Simulation of a Gas Power Plant

HYSYS®

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"My conscience has from all over the
world for me more weight than the opinion"

Marco Tulio Cicerone
106 BC -43 BC

Preface

This project work has been carried out at the NTNU in Trondheim (Norway), framed by the Socrates-Erasmus exchange program. This has given me the opportunity to study in a different university, in a different country, in a different culture and with different people. It has given me the possibility to learn how to be alone and accompanied, to be sad and I happy... all things are they make that at the end; this project has an incalculable value for me and I don't care the final qualification that has, I am proud of my work and of my effort in a different country.

In Trondheim I have learnt, and I am still learning, much more than chemical engineering and I can say that this is being one of the most enriching experiences in my life. Now, when I am near finishing my studies, it is time to reflect on which I have learned, not only in relation to the studies but also to the life.

Acknowledgments

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Introduction

The basic principle of the Combined Cycle is simple: burning gas in a gas turbine (GT) produces not only power - which can be converted to electric power by a coupled generator but also fairly hot exhaust gases. Routing these gases through a water-cooled heat exchanger produces steam, which can be turned into electric power with a coupled steam turbine and generator.

This set-up of Gas Turbine, waste-heat boiler, steam turbine and generators is called a combined cycle. This type of power plant is being installed in increasing numbers round the world where there is access to substantial quantities of natural gas. This type of power plant produces high power outputs at high efficiencies and with low emissions. It is also possible to use the steam from the boiler for heating purposes so such power plants can operate to deliver electricity alone

Efficiencies are very wide ranging depending on the lay-out and size of the installation and vary from about 40-56% for large new natural gas-fired stations. Developments needed for this type of energy conversion is only for the gas turbine. Both waste heat boilers and steam turbines are in common use and well-developed, without specific needs for further improvement.

The primal objective of this report is to show the efficiency into simulate a Gas Power Plant with Combined Cycle technology with HYSYS® software; and to optimize the process to get the biggest possible economic benefit, making changes in the feed variables of the combined cycle plant. The data of this project are based on the document of the Department of Energy of United States.

1. Theoretical principles

1.1 Gas turbine

The gas turbine (Brayton) cycle is one of the most efficient cycles for the conversion of gas fuels to mechanical power or electricity. The use of distillate liquid fuels, usually diesel, is also common where the cost of a gas pipeline cannot be justified. Gas turbines have long been used in simple cycle mode for peak lopping in the power generation industry, where natural gas or distillate liquid fuels have been used, and where their ability to start and shut down on demand is essential.

Gas turbines have also been used in simple cycle mode for base load mechanical power and electricity generation in the oil and gas industries, where natural gas and process gases have been used as fuel. Gas fuels give reduced maintenance costs compared with liquid fuels, but the cost of natural gas supply pipelines is generally only justified for base load operation.

More recently, as simple cycle efficiencies have improved and as natural gas prices have fallen, gas turbines have been more widely adopted for base load power generation, especially in combined cycle mode, where waste heat is recovered in waste heat boilers, and the steam used to produce additional electricity. The efficiency of operation of a gas turbine depends on the operating mode, with full load operation giving the highest efficiency, with efficiency deteriorating rapidly with declining power output.

1.2 Steam turbine

The operation of the turbine of steam is based on the thermodynamic principle that expresses that when the steam expands it diminishes its temperature and it decreases its internal energy

This situation reduction of the energy becomes mechanical energy for the acceleration of the particles of steam, what allows have a great quantity of energy directly. When the steam expands, the reduction of its internal energy can produce an increase of the speed from the particles. To these speeds the available energy is very high, although the particles are very slight.

The action turbine, it is the one that the jets of the turbine are subject of the shell of the turbine and the poles are prepared in the borders of wheels that rotate around a central axis. The steam passes through the mouthpieces and it reaches the shovels. These absorb a part of the kinetic energy of the steam in expansion that it makes rotate the wheel that with her the axis to the one that this united one. The steam enters in an end it expands through a series of mouthpieces until it has lost most of its internal energy. So that the energy of the steam is used efficiently in turbines it is necessary to use several steps in each one of which it becomes kinetic energy a part of the thermal energy of the steam. If the energy conversion was made in a single step the rotational speed of the wheel was very excessive.

1.3 Heat Recovery Steam Generator

In the design of an HRSG, the first step normally is to perform a theoretical heat balance which will give us the relationship between the tube side and shell side process. We must decide the tube side components which will make up our HRSG unit, but only it considers the three primary coil types that may be present, Evaporator, Superheater and Economizer.

> ***1.3.1 Evaporator Section:*** The most important component would, of course, be the Evaporator Section. So an evaporator section may consist of one or more coils. In these coils, the effluent (water), passing through the tubes is heated to the saturation point for the pressure it is flowing.
>
> ***1.3.2 Superheater Section****:* The Superheater Section of the HRSG is used to dry the saturated vapour being separated in the steam drum. In some units it may only be heated to little above the saturation point where in other units it may be superheated to a significant temperature for additional energy storage. The Superheater Section is normally located in the hotter gas stream, in front of the evaporator.
>
> ***1.3.3 Economizer Section:*** The Economizer Section, sometimes called a preheater or preheat coil, is used to preheat the feedwater being introduced to the system to replace the steam (vapour) being removed from the system via the superheater or steam outlet and the water loss through blowdown. It is normally located in the colder gas downstream of the evaporator. Since the evaporator inlet and outlet temperatures are both close to the saturation temperature for the system pressure, the amount of heat that may be removed from the flue gas is limited due to the approach to the evaporator, whereas the economizer inlet temperature is low, allowing the flue gas temperature to be taken lower.

1.4 PID Controller

PID stands for Proportional-Integral-Derivative. This is a type of feedback controller whose output, a control variable (CV), is generally based on the error between some user-defined set point (SP) and some measured process variable (PV). Each element of the PID controller refers to a particular action taken on the error:

- Proportional: error multiplied by a gain, K_p. This is an adjustable amplifier. In many systems K_p is responsible for process stability: too low and the PV can drift away; too high and the PV can oscillate.
- Integral: the integral of error multiplied by a gain, K_i. In many systems K_i is responsible for driving error to zero, but to set K_i too high is to invite oscillation or instability or integrator windup or actuator saturation.
- Derivative: the rate of change of error multiplied by a gain, K_d. In many systems K_d is responsible for system response: too low and the PV will oscillate; too high and the PV will respond sluggishly. The designer should also note that derivative action amplifies any noise in the error signal.

Tuning of a PID involves the adjustment of K_p, K_i, and K_d to achieve some user-defined "optimal" character of system response.

1.5 PID Controller in HYSYS®

The Controller operation is the primary means of manipulating the model in dynamic studies. It adjust a stream (OP) flow to maintain a specific flowsheet variable (PV) at a certain value (SP). The controller can cross the boundaries between flowsheets, enabling you sense a process variable in one flowsheet, and control a valve in another.

To **install** the controller operation, choose **Add Operations** from the flowsheet menu, and select **Controller**. Alternatively, select the **Controller** button in the Palette.

1.5.1 Connections

The connections page allows you to select the PV and OP, as well as providing access to the sizing of the Control Valve.

Process Variable: The Process Variable, or PV, is the variable that must be maintained or controlled at a desired value. To attach the Process Variable Source, choose the **Select PV** button. You then select the appropriate object and variable simultaneously, using the Variable Navigator.

Cascade: In the case of cascade control, the primary (or master) controller checks the primary variable and compares it to the setpoint. The output from the Master controller then becomes the setpoint for the secondary or Slave controller. In this case, the master controller output target is the slave controller. There will be no control valve associated with the master controller. On the slave controller, you will connect the process variable source and output target object as usual, and size the control valve. By selecting the master controller as the cascade SP source, the connection between the two controllers is made.

Output: The output of the controller is the control valve which the controller manipulates in order to reach the setpoint. The output signal, or OP, is the actual percent opening of the control valve, based on the operating range which you define in the **View Control Valve** view.

Control Valve: The information shown on the Control Valve view is specific to the associated valve. For instance, the information for a vapour valve is different than that for a Liquid Valve.

1.5.2 Parameters

The parameters page allows you to set the process variable range, controller, action, operating mode, and depending on the mode, either SP or OP.

PV and SP: The PV or Process variable is the measured variable which the controller is trying to keep at the Set Point. The SP or Set Point is the value of the Process Variable which the controller is trying to meet. Depending on the Mode of the Controller, the SP is either input by user or display only.

OP: The OP or Output is the percent opening of the control valve. The controller manipulates the valve opening for the Output stream in order to reach the set point. HYSYS calculates the necessary OP using the controller logic in all modes with the exception of Manual. In Manual mode, you may input a valve for the Output, and the Set Point will become whatever the PV is at the particular valve opening you specify.

Modes: The controller in HYSYS can operate in different modes. These modes are shown in the next table:

Table 1. Operability modes in HYSYS controller.

Off	- The controller does not manipulate the control valve, although the appropriate is still tracked.
Manual	- Manipulate the controller output manually.
Auto	- The controller reacts to fluctuations in the Process Variable and manipulates the Output according to the logic defined by the tuning parameters.
Ramping	- The Set Point is adjusted gradually to a certain value over a specified period of time.
Cascade	- The master controller determines the Set Point, which is passed to the secondary controller.
Tune	- The ATV method is used to tune the controller.

Action: There are two options for the action of the Controller; these options are shown in the next table:

**Table 2.** Action modes in HYSYS controller.

Direct	- When the PV rises above the SP, the OP increases. When the PV falls below the SP, the OP decreases.
Reverse	- When the PV rises above the SP, the OP decreases. When the PV falls below the SP, the OP increases.

1.5.3 Tuning

The controller tuning page allows you to define the constants associated with the PID control equation, as well as the Ramping parameters. In addition, the Operating Parameters, displayed on the Parameters page, are shown here as well. The Tuning Page contains all of the essential information required to operate the Controller once the initial set up is completed.

2. Process Description

2.1 Figure 1. PFD of the simulated process.
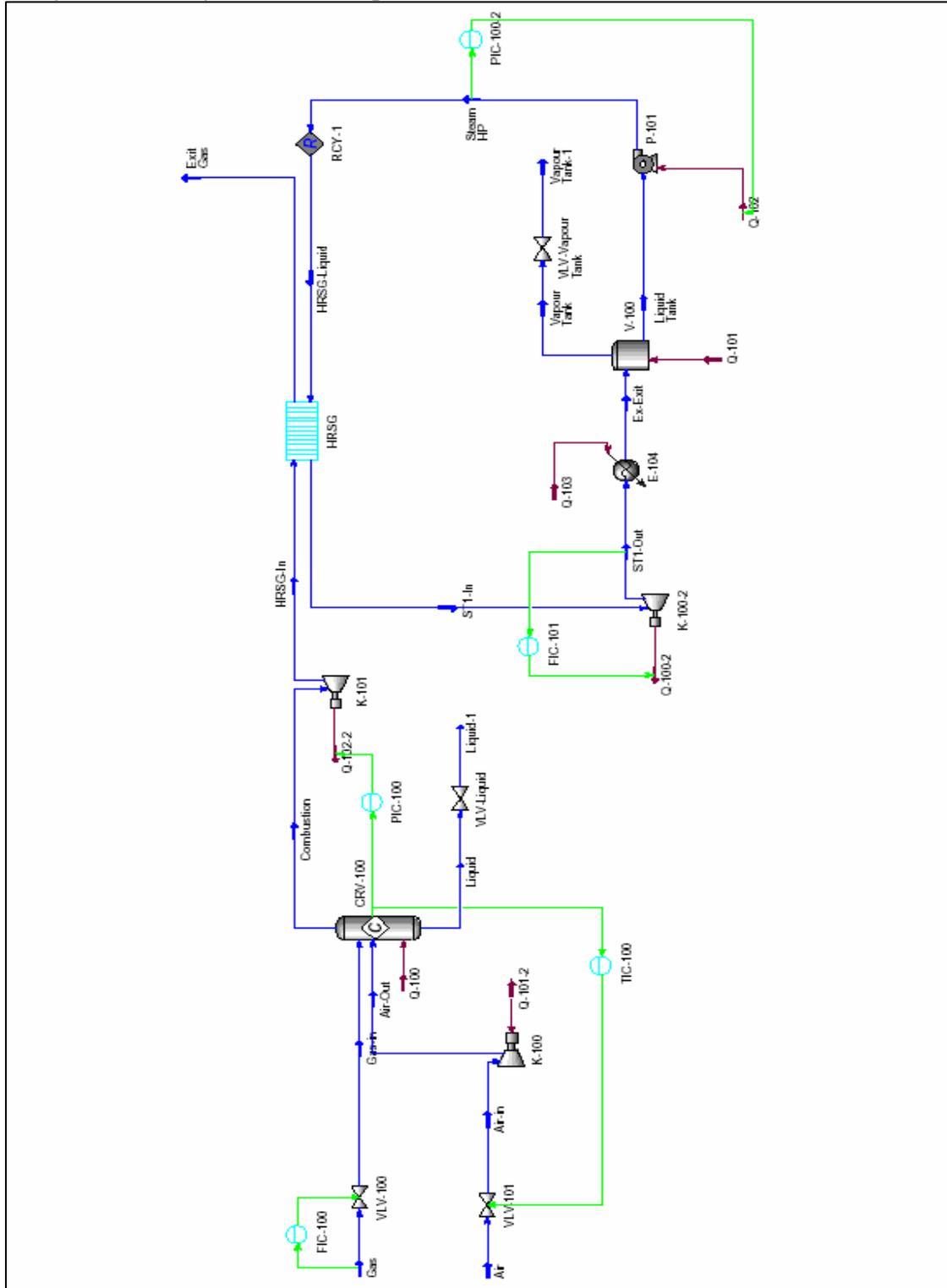
2.2 Units Operations

The unitary operations in that the process is based are:

- 1 Compressor
- 1 Gas turbine
- 1 Steam turbine
- HRSG (Heat Recovery Steam Generator)
- 1 Condensation stage (exchanger and a tank)
- Energy generator.

2.3 Process Description

In general terms, a plant of combined cycle is integrated by two or more thermodynamic cycles of energy to transform the feed energy more efficiently into work or power. With the advances in the dependability and readiness of the gas turbines, the term plants in combined cycle it refers to a compound system of a gas turbine, a heat recovery steam generator (HRSG) and steam turbines. Thermodynamically, this implies to equal a high temperature Brayton cycle of the gas turbine with a low temperature moderate Rankine cycle, the heat of waste of the exit of the Brayton cycle it serves as entrance of heat to the Rankine cycle. The gas turbine (Brayton) cycle is one of the most efficient cycles for the conversion of gas fuels to mechanical power or electricity. The challenge in these systems is to obtain an integration degree that maximizes the efficiency at an economic cost.

Two big parts can differ; a first one, referred to the gas cycle, where energy will be liberated that will serve to be able to carry out the second part, the steam cycle. The air enters in the plant coming from the atmosphere goes by a compressor, which the pressure increases from the atmospheric one up to 23 bars. The compressed air passes to a combustion camera that blended with natural gas, the combustion takes place.

Figure 2. Representative outline of the operation of a combined cycle.
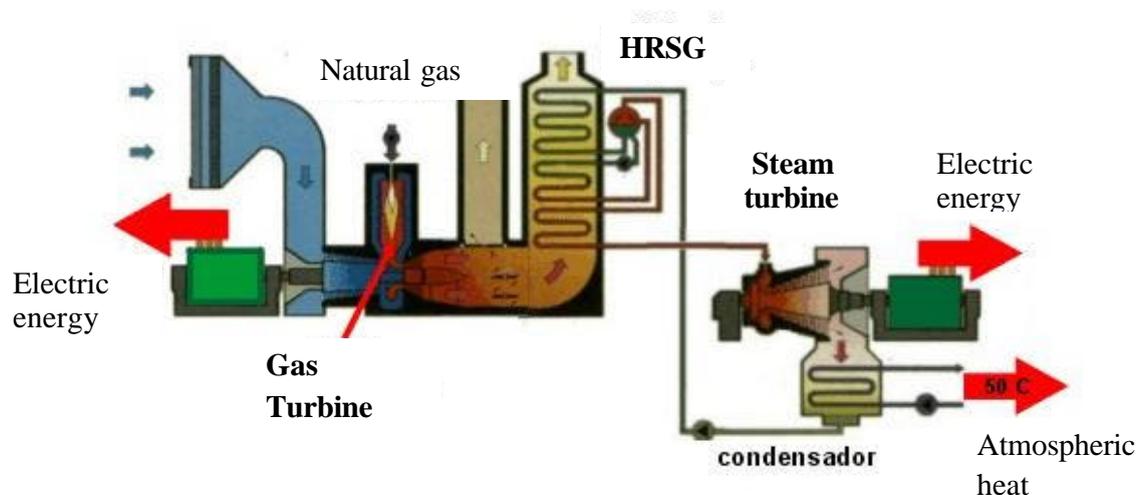
The generated hot gases of combustion go by the gas turbine, where they expand, arriving another time to the atmospheric pressure. These go toward to the HRSG, which recovers the great quantity of thermal energy that subtracts in them to produce steam. This is distributed among the circuit of high pressure to 160 bars.

The steam flow of high pressure will be good to feed the steam turbine. The steam expands from 160 up to 1 bar of exit.

The final stage of this process concerns to the condensation and recirculation of the steam water. In the first condensation stage, the steam that LP has left the turbine passes to a condenser, where it goes to a tank to assure that the bomb always enters liquid . The pump increases the pressure until the 160 bars. This flow of water passes in to the HRSG. The closed steam cycle is completed this way.

With respect to the cycle of gas, the remaining gases that have been good to generate vapour of water when going by the HRSG, have cooled down until the temperature of 500ºC, that later they can use them to sell to others industries.

2.4 Manipulated variables (Degrees of freedom)

In a process that is desired to regulate some condition, a quantity or a condition that is altered by the control in order to initiate a change in the value of the regulated condition.

In the next, is shown a table with the list of the Manipulated variables of the simulation of this gas power plant.

Table 3. Manipulated Variables and degrees of freedom.

Manipulated variables	Quantity
Fuel Valve	1
Air valve	1
Air compressor work	1
Gas turbine work	1
Steam turbine work	1
Cooling water flowrate	1
Pump	1
TOTAL MANIPULATED	**7**
Mass balance air feed flowrate	-1
TOTAL Degrees of freedom	**6**

2.5 Disturbances & Constraints

A **Disturbance** upsets the process system and causes the output variables to move from their desire setpoint. Disturbances variables cannot be controlled or manipulated by the process engineer. The control structure should account for all disturbances that can significantly affect a process. The disturbances to a process can either be measured or unmeasured. The disturbances of the process are shown on the next table:

Table 4. Disturbances and their expected values and variations values.

Disturbance	Expected	Variation
Fuel Concentration (%Methane)	0,96	0,92 – 1
Fuel Temperature (ºC)	25	20 – 30
Fuel Pressure (kPa)	2300	2250 – 2350
Air Concentration (%O_2)	0,210	0,205 – 0,215
Air Pressure (kPa)	101,3	100,3 – 102,3
Air Temperature (ºC)	20	10 – 30
Exit Pressure (kPa)	101,3	100,3 – 102,3

The **Constraints** are the restrictions or limitations that placed on requirements or design of your process. The constraints of the process are shown in the table 5:

Table 5. Constraints values.

Constraints	Value
Temperature combustion	≤ 1500ºC
Temperature steam turbine	≤ 600ºC
Pressure cycle steam	≤ 170 bars

2.6 Real data of the DOE process

Next it is shown different tables of data of the process which my project is based. The real data is extract of the combined cycle of the DOE process, so much the produced total energy, as the auxiliary one used, and the total efficiency of the cycle.

Table 6. Energy produced by the DOE process

Generated energy (kW)	
Gas Turbine	275800
Steam Turbine	127537
TOTAL	**403337**

Table 7. Auxiliary energy by the DOE process

Auxiliar energy (kWe)	
Compresor	1680
Recycle HP pump	1630
Control system, lighting...	900
Steam recycling pump	1240
Refrigeration tower	700
Transformation losses	1370
Others…	670
TOTAL	**8310**

Tabla 8 . Net energies and efficiency.

Net energies (kWe)	
Net energy	395027
Plant efficiency	**53,4**
Generated net heat	6396
GAS NATURAL consumption (kg/h)	524891

Figura 3. Virtual scheme of a combined cycle plant.
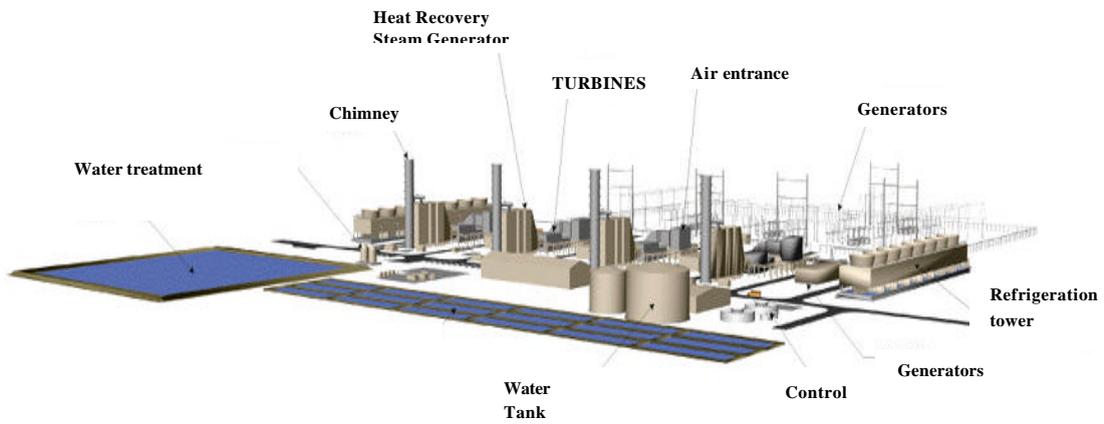
3. Steady-State modelling

3.1 Introduction

The steady-state is a characteristic of a condition, such as value, rate, periodicity, or amplitude, exhibiting only negligible change over an arbitrary long period of time (infinite).

3.2 Assumptions

- I have supposed the camera of combustion of the process from the DOE as a conversion reactor in the HYSYS®.
- The conversion is 100% in the reactor.
- In the compressor and the turbines the efficiencies are adiabatic.
- The components of the natural gas are: methane, ethane and nitrogen.
- The natural gas in the feed comes directly at the pressure of 23 bars.
- It's supposed worthless the mechanical losses.
- I supposed that isn't losses on the conversion energy.
- The losses of heat have been rejected in each unit (turbine, compressor, boiler and HRSG adiabatic).

3.3 Fluid Packages

In HYSYS®, all necessary information pertaining to pure component flash and physical property calculations in contained within the Fluid Package. This approach allows you to define all the required information inside a single entity. There are four keys advantages to this approach and are listed below:

- All associated information is defined in a single location, allowing for easy creation and modification of the information.
- Fluid packages can be exported can be exported and imported as completely defined packages for use in any simulation.
- Fluid packages can be cloned, which simplifies the task of making small changes to a complex Fluid package.
- Multiple Fluid Packages can be used in the same simulation; however; they are all defined inside the common Simulation Basis Manager.

Before beginning the simulation, I have made a study on which it was the best fluid package to simulate a Gas Power Plant. To decide with which fluid package I should catch, I have proven the package that treat hydrocarbons flow (natural gas), and the results of each fluid package, I have compared them with the data of the DOE process.

I have compared the results of temperature, pressure and work in the most important unitary operations. Next a table is shown with the different data for each fluid package.

Tabla 9. Temperature and Pressure data for each fluid package tested.

	UNIQUAC	SRK	Wilson	PRSV	DOE
T(°C) exit compressor	494,2	494,5	494,2	494,7	**481,9**
kW compressor	$2,76x10^5$	$2,88x10^5$	$2,77x10^5$	$2,77x10^5$	**$2,69x10^5$**
T(°C) combustion	1517	1516	1517	1515	**1471**
kW turbine HP	$4,39x10^5$	$7,74x10^5$	$5,67x10^5$	$7,73x10^5$	**$5,54x10^5$**
T(°C) exit turbine HP	1240	849,7	720,6	894,4	**594,6**
T(°C) exit gases HRSG	1059	653,7	322,6	656,1	**100,9**
T(°C) exit steam turbine	212,4	183,2	166,4	182,5	**332**
kW steam turbine	$9,09x10^4$	$9,11x10^4$	$9,02x10^4$	$9,44x10^4$	**$6,49x10^4$**
T(°C) exit pump HP	31,58	31,03	31,58	31,53	**44**

According to the results of temperatures, pressures and works, I have chosen the thermodynamic model **SRK**, since it is the one that more it resembles the results of the DOE process. For similarity of results I had to have caught WILSON, but this fluid package, it is not correct, since liquid is obtained in the exit of the combustion camera. That is unthinkable in a combustion camera to a temperature of 1500ºC and a pressure of 23 bars.

During the simulation of HYSYS in stationary state mode, I have had many problems to choose the fluid package, since none of the thermodynamic models resembled the results of the process of the DOE. Most of them had the problem that we obtained liquid in the exit of the reactor, when this occurred, discarded the thermodynamic package.

3.4 Components of the Fluid Package

The components that I have used for the simulation of Gas Power Plant in HYSYS® software are the following ones:

- Methane
- Ethane
- Nitrogen
- CO_2
- Oxygen
- H_2O

Next is shown a table with the composition of the natural gas that feeds the power plant.

Table 10. Composition of the natural gas.

| Component	% (molar)
Methane	0,96
Ethane	0,02
Nitrogen	0,02

3.5 Combustion Reaction

During the definition of the fluid package, I have also defined the reaction that takes place in the combustion camera, where it mixes the natural gas with the air that it comes from the compressor. The reaction in the reactor is the following one:

$$CH_4 + 2 \cdot O_2 \Rightarrow CO_2 + 2 \cdot H_2O$$
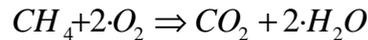
In the HYSYS® software, the combustion reaction between the natural gas and air is defined like the next figure:

Figure 4. Definition of the combustion reaction in HYSYS®.
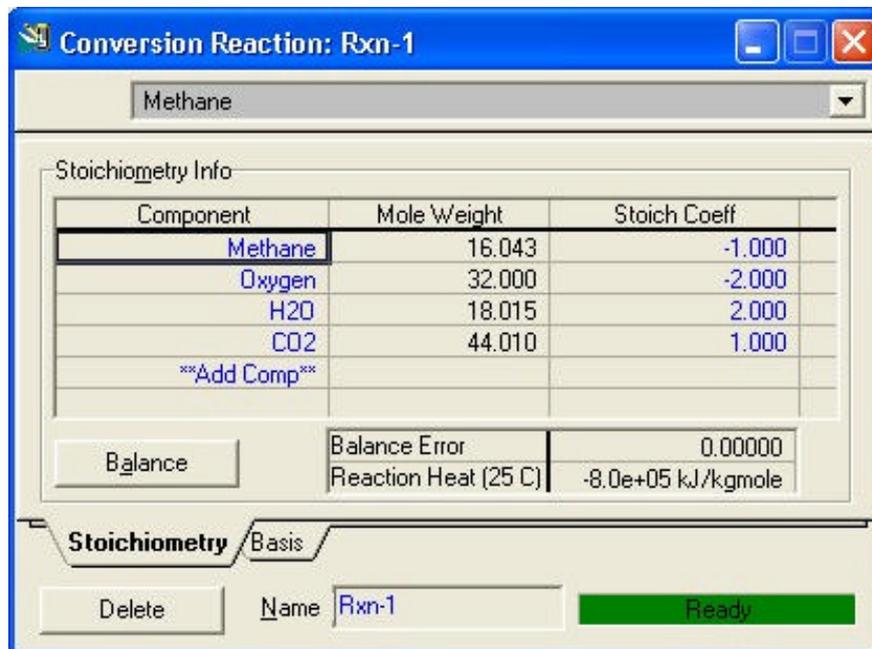
3.6 Results of the Steady-State

For the calculate of the efficiency of the combined cycle are needed the net work produced by the cycle. Net work: The net work corresponds the one generated by the turbines less the one consumed by the bomb and the compressor.

The results of the simulated cycle are shown in the following tables, where the efficiencies of compressors, turbines and bomb are included; the produced energy and the one consumed for the total calculation of combined cycle. The global efficiency of the plant is obtained relating the Wnet obtained with the heat that we put in the system through the combustion camera.

Table 11. Efficiencies of turbines, compressors and the pump.

Efficiency (%)	
Compressor	83,0
Gas Turbine	84,0
Steam Turbine	83,0
Pump	77,0

Table 12. Net work of the combined cycle.

Works (MW)	
Compressor	287,8
Gas Turbine	778,5
Steam Turbine	91,1
Pump	1,51
TOTAL	**580,3**

Table 13. Global efficiency of the simulated plant.

Global efficiency (%)	
Net Work (MW)	580,3
Heat (combustion) (MW)	970
Combined Cycle efficiency	**59,8 %**

3.7 The Profit (expected disturbances)

The Profit is the positive gain from a business, investment or process operation after subtracting for all expenses in the process. In our case, the profit is defined:

$$-J = P_{elect}\left(W_{gt} + W_{st} - W_c - W_p\right) - P_{fuel}F_{fuel} - P_{air}F_{air} - P_{water}F_{water}$$

Where:

J=profit
P_{elect} = electricity price
W_{gt} = gas turbine work
W_{st}= steam turbine work
W_c= compressor work
W_p= pump work
$P_{fuel, air, water}$= price of the fuel, air and water
$F_{fuel, air, water}$= flowrate of the fuel, air and water

In our case, we have to despise the water price, because in the Norway there isn't problem with water supply; and we have to despise the price of the air, because our plant takes the air directly from the atmosphere and we don't have any cost of water and air.

Next a study of the profit is shown. All the possibilities have been simulated with their respective disturbances. Starting from there, it has been calculated the values of the profit and the disturbances has been determined that have more effect on the profit:

Table 14. Results of the study of the effect of the disturbances on the process

Disturbance	Expected	W_{gt}	W_{st}	W_c	W_p	J
Fuel concentration	0,92	7,78E+05	9,24E+04	2,88E+05	1512	**85907,5**
	0,96	7,79E+05	9,11E+04	2,88E+05	1512	**85835,5**
	1	7,79E+05	8,98E+04	2,88E+05	1512	**85754,5**
Fuel temperature	20	7,78E+05	9,10E+04	2,88E+05	1512	**85744,0**
	25	7,79E+05	9,11E+04	2,88E+05	1512	**85835,5**
	30	7,79E+05	9,12E+04	2,88E+05	1512	**85928,5**
Fuel pressure	2250	7,74E+05	9,15E+04	2,88E+05	1512	**85265,5**
	2300	7,79E+05	9,11E+04	2,88E+05	1512	**85835,5**
	2350	7,79E+05	9,11E+04	2,88E+05	1512	**85834,0**
Air concentration	0,205	7,77E+05	8,86E+04	2,88E+05	1512	**85124,5**
	0,21	7,79E+05	9,11E+04	2,88E+05	1512	**85835,5**
	0,215	7,89E+05	9,36E+04	2,88E+05	1512	**87880,0**
Air pressure	100,3	7,79E+05	9,12E+04	2,90E+05	1512	**85673,5**
	101,3	7,79E+05	9,11E+04	2,88E+05	1512	**85835,5**
	102,3	7,78E+05	9,10E+04	2,87E+05	1512	**85973,5**
Air temperature	10	7,72E+05	8,96E+04	2,74E+05	1512	**86690,5**
	20	7,79E+05	9,11E+04	2,88E+05	1512	**85835,5**
	30	7,81E+05	9,16E+04	2,93E+05	512	**85700,5**
Exit Pressure	100,3	7,79E+05	9,11E+04	2,88E+05	1512	**85895,5**
	101,3	7,79E+05	9,11E+04	2,88E+05	1512	**85835,5**
	102,3	7,79E+05	9,11E+04	2,88E+05	1512	**85820,5**

Where:

J=profit
P_{elect} = *electricity price*
W_{gt} = *gas turbine work*
W_{st}= *steam turbine work*
W_c= *compressor work*
W_p= *pump work*

In the chart one can observe as the disturbances more important they are relating to the air, since the flow rate is some bigger four times, for that reason it has so much importance and the result of the profit is more affected.

4. Dynamic Modelling

4.1 Introduction

Dynamic simulation can help you to better design, optimize, and operate your chemical process or refining plant. Chemical plants are never truly at steady-state. Feed and environmental disturbances, heat exchanger fouling, and catalytic degradation continuously upset the conditions of a smooth running process. The transient behaviour of the process system is the best studied using a dynamic simulation tool like HYSYS®.

With dynamic simulation, you can confirm that the plant can produce the desired product in a manner that is safe and easy to operate. By defining detailed equipment specifications in the dynamic simulation, you can verify that the equipment functions as expected in an actual plant situation. Offline dynamic simulation can optimize controller design without adversely affecting the profitability or safety of the plant.

You can design and test a variety of control strategies before choosing one that is suitable for implementation. You can examine the dynamic response to system disturbances and optimize the tuning controllers. Dynamic analysis provides feedback and improves the steady-state model by identifying specific areas in a plant that have difficulty achieving the steady state objectives. You can investigate:

- Process optimization
- Controller optimization
- Safety evaluation
- Transition between operating conditions
- Start-up/Shutdown conditions

4.2 Fine tuning of controllers in HYSYS®

Before the Integrator runs, each controller should be turned off and then put back in manual mode. This initializes the controllers. Placing the controllers in manual defaults the setpoint to the current process variable and allow you to "manually" adjust the valve % opening of the operating variable.

If reasonable pressure-flows specifications are set in the dynamic simulation and all the equipment is properly sized, most process variables should line out once the Integrator runs. The transition of most unit operations from steady-state to Dynamics mode is smooth.

However, controller tuning is critical if the plant simulation is to remain stable. Dynamic columns, for example, are not open loop stable like many of the unit operations in HYSYS. Any large disturbances in the column can result in simulation instability.

After the Integrator is running:

- Slowly bring the controllers online starting with the ones attached to upstream unit operations. The control of flow and pressure of upstream unit operations should be handled initially since these variables have a significant effect on the stability of downstream operations.
- Concentrate on controlling variables critical to the stability of the unit operation. Always keep in mind that upstream variables to a unit operation should be stabilized first.
- Start conservatively using low gain and no integral action. Most unit operations can initially be upset to use P-only control.
- Trim the controllers using integral or derivative action until satisfactory close-loop performance is obtained.
- At this point, we can concentrate on changing the plant to perform as desired.

4.3 PID Controllers used in the process

Now are shown all the controllers are that I have put on in the process. The function is described that carry out, the object, the manipulated variable and the Output Target Object. Also, it describes all the parameters of each controller:

FIC-100

Object: Gas
Variable: Mass Flow
Output: VLV-100
Action: Reverse
Mode: Automatic
K_c: 0,2
t_i : 0,1 (6 seconds)
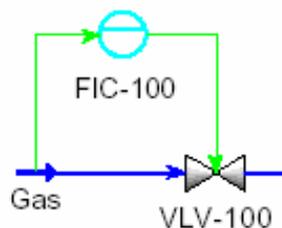
Figure 5. Flow control in the natural gas feed

TIC-100

Object: CRV-100
Variable: Vessel Temperature
Output: VLV-101
Action: Reverse
Mode: Automatic
K_c: 1
t_i : 5 (300 seconds)
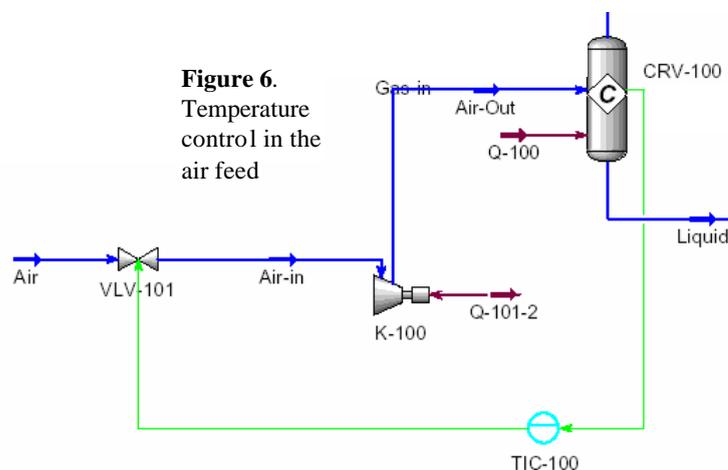
Figure 6. Temperature control in the air feed

PIC-100

Object: CRV-100
Variable: Vessel Pressure
Output: Q-102-2
Action: Direct
Mode: Automatic
K_c: 1
t_i : 10 (600 seconds)
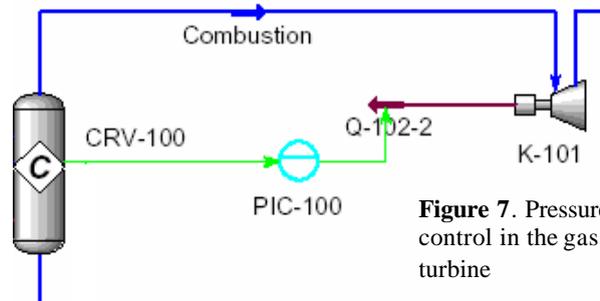
Figure 7. Pressure control in the gas turbine

FIC-101
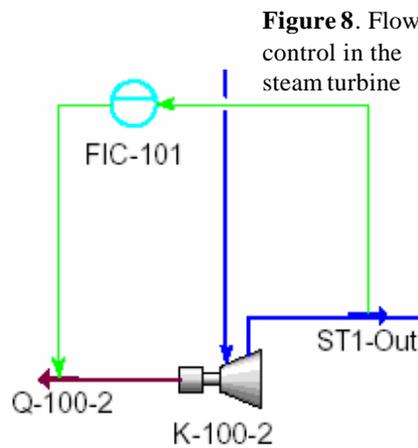
Figure 8. Flow control in the steam turbine

Object: ST1-Out
Variable: Mass Flow
Output: Q-100-2
Action: Reverse
Mode: Automatic
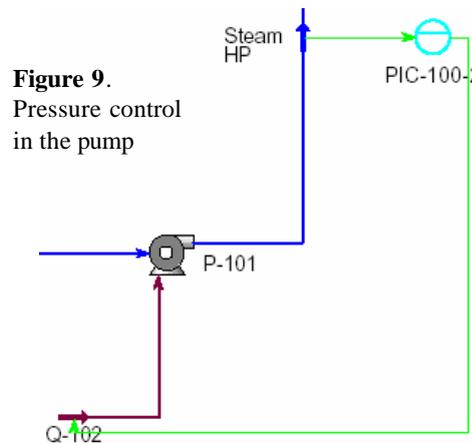K_c: 1
t_i : 10 (600 seconds)

PIC-101

Object: ST1-Out
Variable: Mass Flow
Output: Q-100-2
Action: Reverse
Mode: Automatic
K_c: 1
t_i : 10 (600 seconds)

Figure 9. Pressure control in the pump

4.3.1 Start-up simulation

Next were shown graphic corresponding to different states of the simulation. First of all, the relating graphs are shown to the start-up of the plant. The 5 graphs of the 5 controllers are represented. The average time of stabilization is about 2 hours.

Figure 10. FIC-100 control in start-up

Figure 11. TIC-100 control in start-up
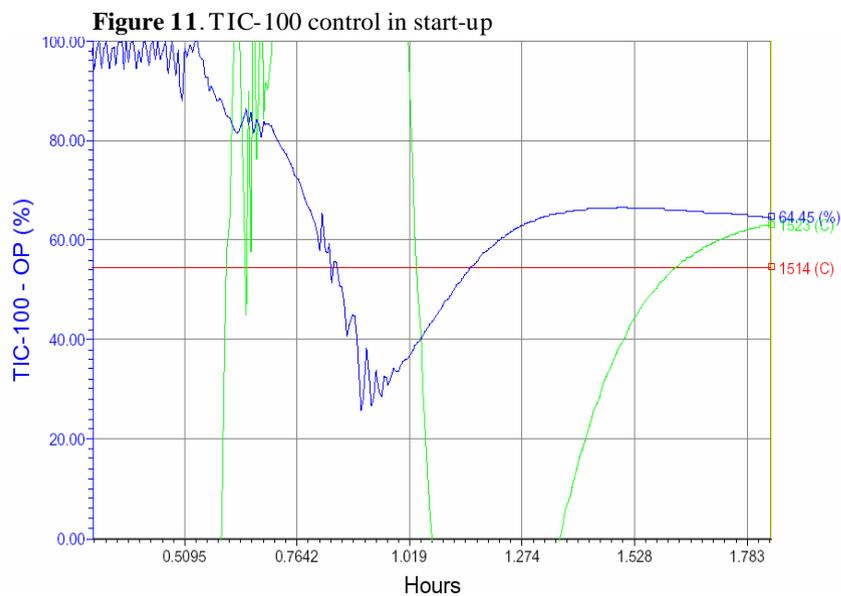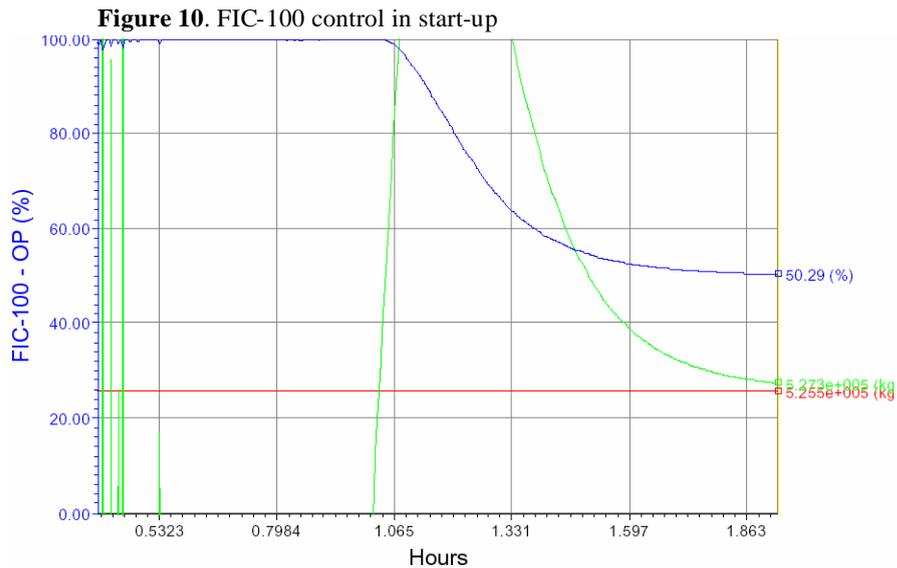
Figure 12. PIC-100 control in start-up
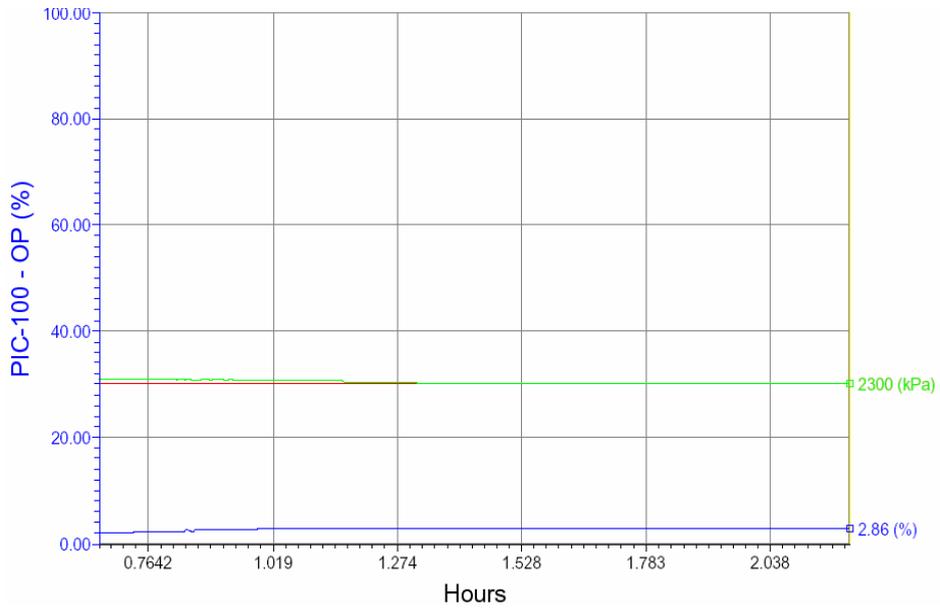
Figure 13. PIC-100-2 control in start-up
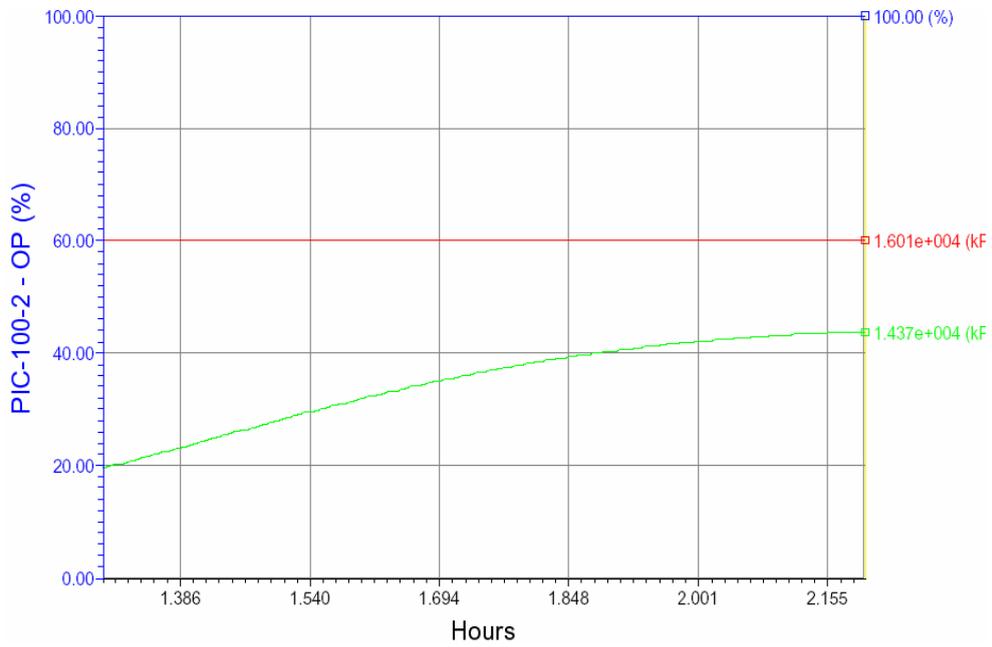
Figure 14. FIC-101 control in start-up
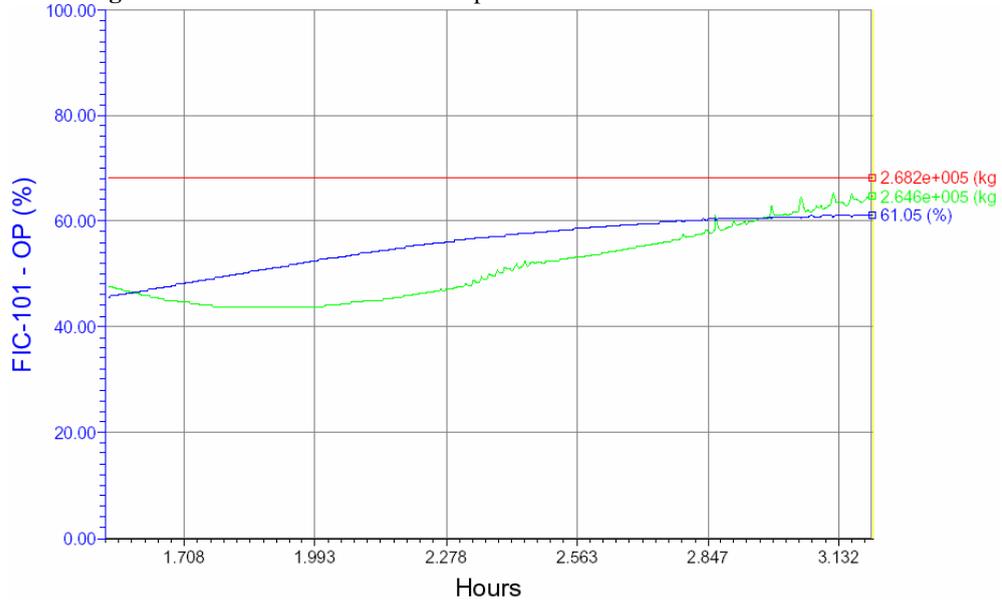
4.3.2 Infinite time (stabilized)

Now I show the corresponding graphs on long time (infinite), where the system is stabilized and the controllers don't suffer any variation. How it is observed once initialized the system and past a very long time the system works correctly.

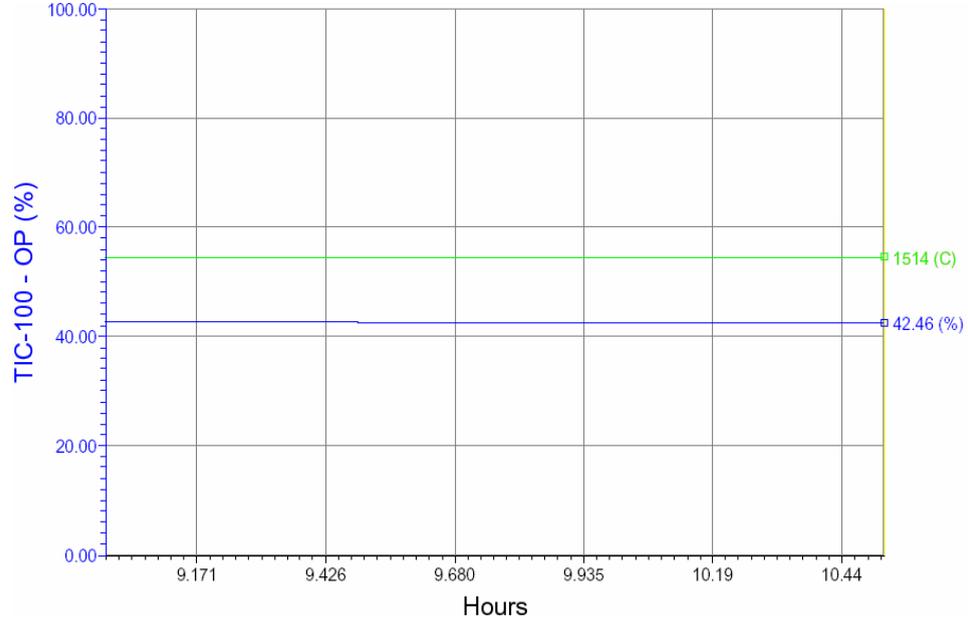**Figure 15**. FIC-100 control in large time.
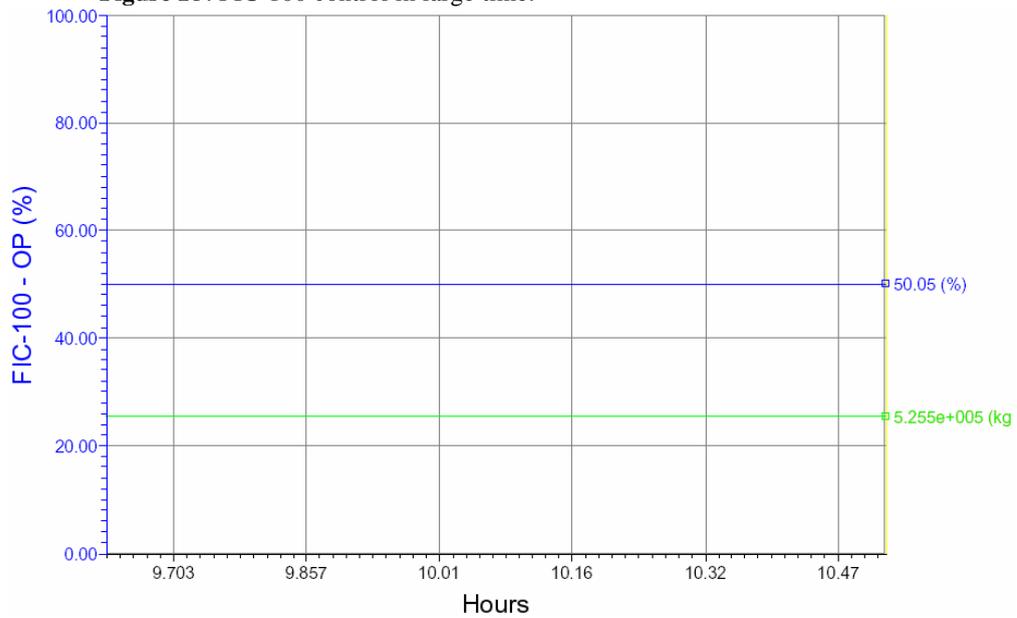
Figure 16. TIC-100 control in large time.

Figure 17. PIC-100 control in large time.
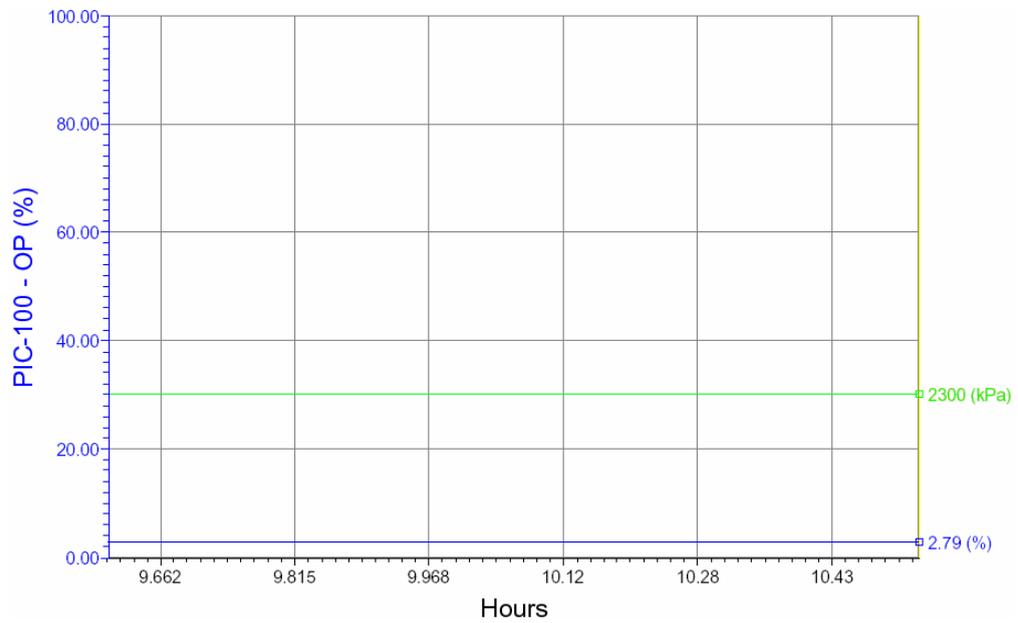
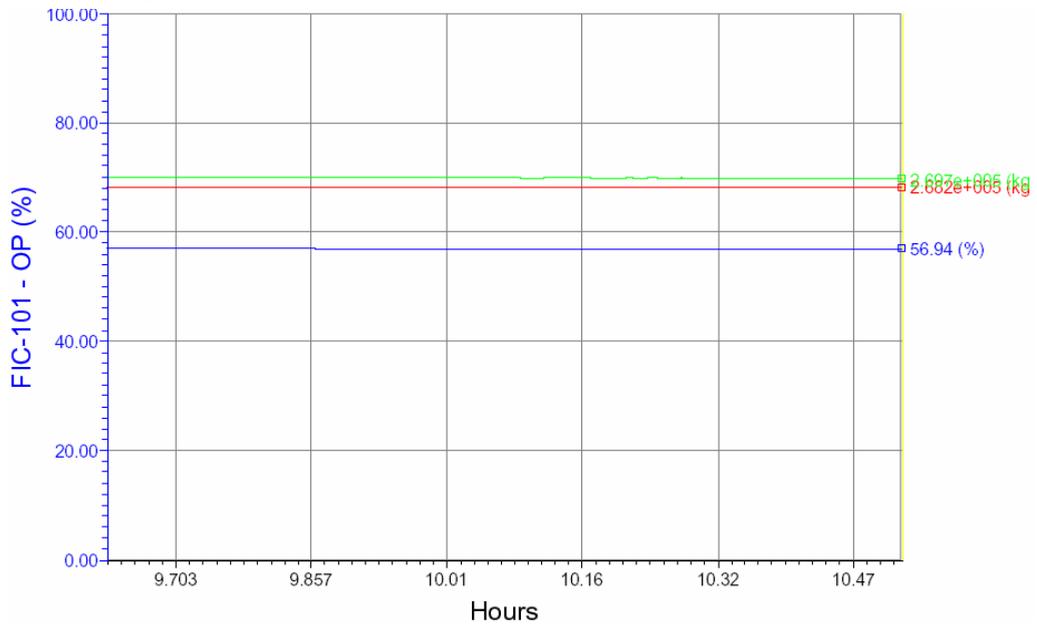**Figure 18**. PIC-100-2 control in large time.
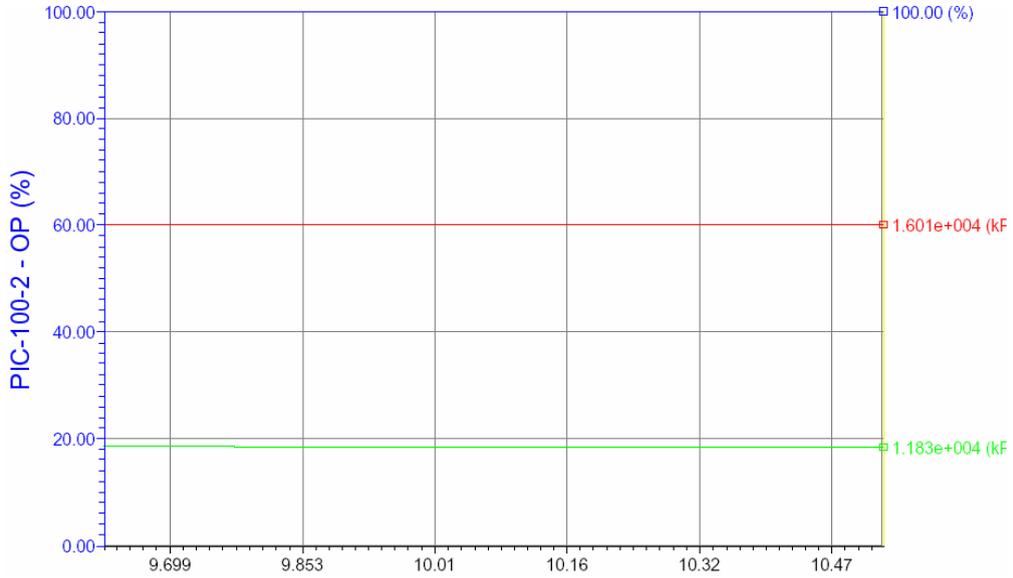
Figure 19. FIC-101 control in large time.

4.3.3 Disturbances in the fuel flow

The graphics that come next go referred to different variations that are made in the feeding of the plant. The first variation corresponds to the variation of the fuel flow. The setpoint changes to **5,25x10^5 kg/h**. to **3,00x10^5 kg/h.**

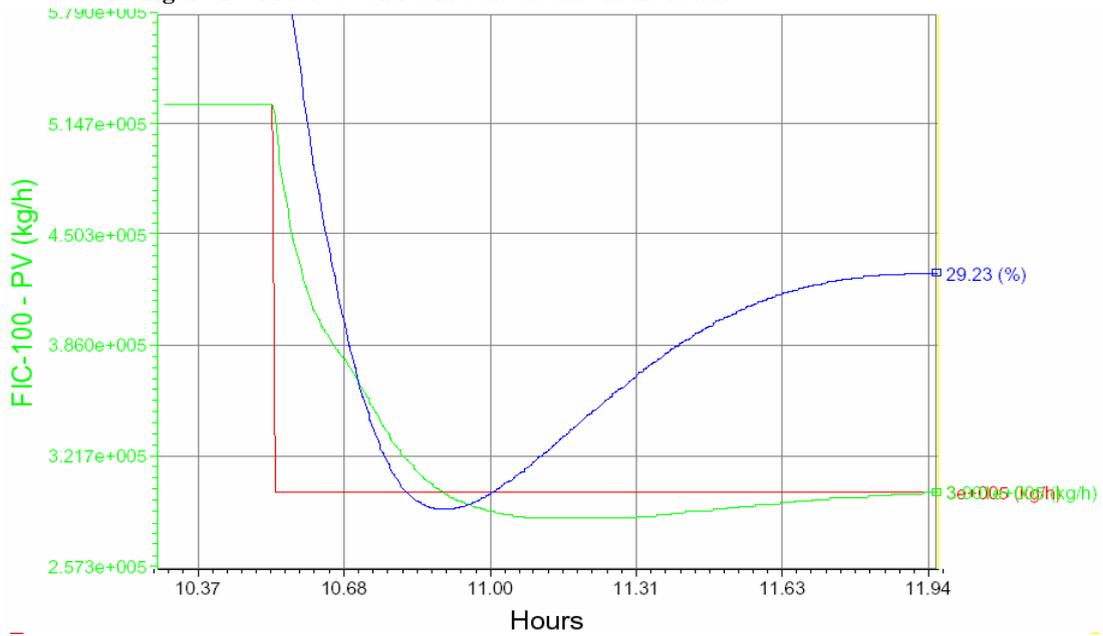**Figure 20**. FIC-100 control in a disturbance in the fuel flow.

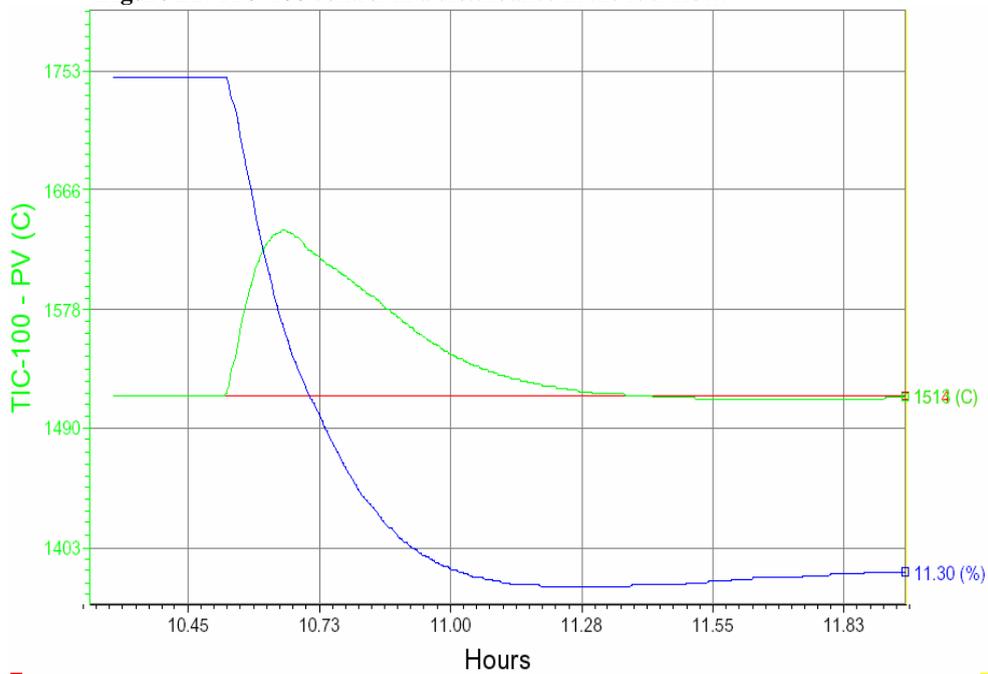**Figure 21**. TIC-100 control in a disturbance in the fuel flow.

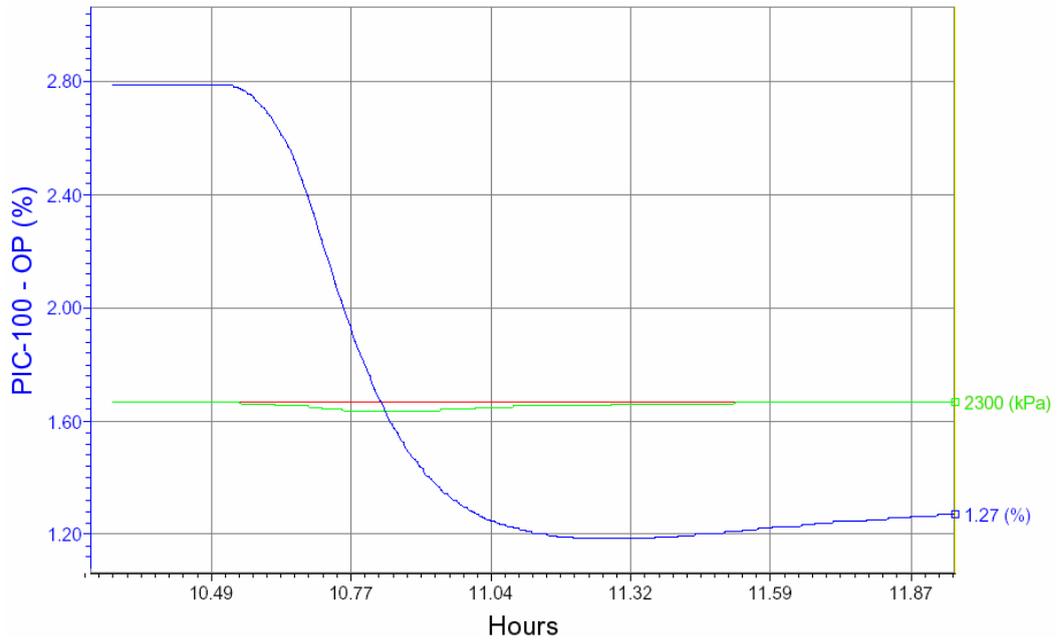**Figure 22**. PIC-100 control in a disturbance in the fuel flow.

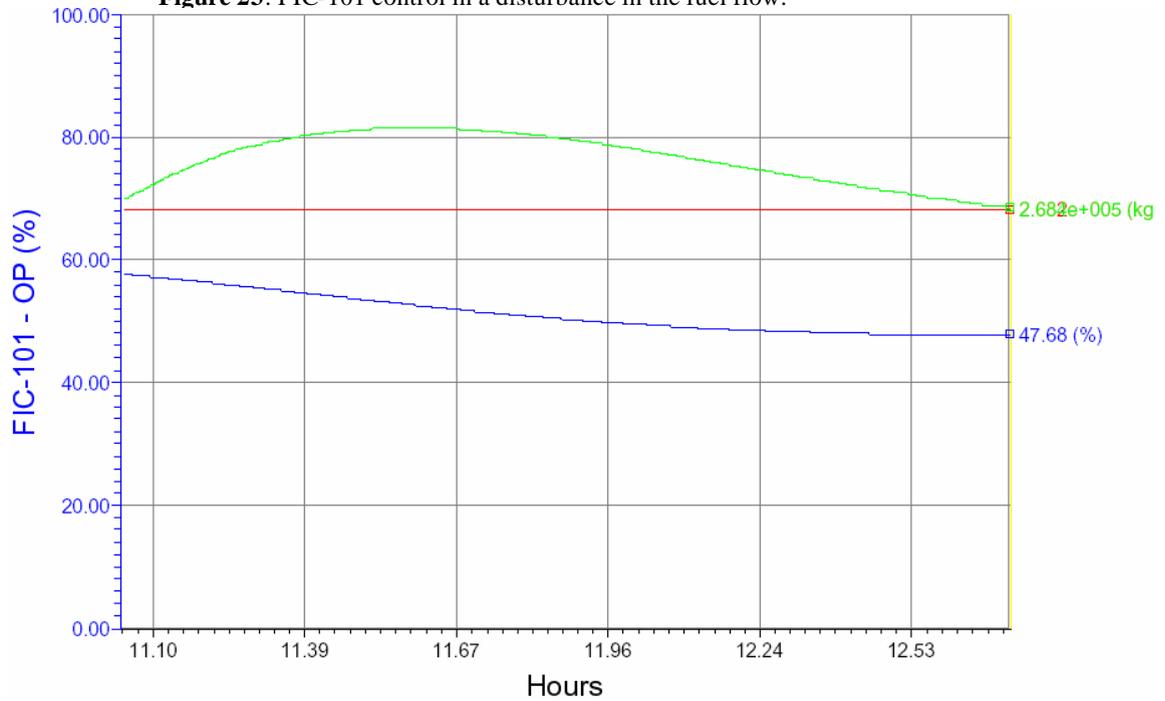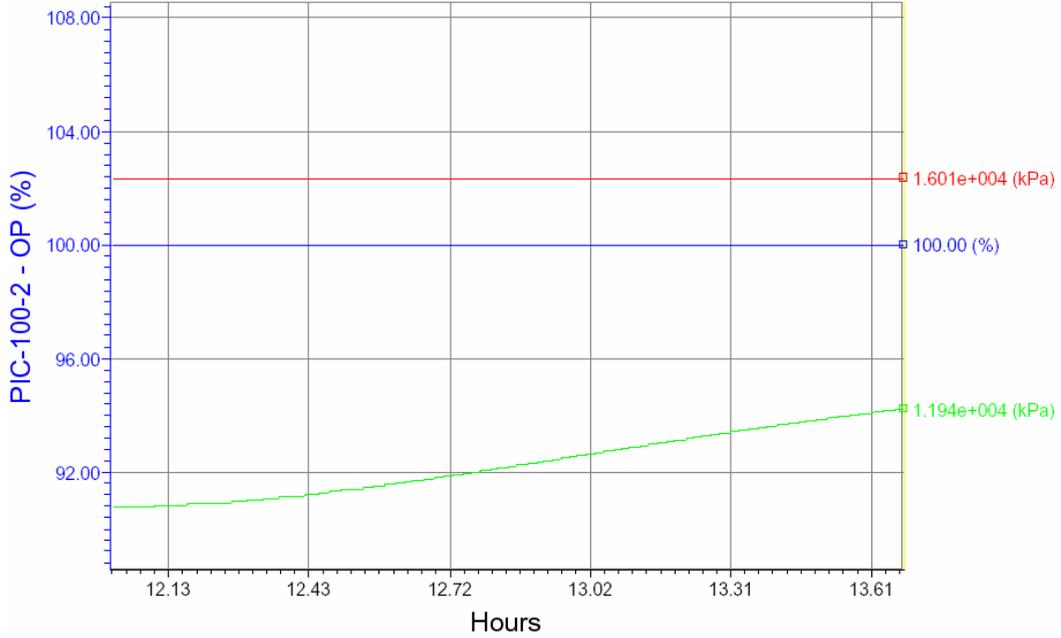**Figure 23**. FIC-101 control in a disturbance in the fuel flow.

Figure 24. FIC-100-2 control in a disturbance in the fuel flow.

4.3.4 Disturbances in the Temperature setpoint

The variation that is shown next is made in the controller's setpoint TIC-100, where I change the setpoint from **1514ºC** to **1490ºC.**

Figure 25. FIC-100 control in a disturbance in the temperature setpoint.

Figure 26. TIC-100 control in a disturbance in the temperature setpoint.

Figure 27. PIC-100 control in a disturbance in the temperature setpoint.

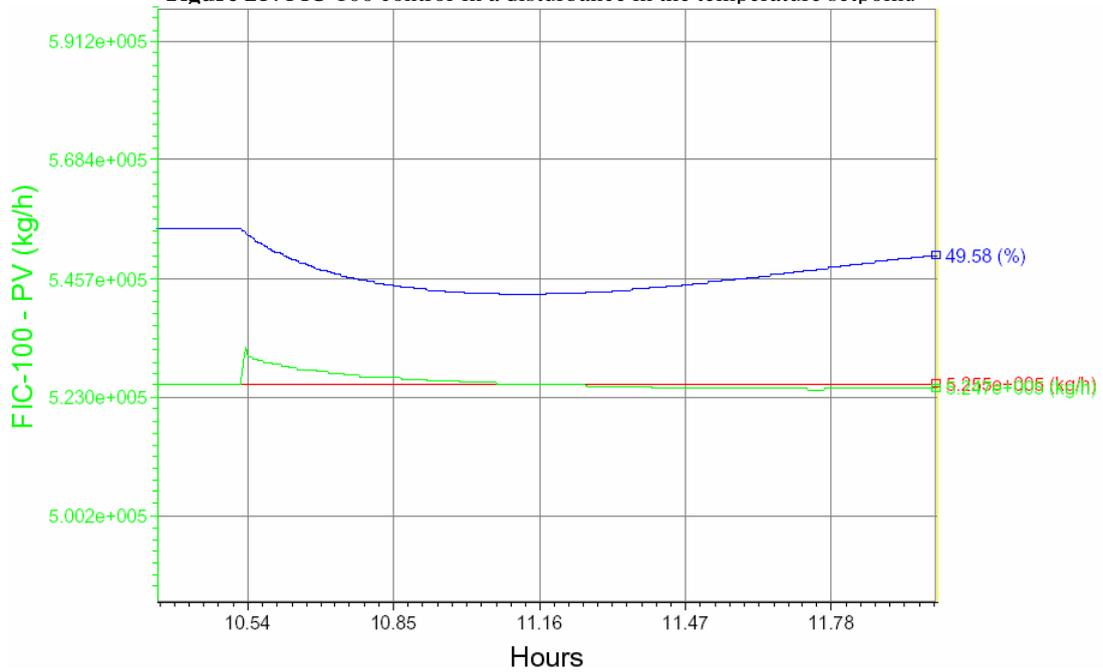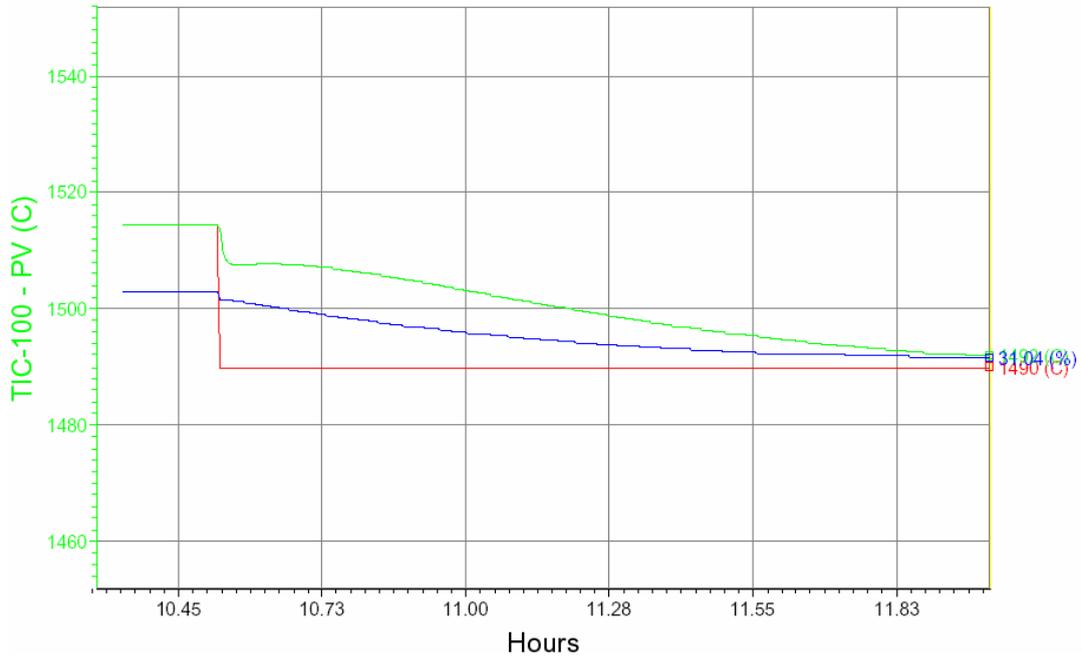**Figure 28**. FIC-101 control in a disturbance in the temperature setpoint.
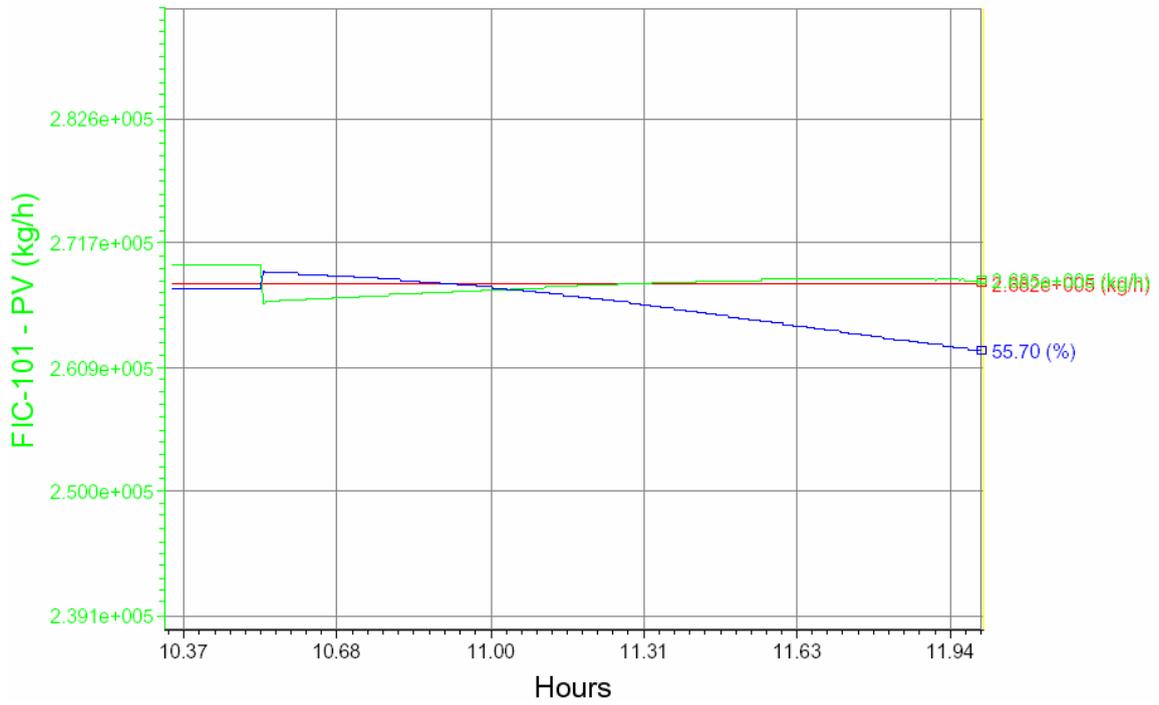
Figure 29. PIC-100-2 control in a disturbance in the temperature setpoint.
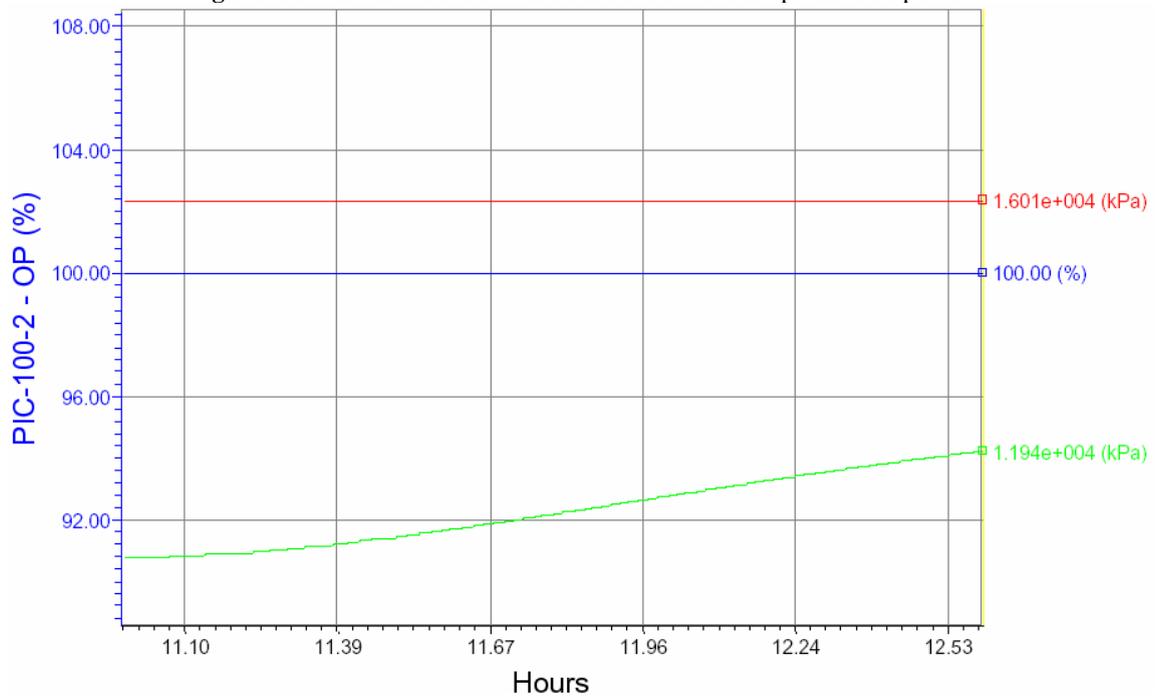
4.3.5 Disturbances in the Pressure setpoint (Gas Turbine)

The variation that is shown next is made in the controller's setpoint PIC-100, where I change the setpoint from **2300 kPa** to **2200 kPa,** in the gas turbine.

Figure 30. PIC-100 control in a disturbance in the pressure setpoint.

Figure 31. TIC-100 control in a disturbance in the pressure setpoint.

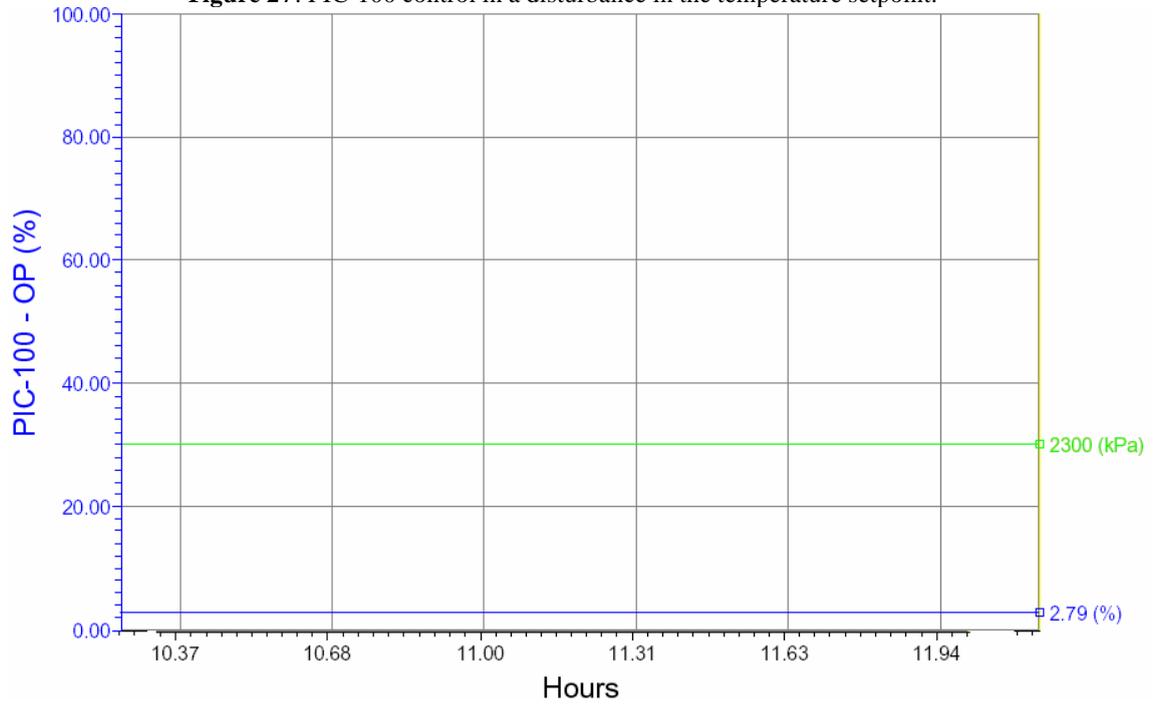

control in a disturbance in the pressure setpoint.

Figure 33. FIC-101 control in a disturbance in the pressure setpoint.

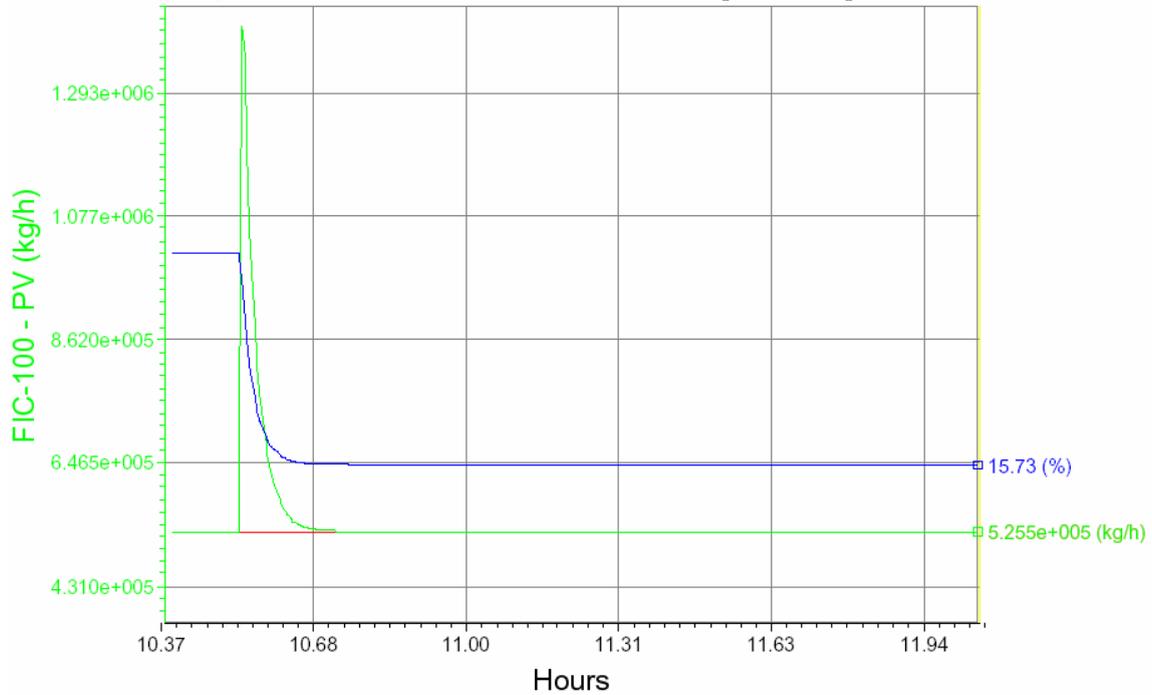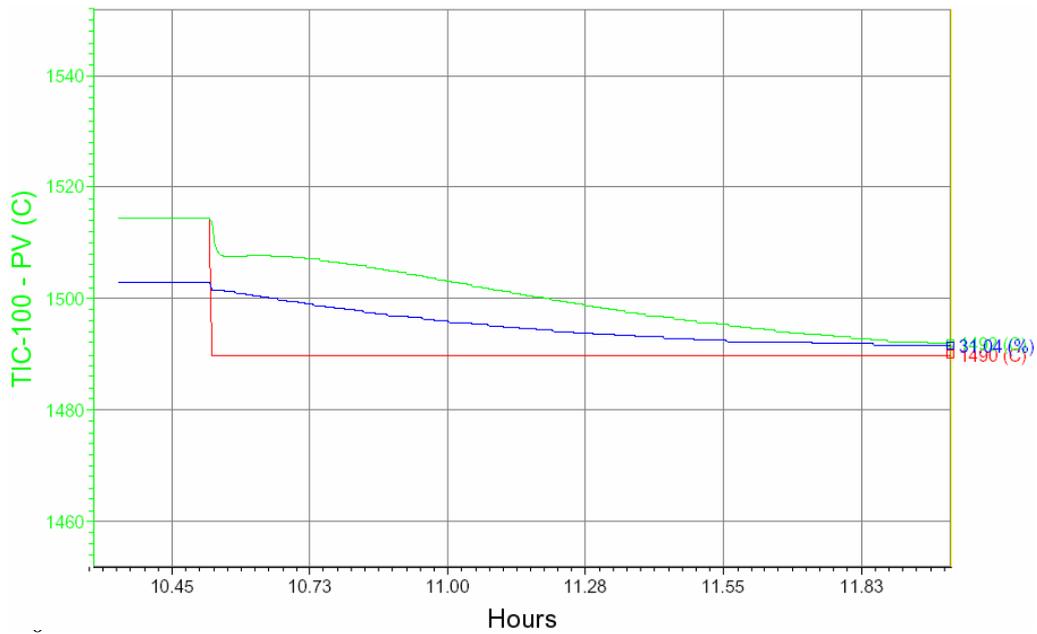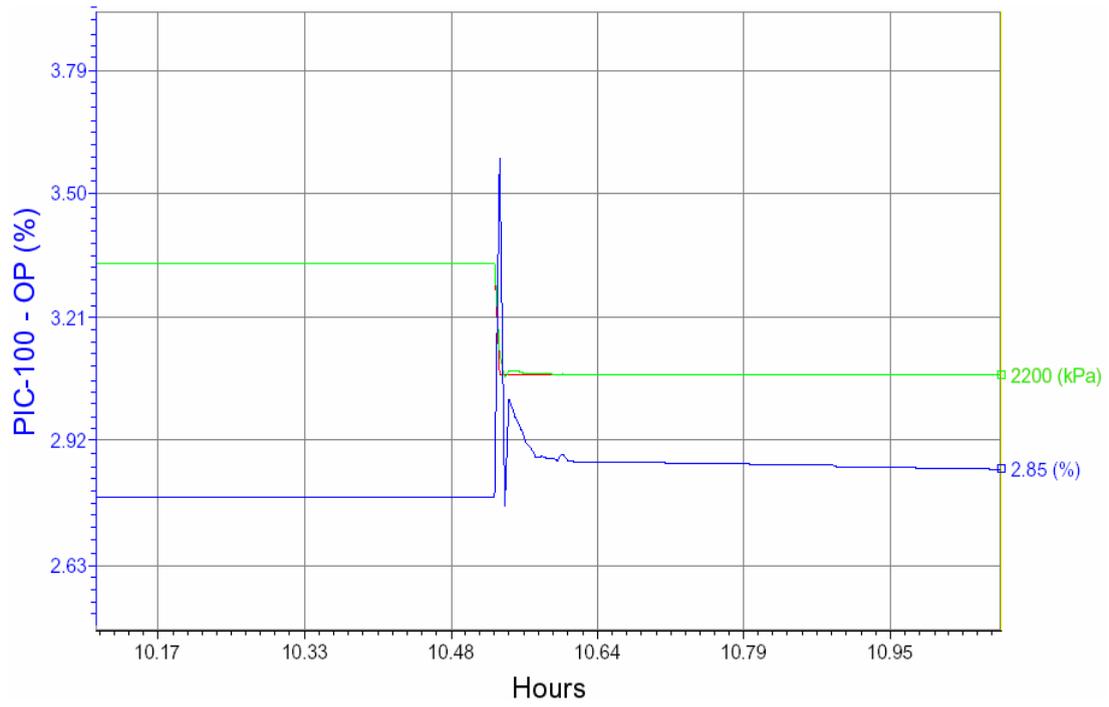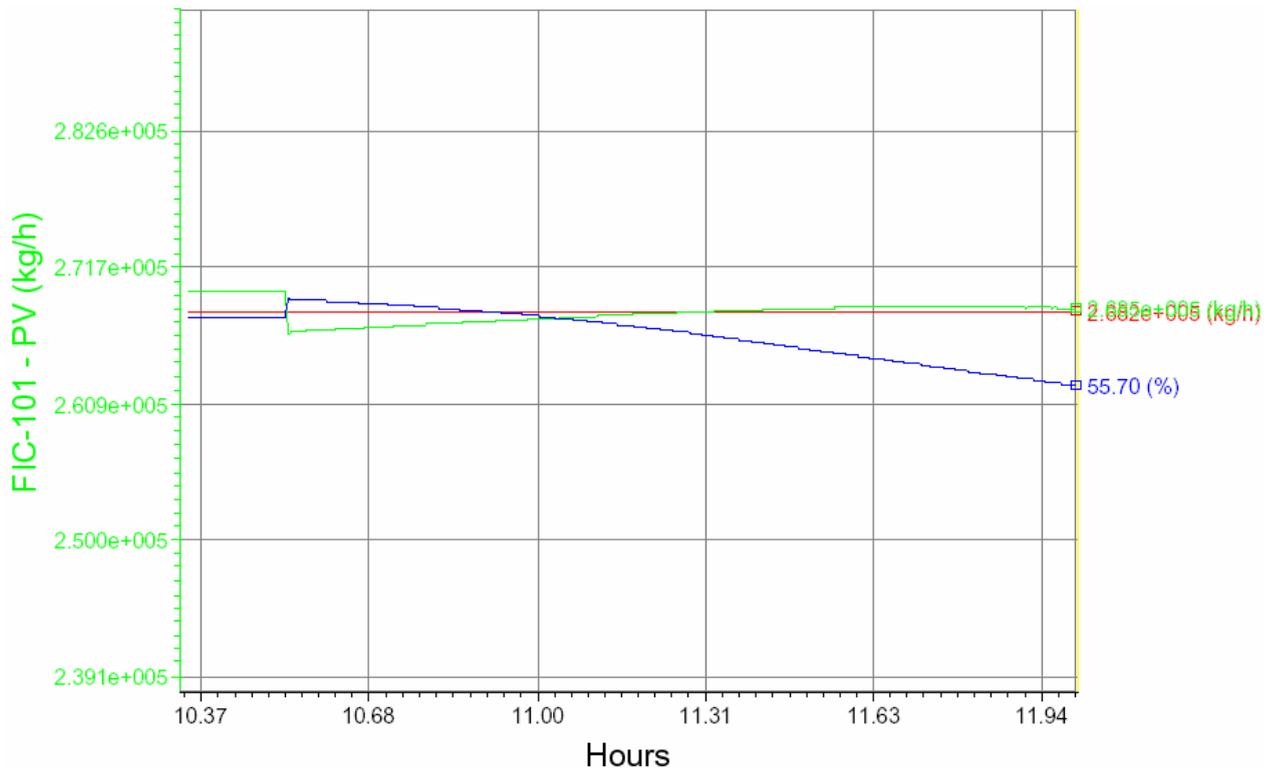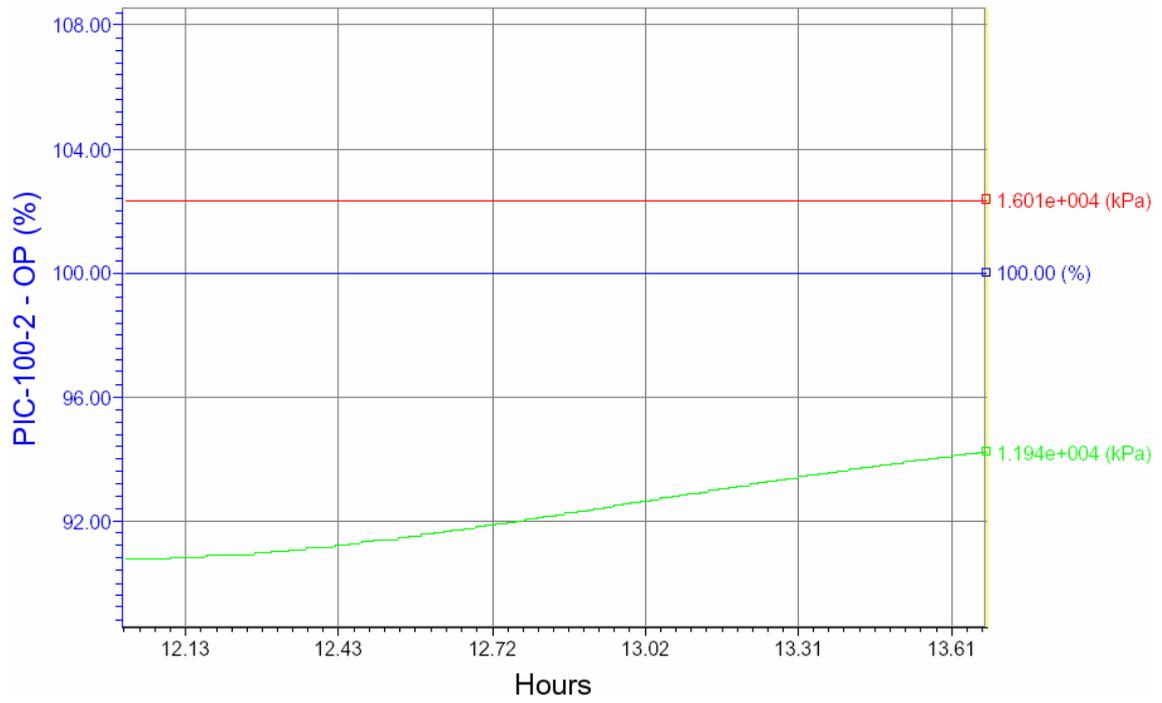**Figure 34**. PIC-100-2 control in a disturbance in the pressure setpoint.

5. *Discussions*

The simulation of this energy plant has been very complicated in dynamic state. The stationary state has not supposed any problem, since all the units operations were much defined and the results have been coherent.

In dynamic mode, the things have been very complicated, since the difficulty of controlling compressors and turbines with the combination of valves amid the process, complicated the control of the pressure in the system. The cycle of vapour has been without a doubt the most complex of this project, since it is a closed cycle. The cycle of gas is an open cycle and although the flow is not constant there are not problems of matter accumulation in the unit operations. On the other hand in the cycle vapour, the problems of matter accumulatio n have been a constant problem during the whole simulation. The only solution to avoid problems of accumulation, it has been oversized the exchangers and to put a tank to have controlled the flow and the pressure of the closed cycle of vapour.

Anyway, it is necessary to clarify that the HYSYS for cycles closed in dynamic way is not very solvent because there are many numeric problems with the equations in those that the thermodynamic pattern is based; a clear example is with what I have commented before on the oversized of the exchangers. HYSYS neither is very good simulator with the polymers, and for that reason I believe that neither it is designed for simulation of energy plants. But HYSYS is very solvent and useful to simulate hydrocarbons.

To see the complications that I have had to simulate the dynamic way, next I expose the quantity of alternatives that I have simulated to be able to solve the problems of pressure of the system. Of the first alternatives that I proposed it was to control the entrance flow with a Spreadsheet (HYSYS), but there were many interactions among the controllers of temperature and pressure that controlled in cascade these same flow controllers (to see figure 35).

Figure 35. Alternative to control the gas cycle.
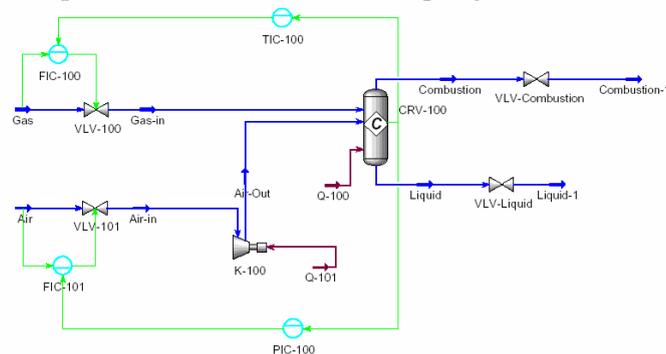
Another alternative was control the only the temperature of the reactor, removing the valves on the process to avoid lost of pressure that cause problems in the compressor and in the turbine.

I believe that for the simulation of this process, software has possib ly been better. For example with MATLAB software, has not possibly been so complicated with the topic of the accumulation of vapour in the units.

As part of improvement of this process, one can say that another alternative that has been proven to be able to stabilize the cycle of vapour, has been just controlling the pressure different over the turbine by manipulating the turbine work, only a reasonable fast P controller is required, increased work give larger pressure difference, with $K_c = 1$ and the integral time is not needed. Then the liquid hold-up in the cooler is not needed to be controlled since the hold-up is much larger than other hold-ups in the steam cycle. No control of the vapour hold-ups are needed, since they are self-regulating.

6. Economic Study of the process

6.1 Introduction

A capital investment is required for any industrial process, and determination of the necessary investment is an important part of a plant design project. The total investment for any process consists of fixed capital investment for physical equipment and facilities in the plant plus working capital which must be available to pay salaries, keep raw materials and products on hand, and handle other special items requiring a direct cash outlay. Thus, in an analysis of costs in industrial processes, capital-investment costs, manufacturing costs and general expenses including taxes must be taken into consideration.
The purchased cost of each piece of process equipment is estimated from published cost data or from appropriate manufacturers´ bulletins. Regarding to the source, the published purchased-cost data must be corrected to the current cost index.
The probable error of the fixed-capital investment regarding the cost estimating method used is about ±30 percent.

6.2 Operation Costs

The general equation for the calculation of the operation costs for a cogeneration plant is:

$$C_{CG} = Ea \cdot v_e{}' + Qa \cdot v_q{}' + E_{CG} \cdot (v_{cg} + v_m)$$

Where **Ea** and **Qa** are respectively the electricity and the auxiliary heat that the plants needs and **ve, vq** are the prices for electric and thermal MW. The last term makes reference to the additional cost that supposes to work with a cogeneration plant.

Assumptions
- Complete combustion is supposed in the boiler
- The purchase price and sale of the electricity is the same one (ve=ve ')
- The prices have been extracted of the web except the cost added due to the cogeneration existence (vm) that has been obtained of the papers of Spanish subject.
- The entire operations take place in units is adiabatic.
- The mechanical yield that the teams (bombs, turbine and compressor) it is of 100% and since the net work of the plant is zero, that is to say, the whole work generated in the turbine wastes away in the bombs and the compressor, there are not an excess neither extra demand of electricity. This way, Ea=0.

For the vq' calculation the equation has been used:

$$v_q{}' = Price\ _{natural\,gas} / PCI\ _{gas\,natural}$$

6.3 Investment costs

The total capital investment is the sum of the fixed capital investment and the working capital. The fixed capital investment is the capital needed to supply the necessary plant manufacturing facilities, and the working capital is the one needed for the operation of the plant;

$$TCI = FCI + WC$$

Where TCI is the total investment of capital ($), FCI is the investment of fixed capital ($) and WC makes reference to another type of costs (Working capital or necessary capital for the initial operations of the plant). in turn, FCI is defined as;

$$FCI = Direct\ costs + Indirect\ Costs$$

The direct costs are divided in internal (onsite) and external (offsite). Each one of these it can be removed in costs for different activities.

There are several methods for estimating the total capital investment. In this project, the method used has been the proposed by *Peters & Timmerhaus*: percentage of delivered equipment cost. This method for estimating the total-capital investment requires determination of the delivered-equipment cost. The other items included in the total direct plant cost are then estimated as percentages of the delivered-equipment cost. The additional components of the capital investment are based on average percentages of the total direct plant cost, total direct plant costs or total capital investment. These are the items that *Peters & Timmerhaus* method takes into account in the estimation of the total capital investment:

Table 15. Terms that composes the investment of fixed capital.

DIRECT COSTS	
Intern Costs (onsite)	
Purchase equipment	E
Purchased installation	47 % E
Instrumentation	18 % E
Piping	66 % E
Electrical installation	11 % E
Extern Costs (offsite)	
Buildings	18 % E
Yards improvement	10 % E
Services facilities	70 % E
Land	6 % E
INDIRECTS COSTS	
Engineering (Eng)	33 % E
Construction (Const)	41 % E
Contractor's fee	5 % (Direct + Eng + Const)
Contingency	10 % (Direct + Eng + Const)
WORKING CAPITAL	
Working capital	15 % TCI

Once the different items to be taken into account have been briefly described, the purchased equipment cost is estimated and then multiplied by the correspondent percentage of each item. These percentages or ratio factors have been taken from the book *Chemical engineering series* by Peters and Timmerhaus. These percentages are shown in table X.

First of all the cost of the purchase of teams has been calculated (E), starting from the costs of purchase of each module or unit (turbines, compressors, exchangers…). Then, the costs of each unit are obtained from some reference graphics [2] that provide the unitary cost in function of the capacity of each one (flow, power…). The obtained results are shown in the following table:

Table 16. Costs of the units operation.

Unit Operation	CAPACITY (MW)	COST ($)
Pump	3.22 – 4.66	50000 – 60000
Combustion reactor	2.03	210000
Compressor	25.5 – 1.46	2200000 – 506000
Condensation	4.38	12500
Evaporator	2.75	460000
H. R. S. G.	35	1000000
Gas Turbine	46.2	2800000
TOTAL Cost (E)		**7838500**

Now it's possible to obtain the values of direct costs, indirect costs and capital working. These results are shown in the next table, number X

Table 17. Direct and indirect costs and working capital

COSTES DIRECTOS ($)	
Intern Costs (onsite)	
Purchase equipment	8638500
Purchased installation	4060095
Instrumentation	1554930
Piping	5701410
Electrical installation	950235
Extern Costs (offsite)	
Buildings	1554930
Yards improvement	863850
Services facilities	6046950
Land	518310
TOTAL Direct Costs =	**21250710**
COSTES INDIRECTOS ($)	
Engineering (Eng)	33 % E
Construction (Const)	41 % E
Contractor's fee	5 % (Direct + Eng + Const)
Contingency	10 % (Direct + Eng + Const)
WORKING CAPITAL ($)	
Working capital	15 % TCI

Finally, starting from the previous equations and of the extracted data of the previous charts, you can calculate the final value of the investment of the Gas Power Plant.

FCI = 35,3 $ millions = 40,3 € millions = 306,3 NOK millions

TCI = 41,5 $ millions = 47,5 € millions =361,1 NOK millions

7. Conclusions

The first thing is to say that the goal or objective of the project has been successfully achieved. With the designed plant it has been possible to simulate the gas power plant.

The simulation with HYSYS® has been very complicated in dynamic mode with the steam closed loop. The simulation of the steam cycle has taken me many problems referred to the accumulation (Hold-Up), where I have had to oversize the units operation to avoid problems with the pressure in the closed cycle. In reference to the simulation, it is necessary to say that the election of an adjustable thermodynamic package to this type of utility (gas power plant), it has been complicated, since the data obtained by the simulator didn't resemble the extracted real data of the DOE *(Department of Energy USA)*. Another annotation is that the efficiencies of the compressor, Gas turbine, steam turbine and pump are very important for the final profit. Because if we get a turbines and compressors with a high efficiency, the result of the production energy increase much more than a normal efficiency; but there's a problem because these units operations needs a high investment.

With respect to the materials in the entrance of this plant, the quality of the fuel is not something primordial. You can sacrifice fuel quality (and it is this way cheaper), since controlling the flow of air, one can obtain the optimal temperature for the process.

The plant designed in this project is a small plant. Only the most important elements of it have been taken into account for it. However, although the simulation in HYSYS® has been carried out in steady state and dynamic mode, many problems to run it have come across. Thinking about it is possible to make an idea of how many difficulties involves the design of a real plant and start it up.

Finally, when gathering information for the project many sources were consulted: books, articles, papers, notes and internet. Now that the project is finished, compared to the other processes found in these sources, this work may seem quite simple. And it is true. This is not much more than a basic scheme for a real process. However, basic is not synonym of easy. The beginning of things is usually the most difficult part, which needs more thinking and takes more time. Anyway, this project can be a good approach to study what a real Gas Power Plant should be.

In reference to the attached economic study, many advantages that it has the use of this technology, a series of inconveniences that we need to take in consideration exist; since this process requires of a substantial investment that many companies are not in disposition of investing to be a project that it doesn't increase its production capacity, although it is highly favourable. And the main mechanical problem that is, is referred to the life of the turbines of which this process is composed, since it is relatively low; and that hinders their investment and their maintenance. Talking about the economical part, is important to remark that for a real plant the operating costs and the investment required must be more accurate.

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Appendix HYSYS®
Gas Power Plant