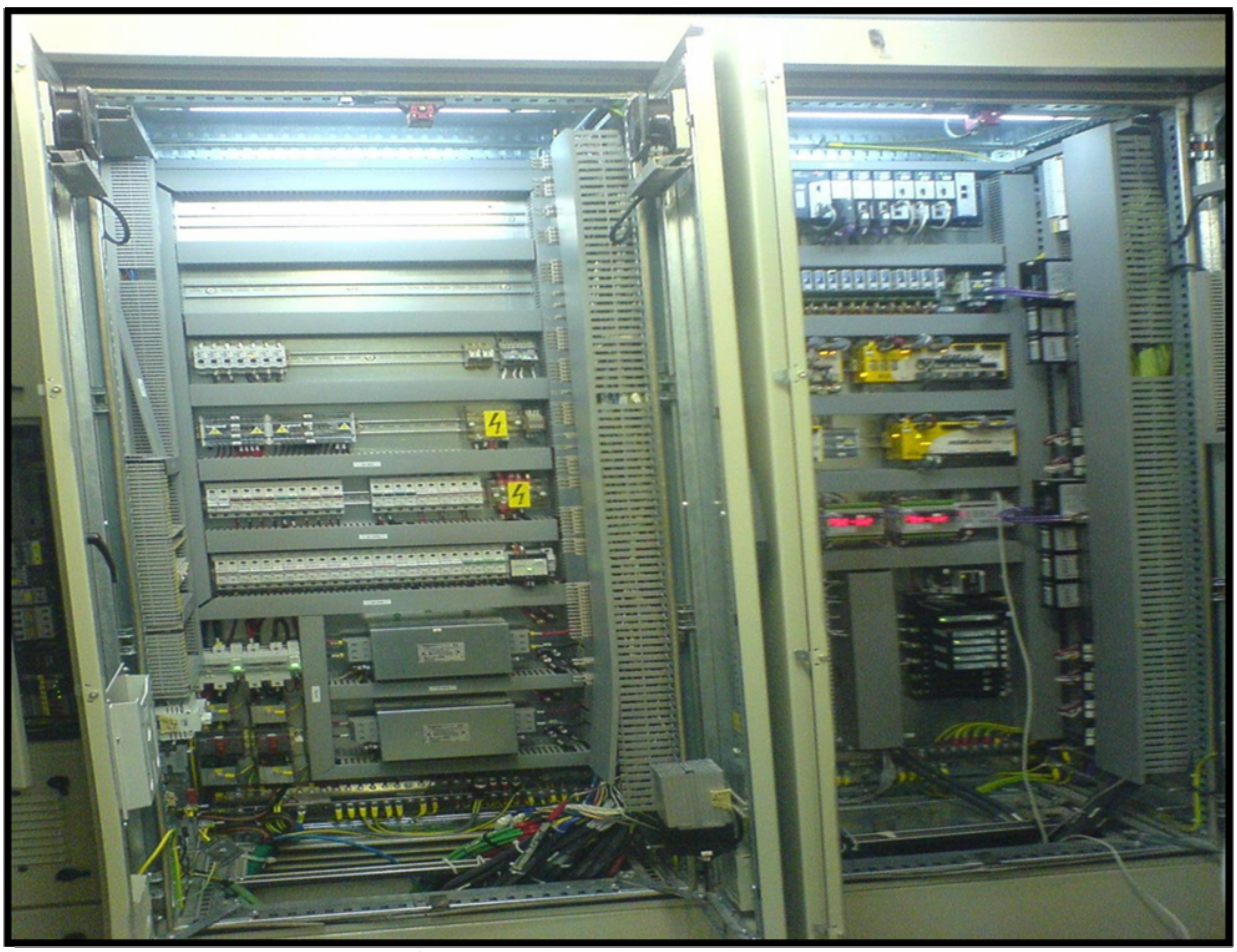
GTG control architecture explains how different control instruments are connected to each other and how they make sure the safe working of a gas turbine.

Gas turbine control architecture has been mainly split among two panels.

1. Unit Control Panel I
2. Unit Control Panel II

In this chapter, we shall see both the panels and various control instruments present in them.

2.1.1. Unit Control Panel I

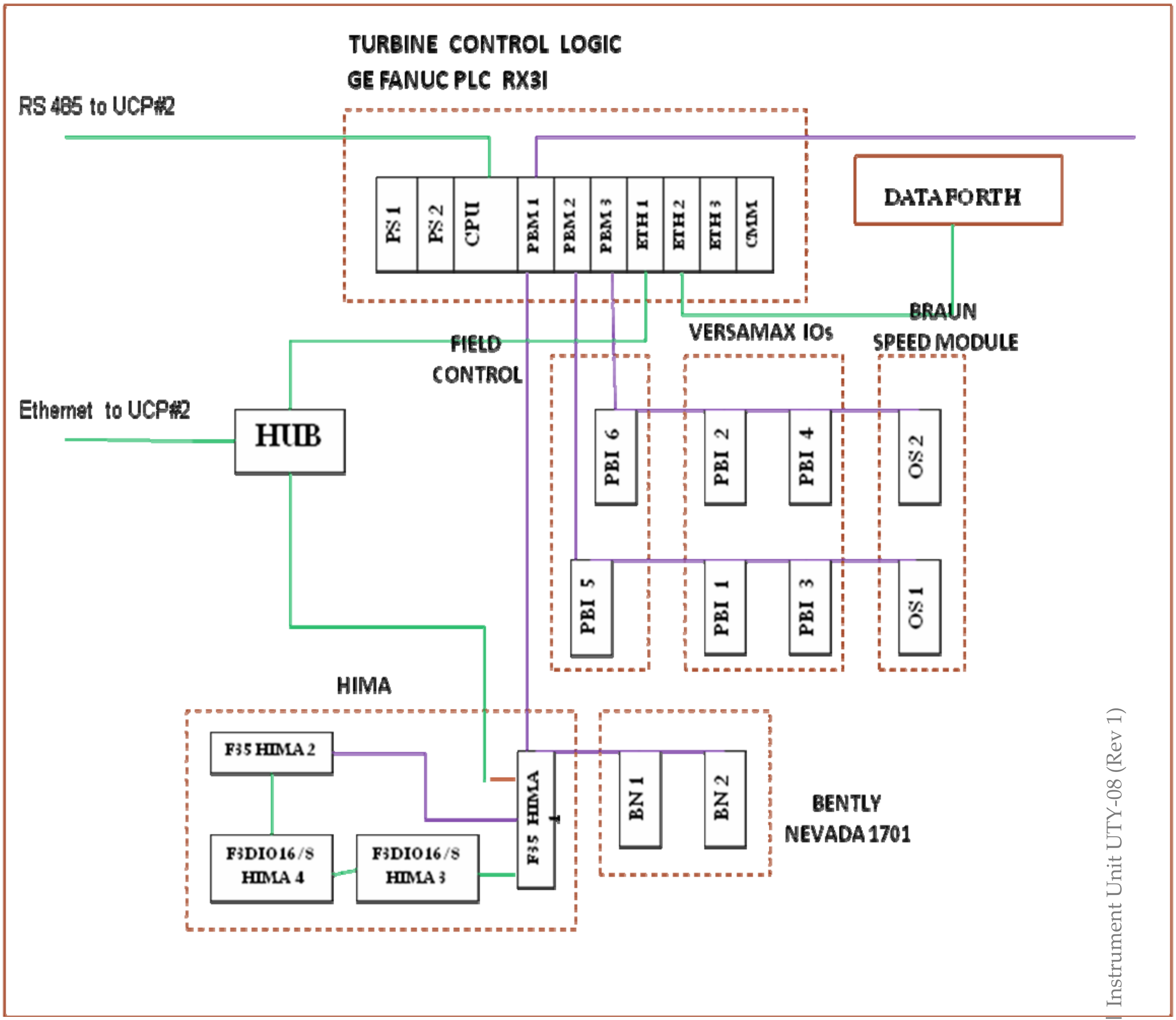


A view of UCP I when the panel doors are open

The above mentioned picture of UCPI contains the following control instruments. To view them in a video, click here.

- RX3i PLC
- Versamax I/O cards
- HIMatrix
- Bentley Nevada 1701
- Dataforth
- Braun Speed module
- Hub

UNIT CONTROL PANEL # 1



2.1.1. a. RX3i PLC

RX3i is the main PLC that controls and communicates with all other I/O cards and modules. It has 2 power supplies which make them redundant, one CPU card (300

MHZ), three profibus modules, three Ethernet modules and one communication module.

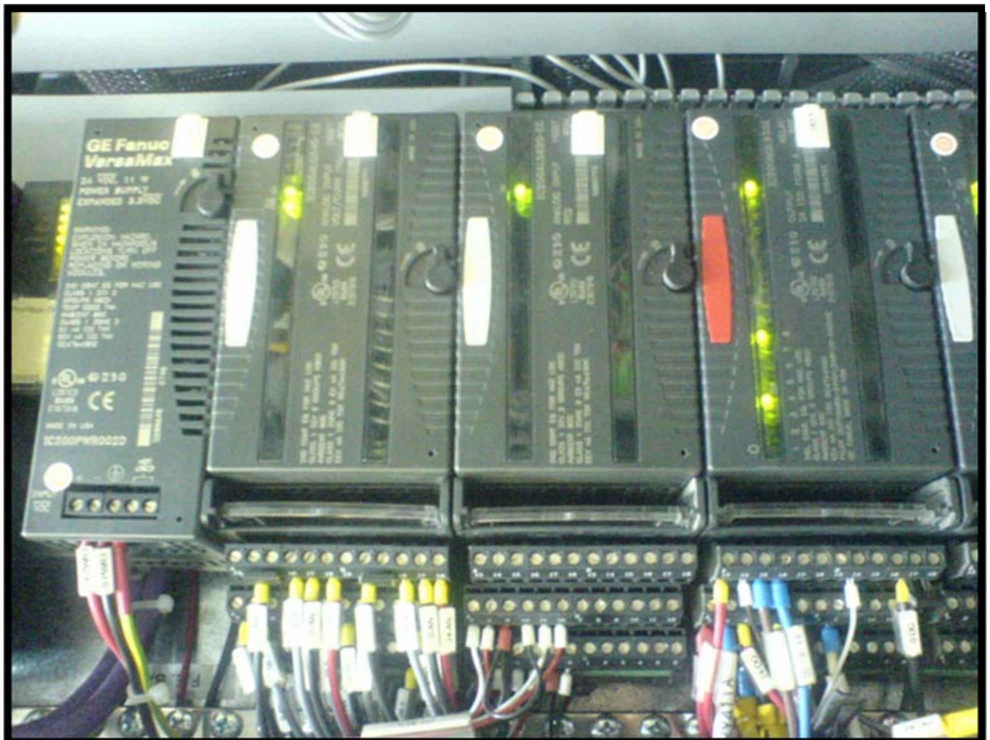
Profibus modules use profibus communication protocol which is a digital communication protocol. The benefit of using a digital communication protocol is to send/receive multiple variables over the same couple of wires.

A pictorial view of RX3i PLC is shown here.

A pictorial view of RX3i PLC at UCP I

2.1.1. b. Versamax I/O cards:

Versamax I/O cards are connected to RX3i via Profibus. They are used for Input and Output handling and final controlling is done by RX3i PLC.

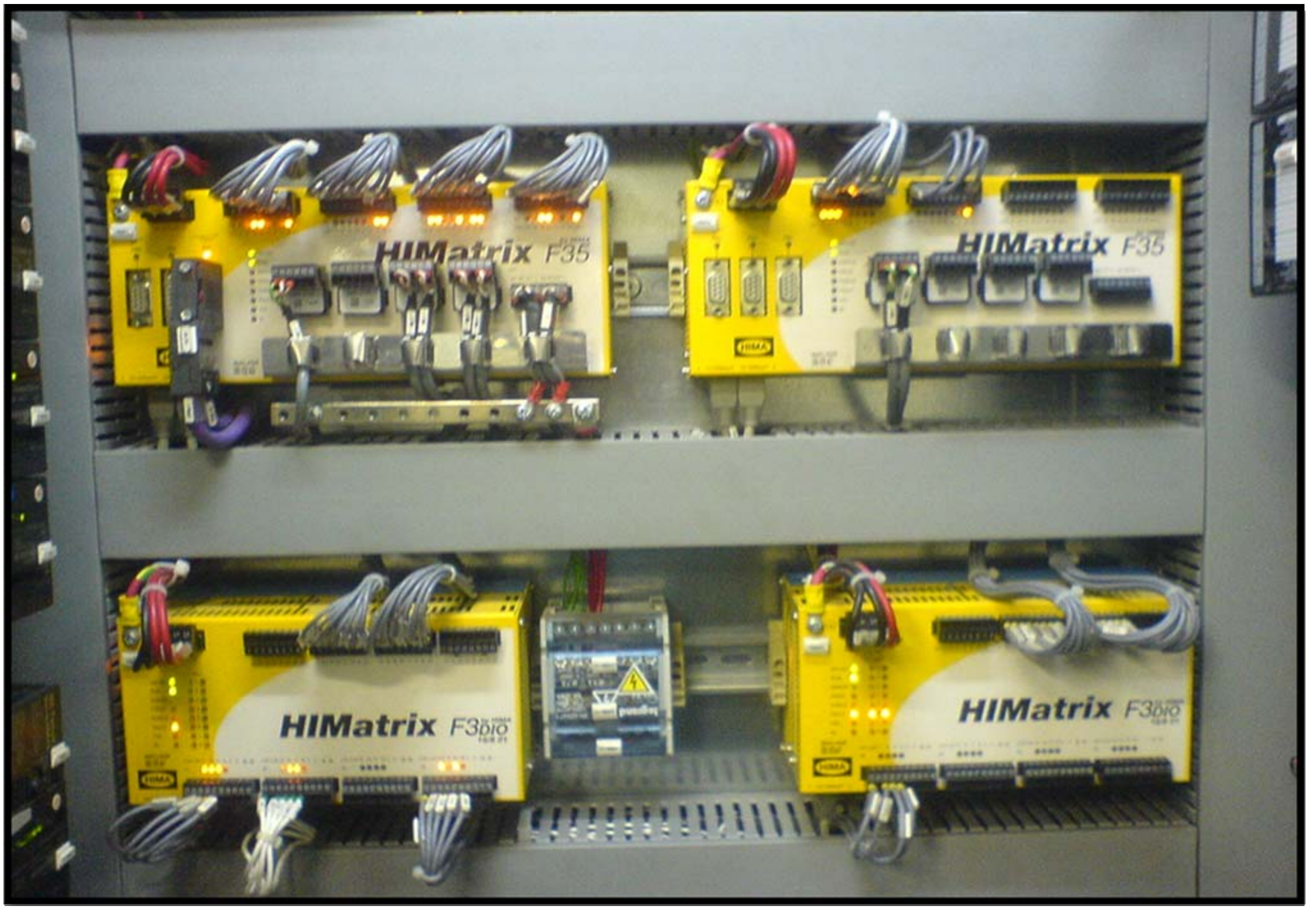


A pictorial view of Versamax I/O cards

2.1.1. c. HIMatrix

HIMatrix F35 I/O cards have been used here at Co-Gen for safety purposes. The I/O cards mainly deal with

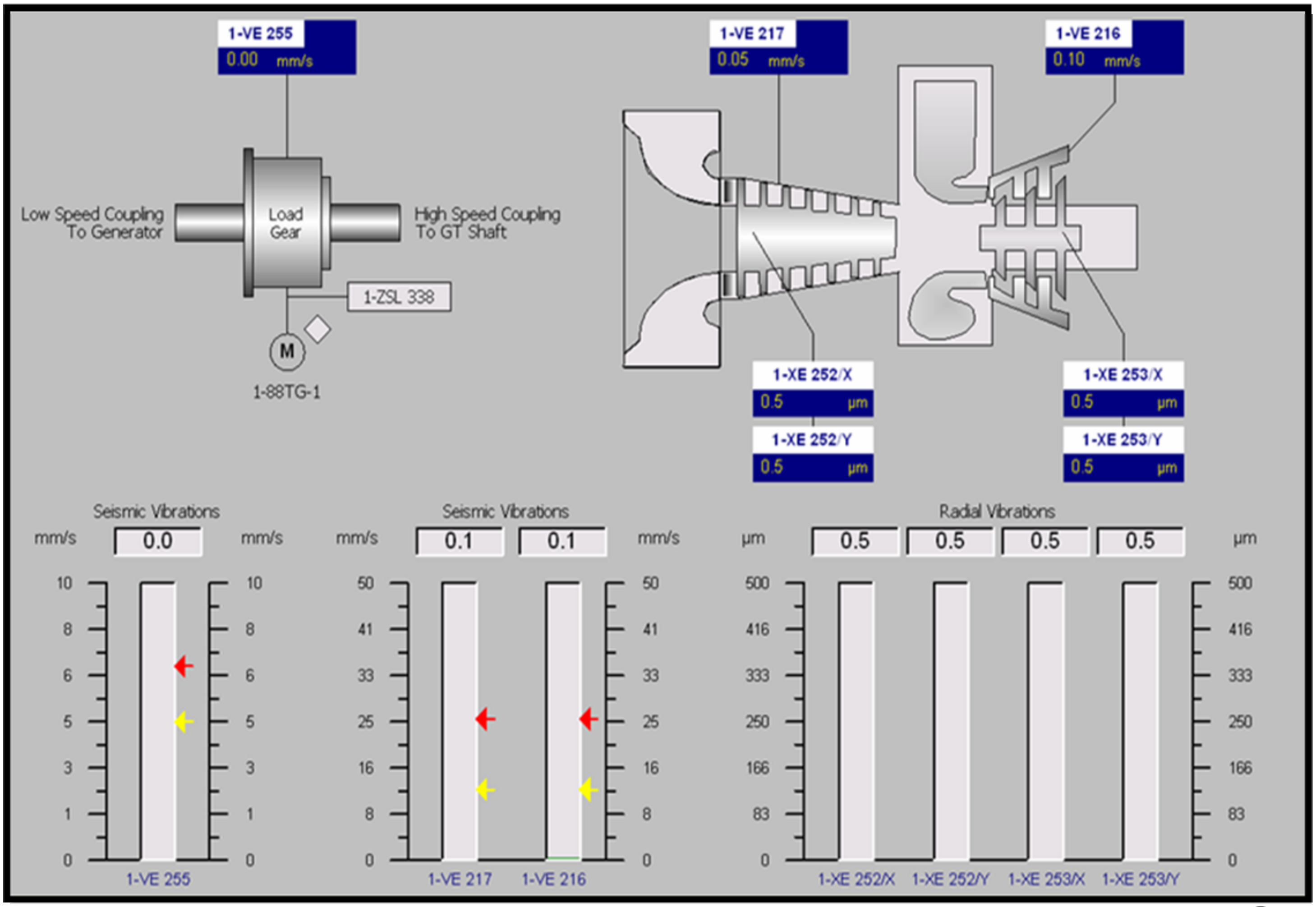
- Fire Alarms
- Smoke Detection



A pictorial view of HIMatrix I/O modules

2.1.1. d. Bentley Nevada 1701

Bentley Nevada vibration monitoring system 1701 has been installed here. It monitors the vibration of *compressor*, *load gear* and *turbine* of GTG as shown below in the graphics. Since Bentley Nevada 1701 does not have a processer to control or take any action against dangerous vibrations, it communicates with RX3i PLC (main PLC) for control purpose.

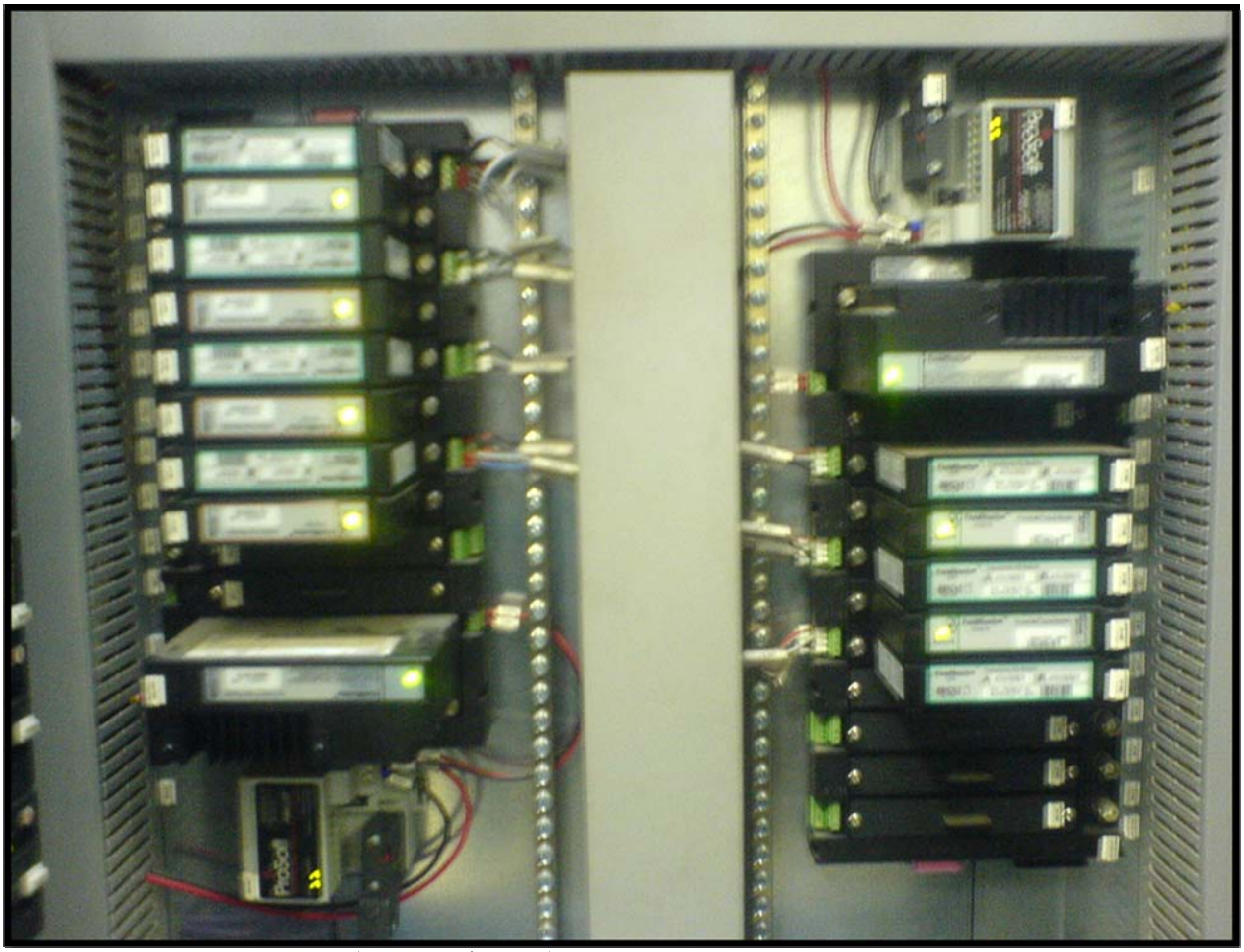


A graphical view of GTG compressor, Turbine and load gear vibration monitoring

1701 monitors two types of vibrations:

1. Radial
   Radial means; spreading from center outward. Radial vibration is measured in *um*.

2. Seismic
   Seismic means; large or extremely large. Basically it is the axial vibration and is comparatively larger than radial vibration. It is measured in *mm/s.*



A pictorial view of Bentley Nevada 1701 in UCP I

For detailed features of Bentley Nevada 1701, click here.

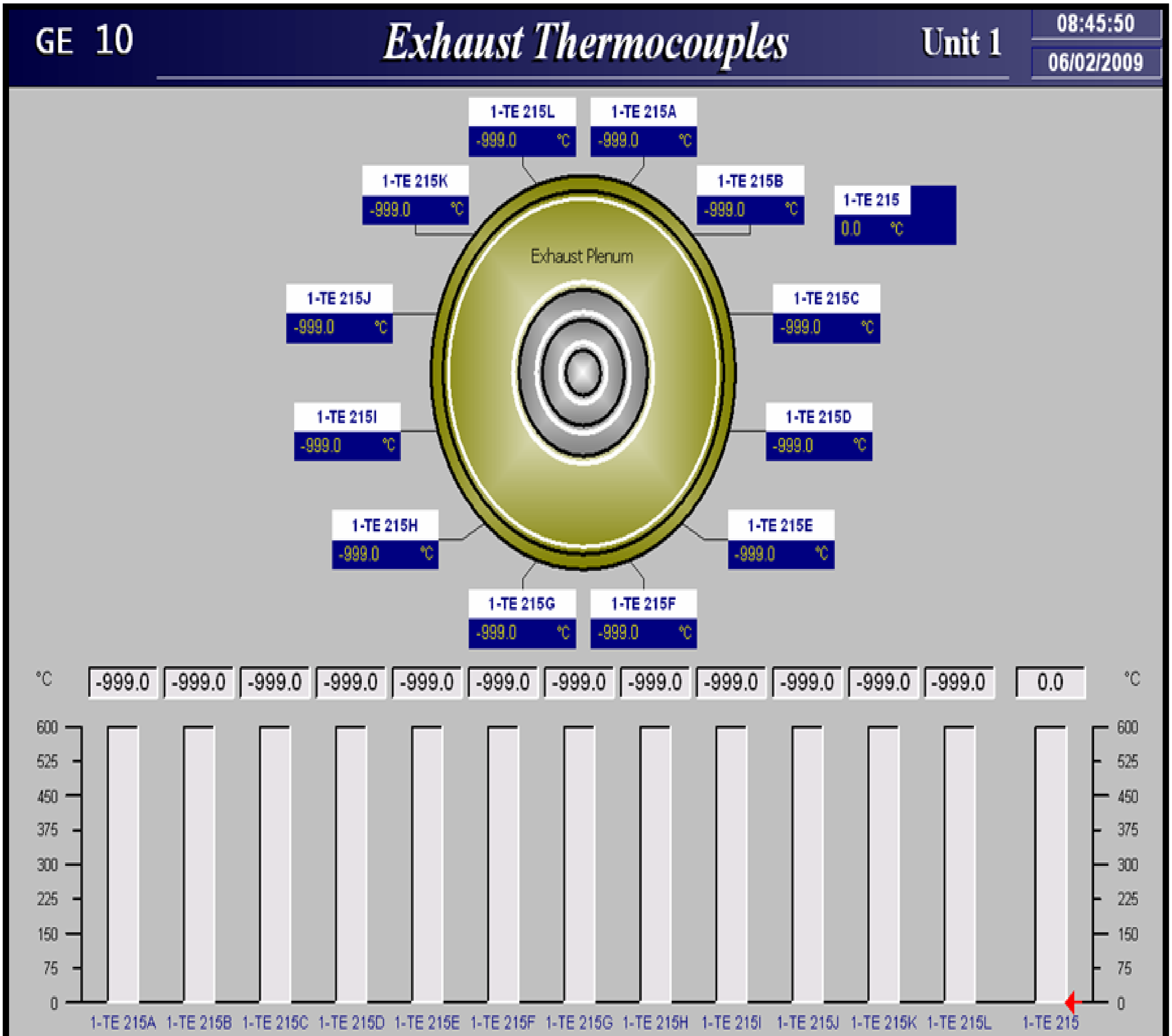
2.1.1. e. Dataforth modules

There are 12 thermocouples installed at the exhaust of the turbine which measure the temperature of the hot gases after turbine. Dataforth modules convert the temperature signals coming out from the thermocouples into 4-20mA current signals for communication with RX3i PLC.

A pictorial view of the Dataforth modules

A view of the GTG exhaust

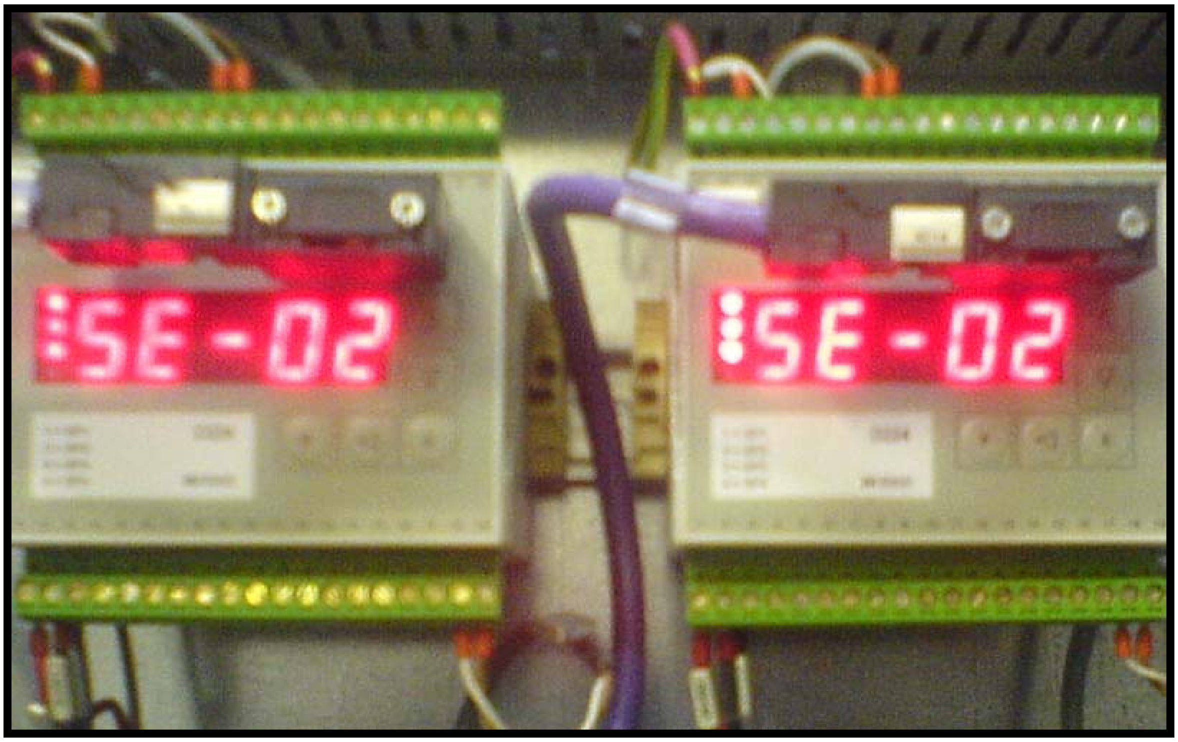
A close view of the thermocouples



A graphical view of exhaust thermocouples

2.1.1. f. Braun Over speed Trip module

Braun over speed trip modules monitor the speed of GTG and send trip signals to RX3i in danger condition. They are located in UCP I.



Braun over speed trip modules

2.1.1. g. Hub

Hub connects RX3i and HIMatrix to UCP II. It is also found in UCP I

A hub at UCP I

2.1.2 Unit Control Panel 2

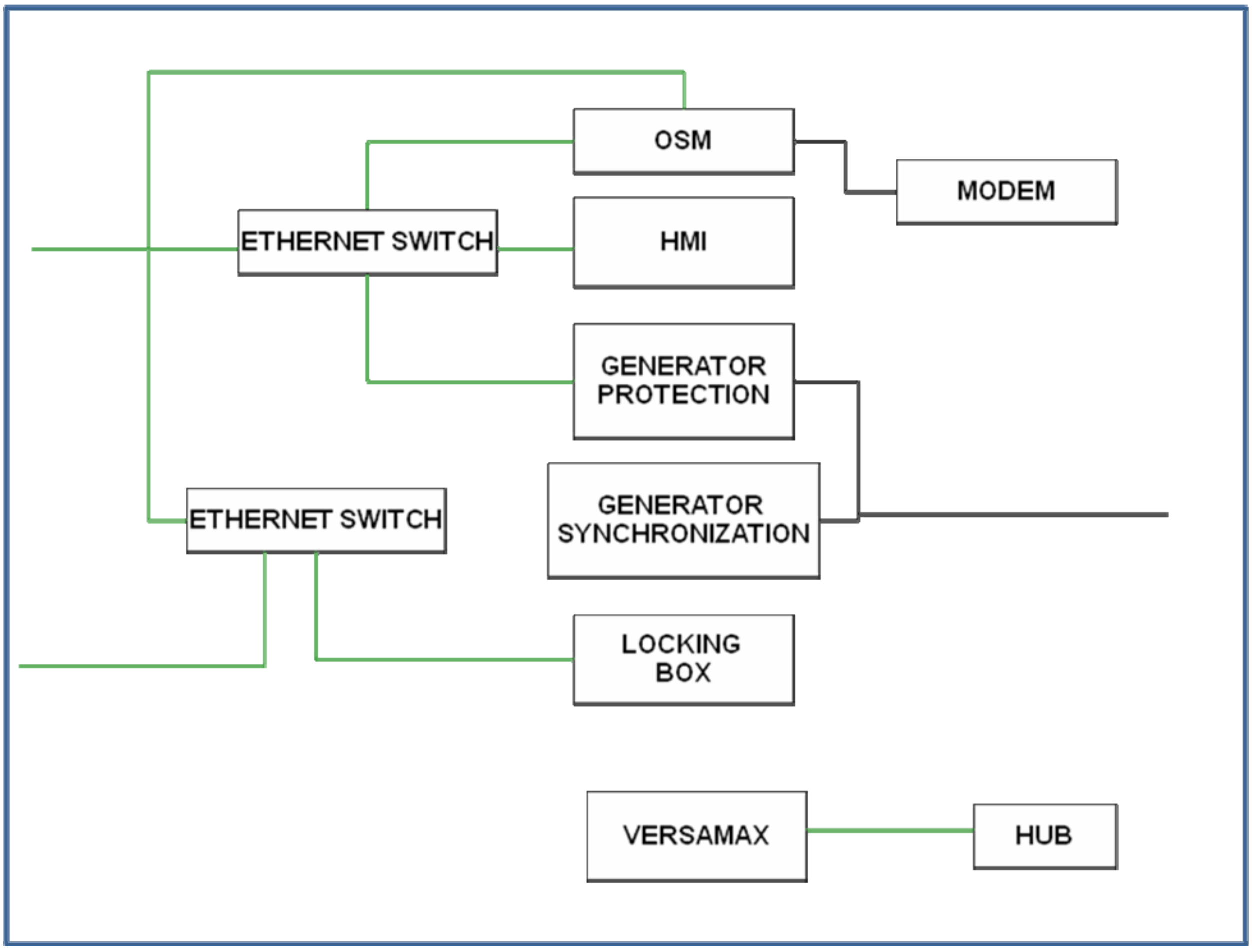
A pictorial view of GTG UCP II

Unit control panel II communicates with UCP I via Ethernet switch. UCP II contains following instrument related equipments.

a. OSM (**Historian**)
b. HMI
c. Generator Protection
d. Generator Synchronization
e. Versamax

The control architecture of UCP II is shown below.

UNIT CONTROL PANEL # 2



UCP II architecture

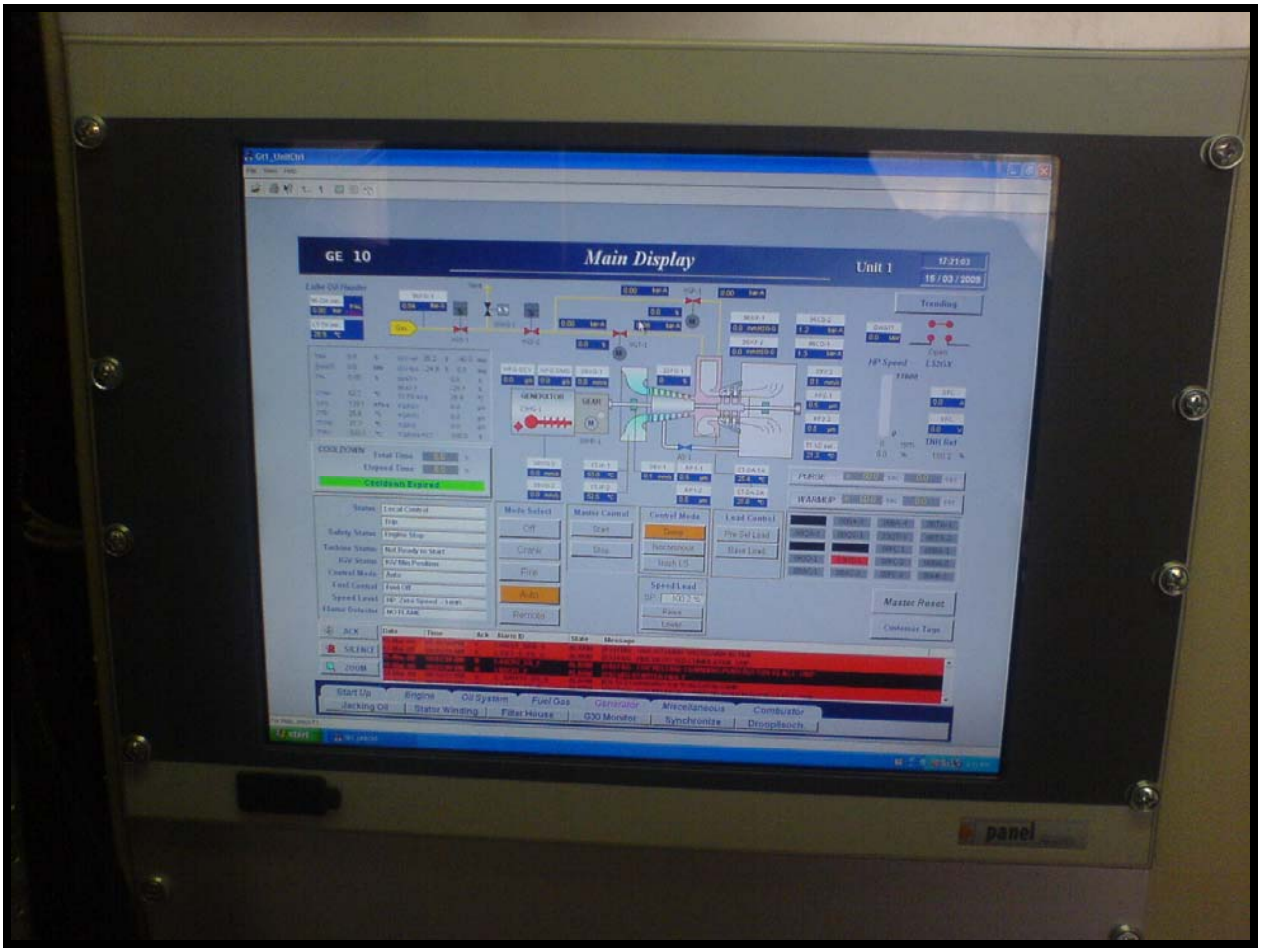
2.1.2. a. OSM (Historian)

OSM Historian stores the alarm and trends history of GTG. It is linked with GTG-HMI (Human Machine Interface) via an Ethernet switch and can be accessed through that HMI.

OSM historian made by panel.

2.1.2 b. Human Machine Interface (HMI)

GTG HMI helps operators control different parameters of GTG. GTG startup takes place through this HMI. This HMI provides a Graphical User Interface between the Gas Turbine and the Operator.



A pictorial view of HMI of GTG

In order to explore all the graphics of GTG HMI, Click Here

2.1.2 c. Generator Protection

Generator protection equipment is mainly related to the electrical side.
The G30 Generator protection system provides comprehensive protection for small to medium sized steam, hydraulic and combustion-turbine generators as well as applications that have both the generator and transformer in the same zone of protection. The G30 is ideal for protecting single and multi-pole generators with single or split phase windings configuration of generators. The G30 includes advanced automation and communication capabilities, extensive I/O options, and powerful fault

recording features that can simplify fault and disturbance troubleshooting and minimize generator downtime

G30 Generator protection system

2.1.2 d. Generator Synchronization

Generator synchronizer is used for the synchronization of the generator with the bus bar. For this purpose, it controls the speed of the generator with the help of governor.

Synchronization

The process of connecting an AC generator (alternator) to other AC generators is known as synchronization and is crucial for the generation of AC electrical power.

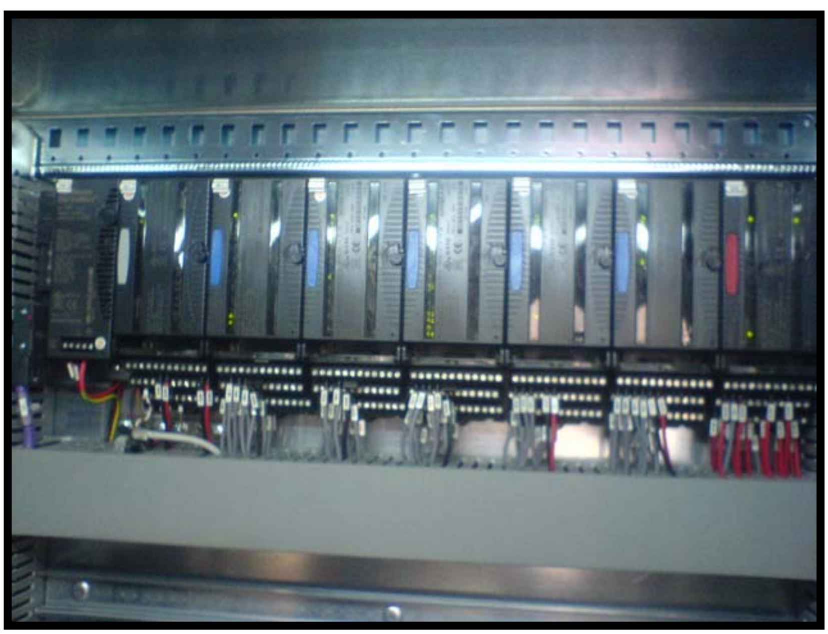
Conditions

There are five conditions that must be met before the synchronization process takes place. The generator must have equal line voltage, frequency, phase sequence, phase angle and waveform to that of the system to which it is being synchronized. Waveform and phase sequence are fixed by the construction of the generator and its connections to the system, but voltage, frequency and phase angle must be controlled each time a generator is to be connected to a grid.

A pictorial view of Generator synchronizer

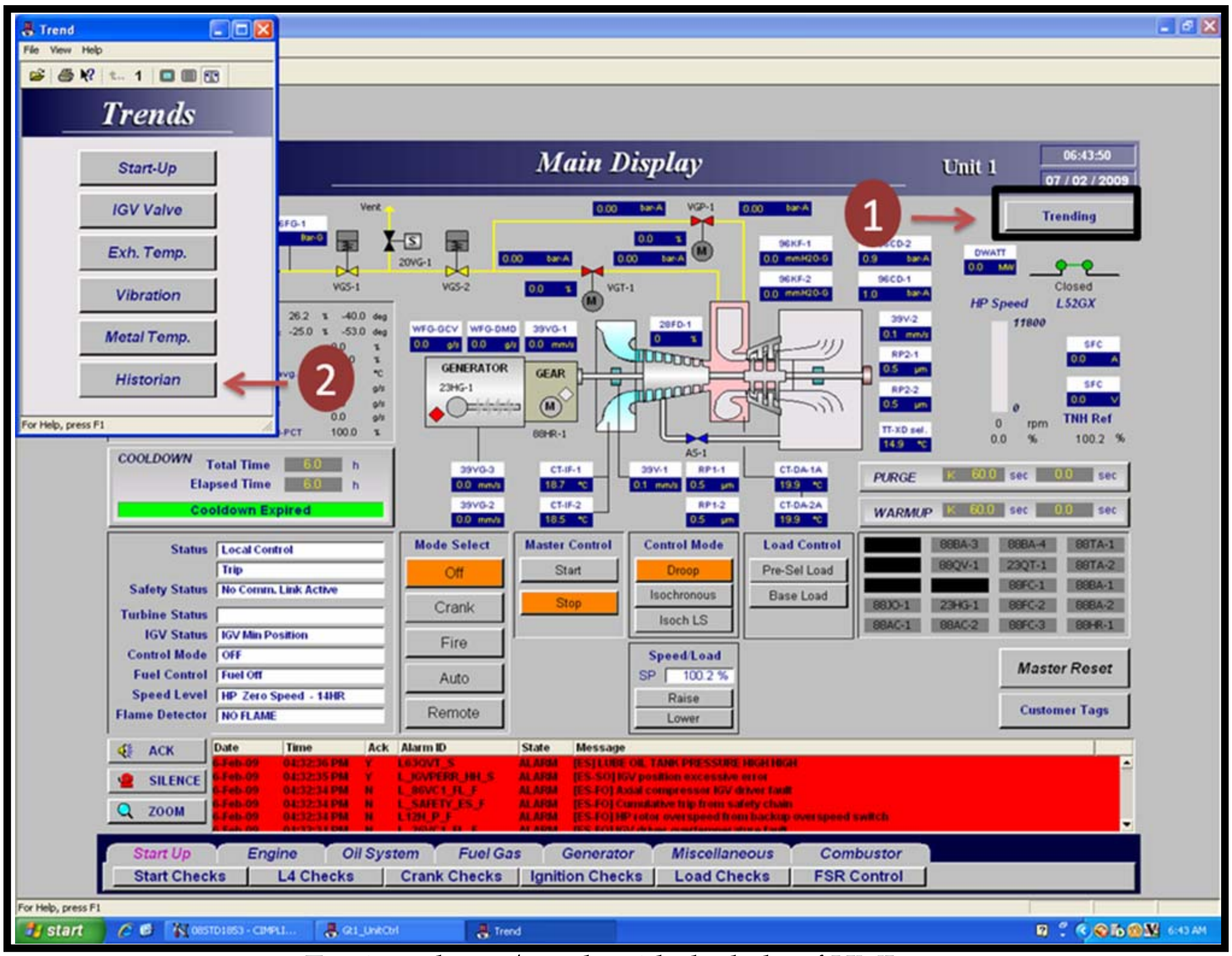
2.1.2 e. Versamax I/O cards

Versamax cards are also present here for communication between UCP II with UCP I via RX3i.


A pictorial view of Versamax I/O cards at UCP II

2.2 OSM historian introduction and Alarms/trends viewing

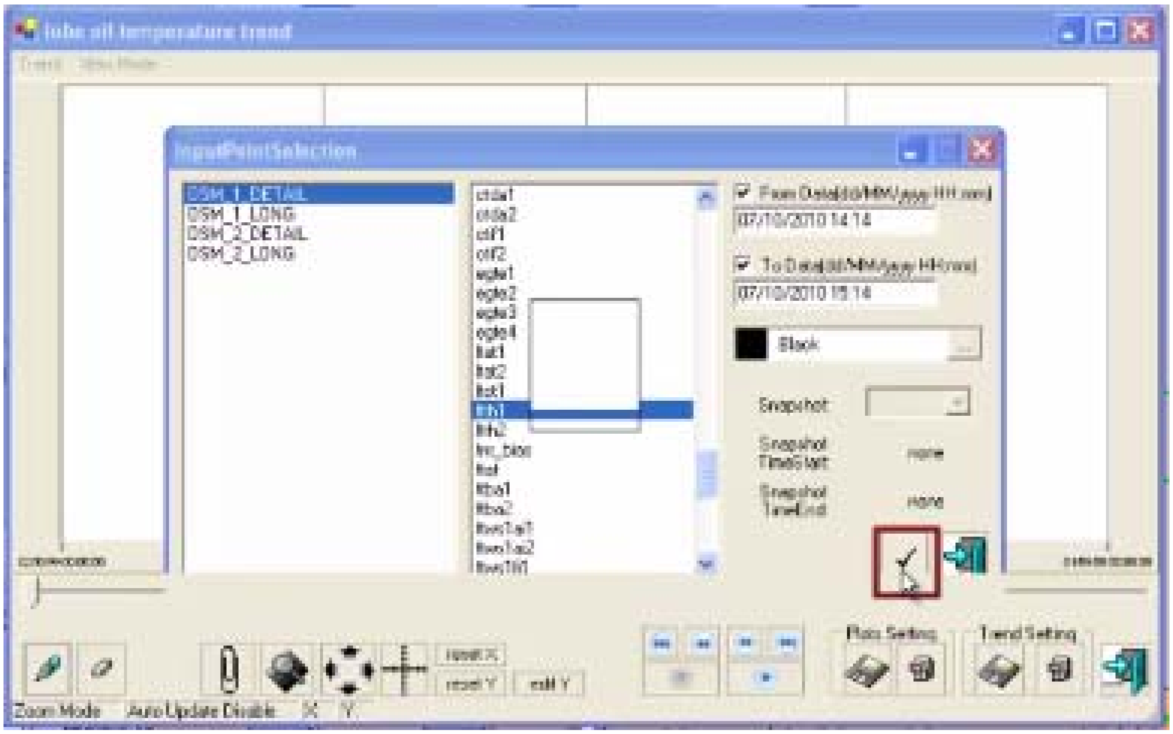
The introduction of Historian has already been given. Below is the graphical explanation of how to use historian for alarms/trends viewing.



To view alarms/trends with the help of HMI

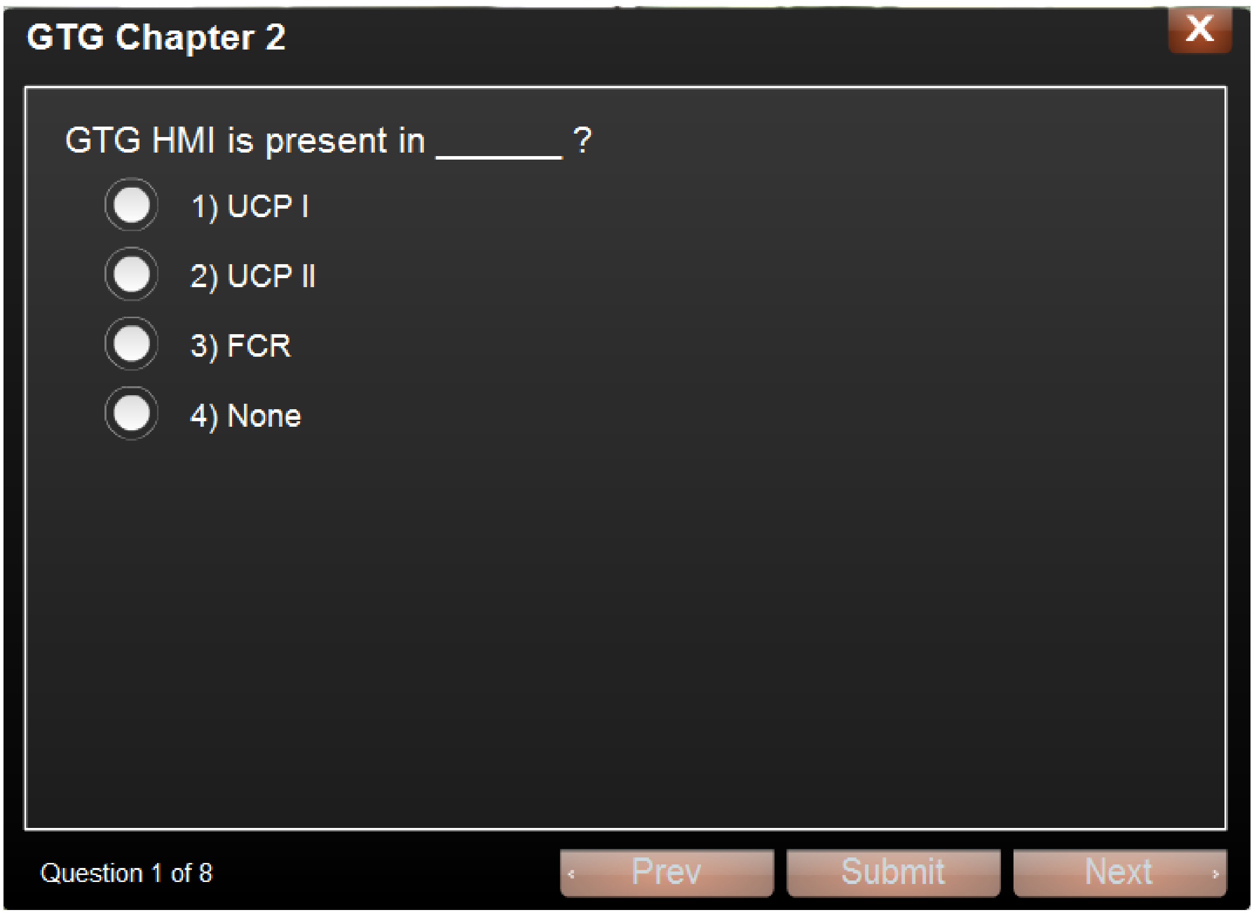
Video tutorial

To view a video tutorial of how to take alarm trends, click here.

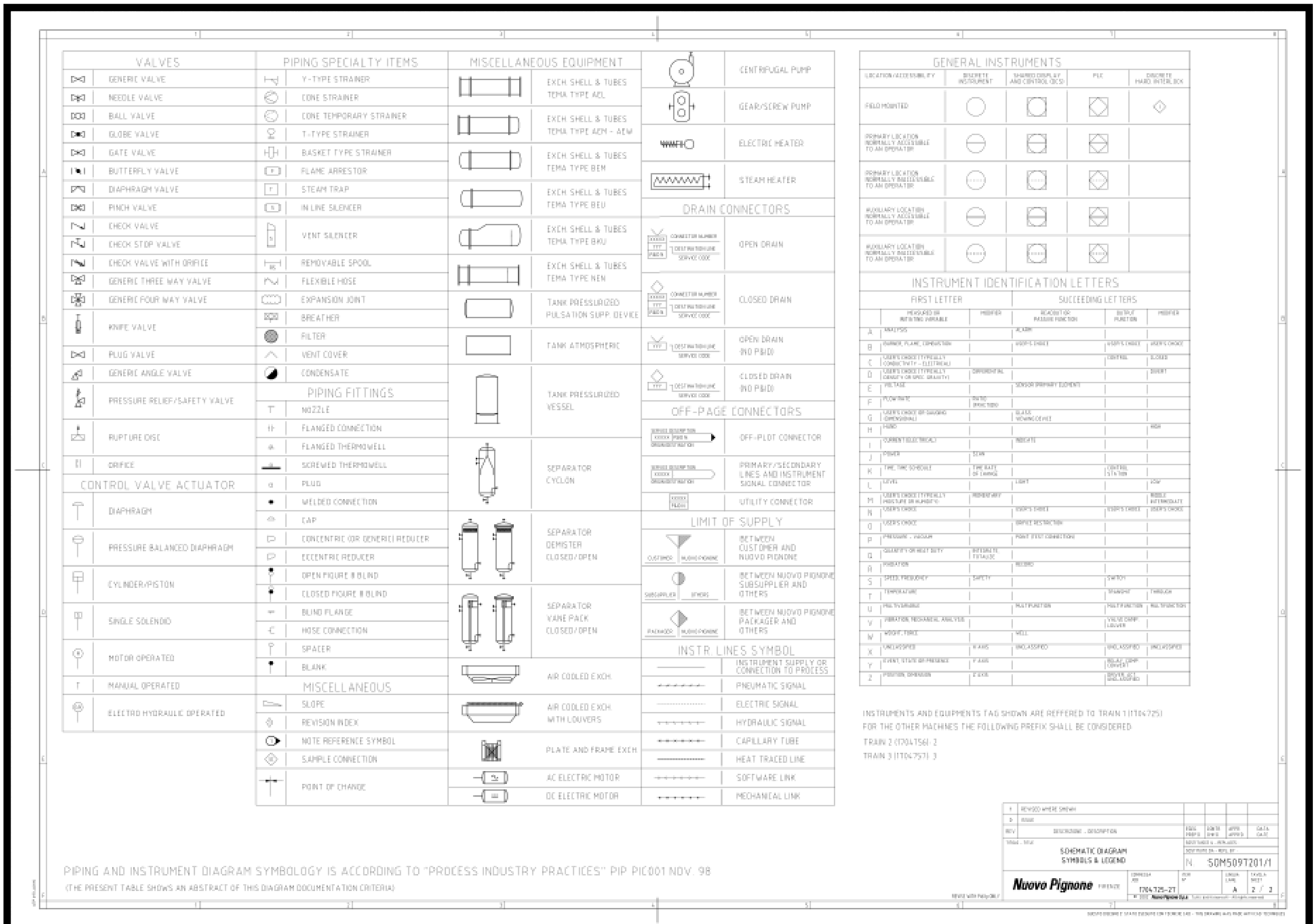


QUIZ

To take a quiz for chapter 2, click here.



3. GTG important P&ID's



Learning objectives

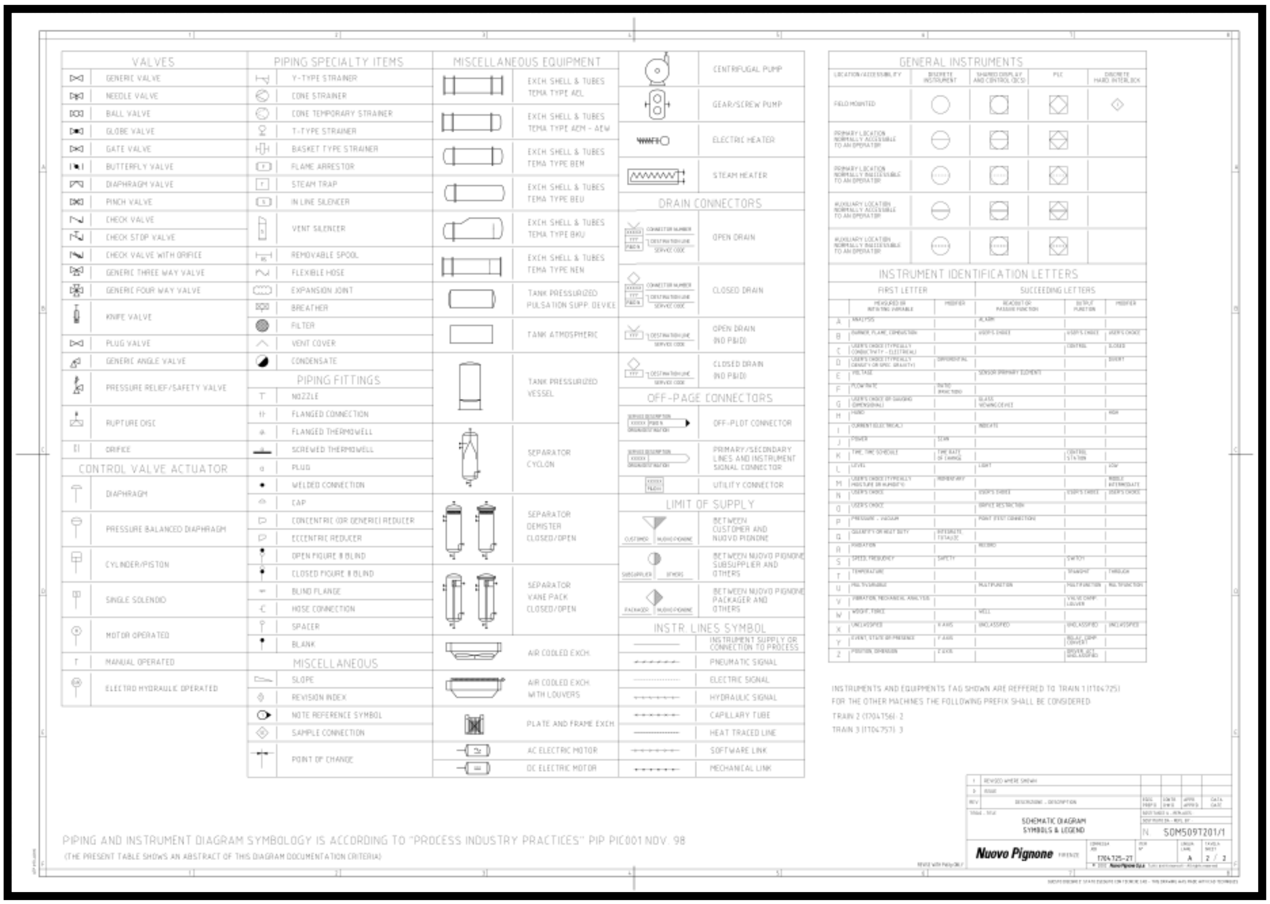
- To locate different important instruments and learn their Tag numbers from the following P&ID's. Also to understand process flow and function of all the instruments. Moreover, learn to use graphics for verification.

    - Fuel gas metering system
    - Fuel gas system (DLN Combustor)
    - Cooling and Sealing Air system
    - Control and protection devices system
    - Lube oil system
    - Electrical generator and gear box
    - Lube oil mist separator system
    - Lube oil cooling system
    - Pulse jet filter house
    - Evaporative cooling system
    - Filter housing generator
    - Fire fighting system
    - Off-Line washing trolley

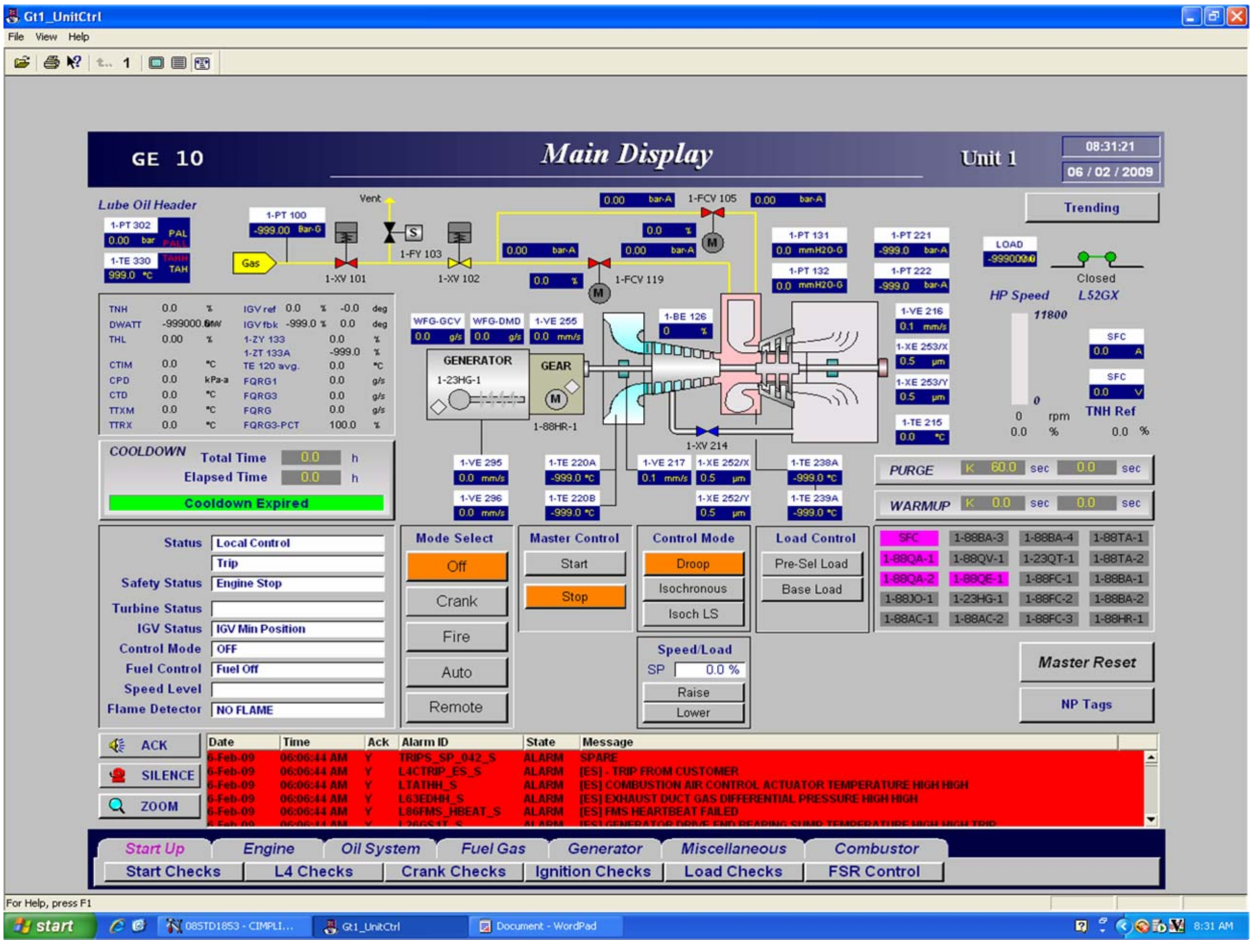
3.1 GTG important P&ID's

P& ID stands for *piping and instrument diagram.*
P&ID is a schematic illustration of functional relationship of piping, instrumentation and system equipment components.

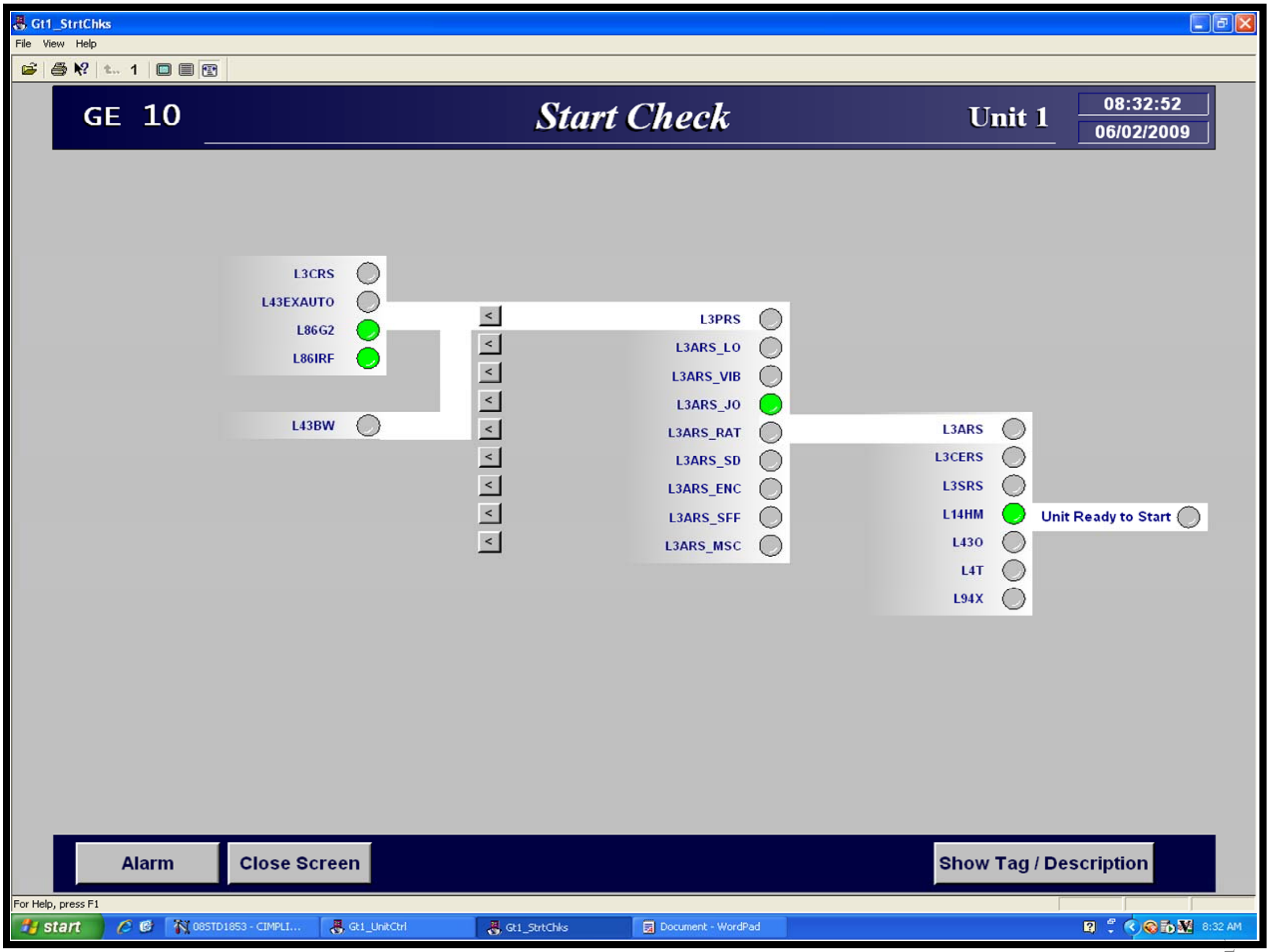
To view the P&IDs of GTG click here.



GTG Graphics can also be used for better understanding.
For GTG Graphics, click here.



4. Start/Stop sequence of GTG



A graphical view of a startup check conditions

Learning objectives

- To understand the following sequence of GTG with the help of flow charts and Graphics. Learn to navigate between the graphics and verify different signals in the graphics.

    - Ready to start
    - Auxiliaries starting
    - Crank
    - Ignition
    - Warm up
    - Acceleration to operative speed
    - Synchronization
    - Load control
    - Shutdown request
    - Trip request
    - Shutdown/trip sequence
    - Cool down sequence

4.1 GTG start/stop sequence

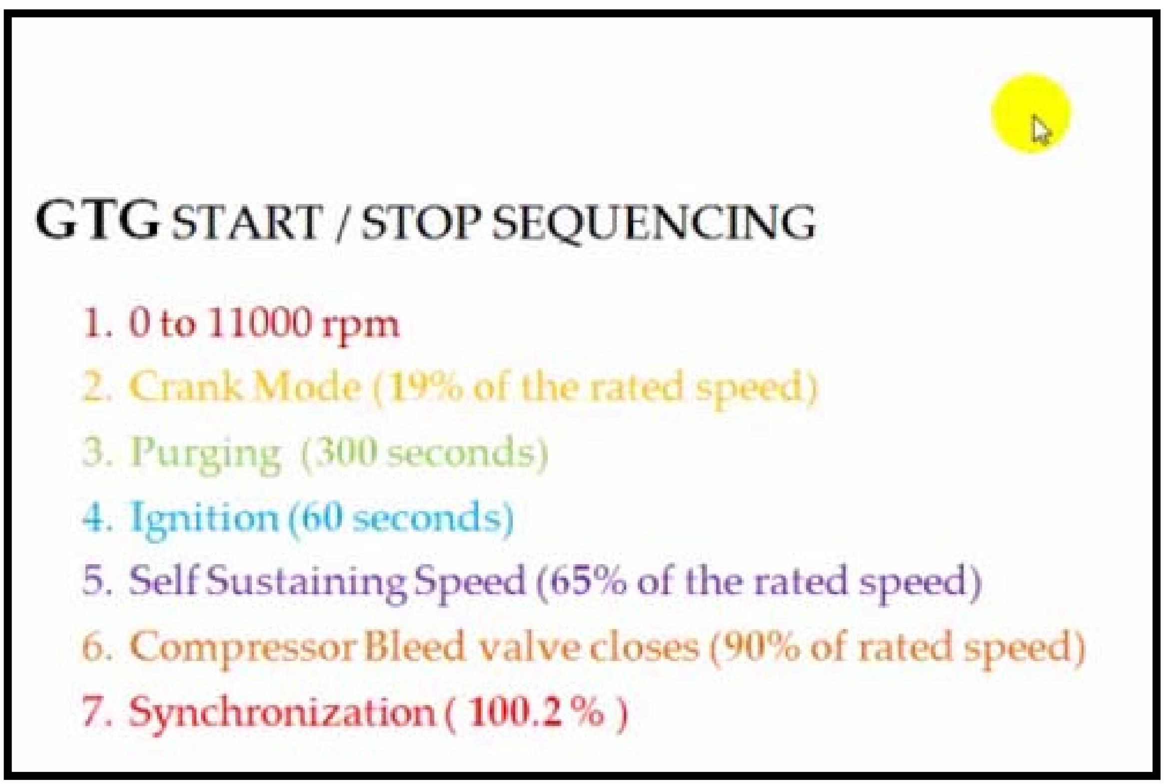
There are several conditions which need to be fulfilled in order to start GTG. Similarly GTG stop requires some conditions to be met too.

To understand the complete startup and stop sequence of a GTG, refer to the flow charts.

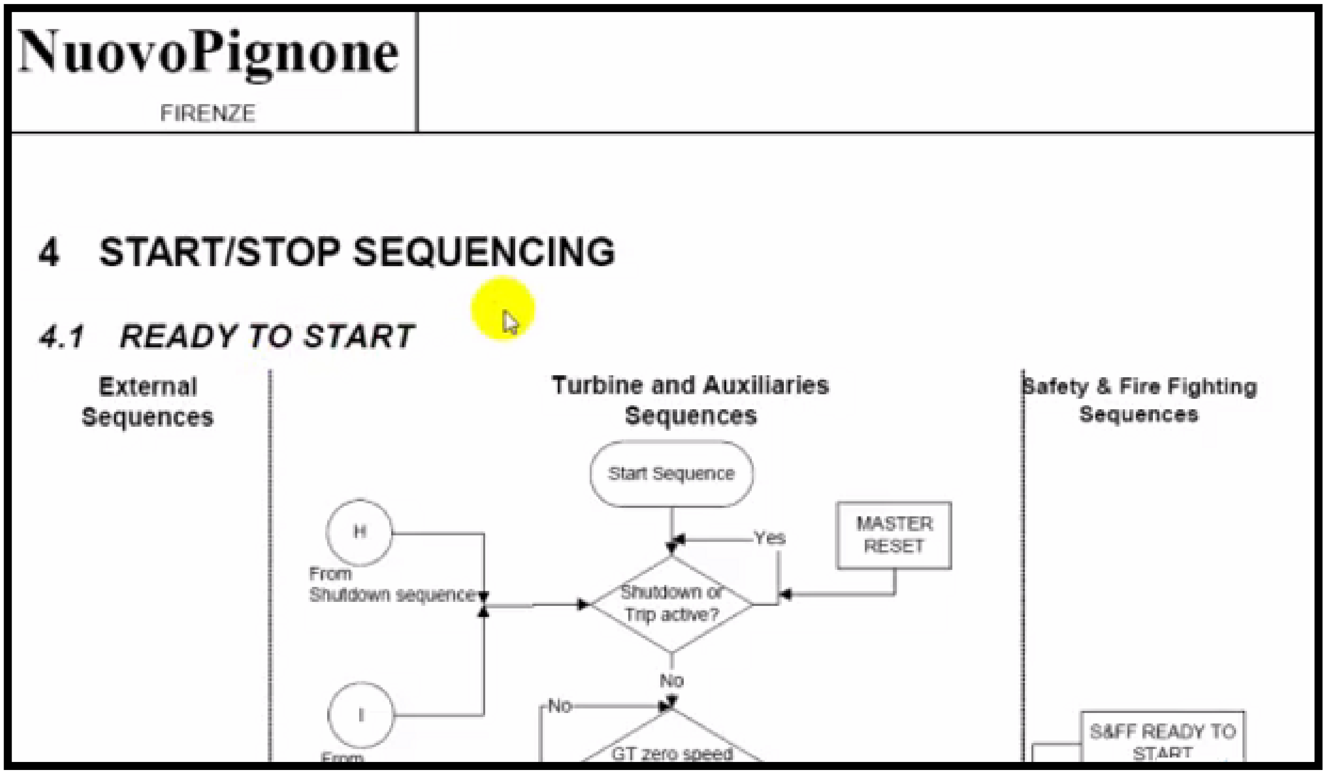
GTG startup/stop sequence can be better understood by using the GTG Graphics.
To view graphics, click here.

VIDEO TUTORIALS

- To understand **different phases of GTG** operation via an AUDIO TUTORIAL, Click here.



- To understand GTG **first part of GTG start / stop sequence** via an Audio Tutorial, click here.



5. GTG loop drawings

Learning objectives

- To be able to locate any specific loop or back trace a loop from the field to control room using the following drawings:

    - Loop Drawings
    - UCP1 Drawings
    - UCP2 Drawings

5.1. Loop Drawings

To view loop drawings of GTG, click here.

5.2. UCP1 Drawings

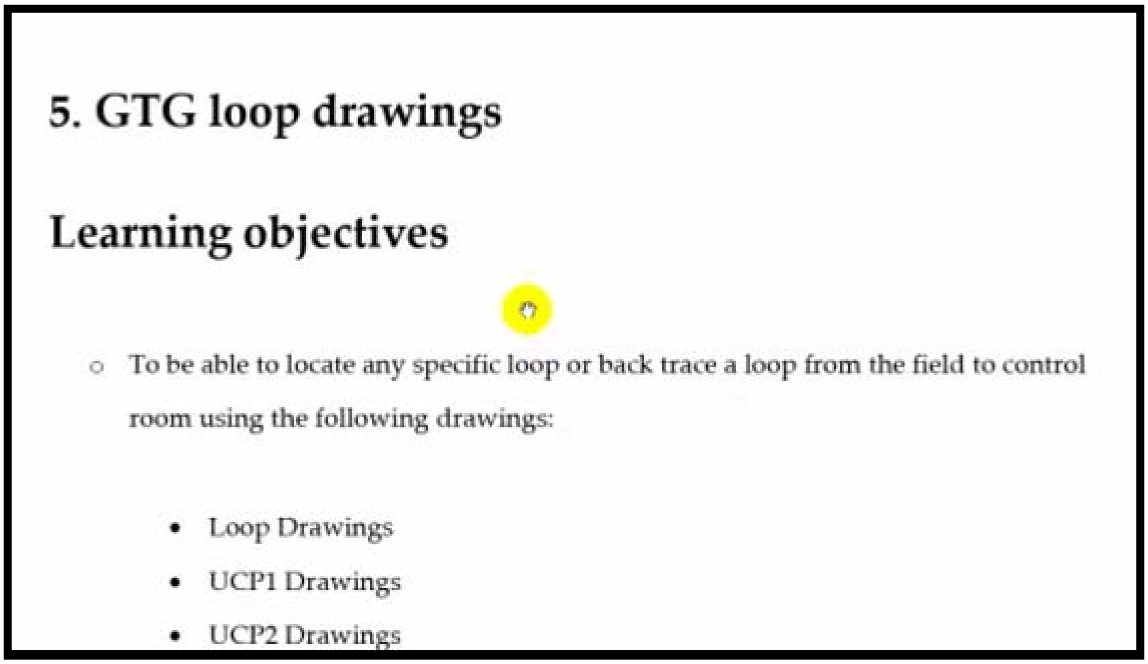
To view UCP I drawings of GTG, click here.

5.3. UCP2 Drawings

To view UCP II drawings of GTG, click here.

• Loop Tracing Video Tutorial

- To understand how to trace a loop using the above mentioned drawings via an example, click here.


5. GTG loop drawings

Learning objectives

- To be able to locate any specific loop or back trace a loop from the field to control room using the following drawings:
  - Loop Drawings
  - UCP1 Drawings
  - UCP2 Drawings

- To **view lube oil compartment** and the above mentioned RTD (TE-323), click here.