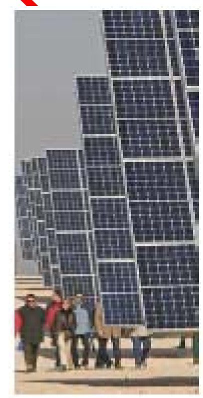
# NSF LARGE FACILITY WORKSHOP

## San Diego, CA May 4 – 7, 2010

***ENERGY SUPPLY AT REMOTE LOCATIONS AND ALTERNATIVE SOURCES***



- Site Evaluation Criteria
- Case of Study: Paranal Observatory
- Case of Study: ALMA Observatory
- Background Material

# APPROACHING TO SITE EVALUATION: PRELIMINARY CONSIDERATIONS

## ***Evaluation Steps:***

•Site characteristics (mainly environmental) like temperature, Relative Humidity, Solar Radiation, Wind strength, Altitude.

•Remoteness from sources of energy like Grids, Fuels.

•Type of operation, Island Mode or Mains Connected.

•Logistic and transportation facilities (roads, airports,…).

•Site power demand and electrical requirements, Active Power, Reactive Power, Power Factor, Frequency, Electrical guaranteed parameters.

•Availability of Renewable energies (solar, wind, water, geothermal and so on…).

# APPROACHING TO SITE EVALUATION: THE "LIFE CYCLE COST ANALYSIS"

Once the operation mode has been defined (Island or Main) a restricted number of solutions shall be considered in a comparative cross table, where technical and economical aspects will be compared and will produce a final ranking, also known as "Life Cycle Cost Analysis". Here less convenient solutions will be discarded.

**Overview of the life cycle costs for alternative electric power supply based on a 10Y period**

| Cost item | Power Supply Alternative | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3612 diesel Genset | Connection to SIC Grid | 3612 gas Genset | Gas turbine Nat. Gas | Gas turbine LPG | Wind Turbine & SING Grid | Wind Turbine & SIC Grid | Fuel Cells |
| | USD | USD | USD | USD | USD | USD | USD | USD |
| Operat.&Maint./year | 2.265.417 | Excluded | 1.572.274 | 1.686.525 | 1.915.540 | Excluded | Excluded | Excluded |
| Operat.&Maint./10 years | 22.654.167 | Excluded | 15.722.742 | 16.865.255 | 19.155.400 | Excluded | Excluded | Excluded |
| Investment | 2.219.820 | Excluded | 4.592.094 | 3.180.000 | 3.180.000 | Excluded | Excluded | Excluded |
| Grand total, 10 years | 24.873.987 | Excluded | 20.314.836 | 19.045.255 | 21.335.400 | Excluded | Excluded | Excluded |
| Energy cost, USD/kWh | 0,1893 | Excluded | 0,1546 | 0,1449 | 0,1624 | Excluded | Excluded | Excluded |
| Ranking, based on energy cost | 4 | | 2 | 1 | 3 | | | |
| Relative cost comparison (Less expensive alternative=1) | 1,306 | Excluded | 1,067 | 1,000 | 1,120 | Excluded | Excluded | Excluded |

# ENERGY SUPPLY AT REMOTE LOCATIONS

## A Case of Study:
## Paranal Observatory in Chile

# Paranal Power Plant

***Site Characteristics:***

•Isolated location, 120 kms far from Antofagasta, at 2800 m a.s.l.

•Power demand raised during last 10 years from 500 kW to 1400 kW.

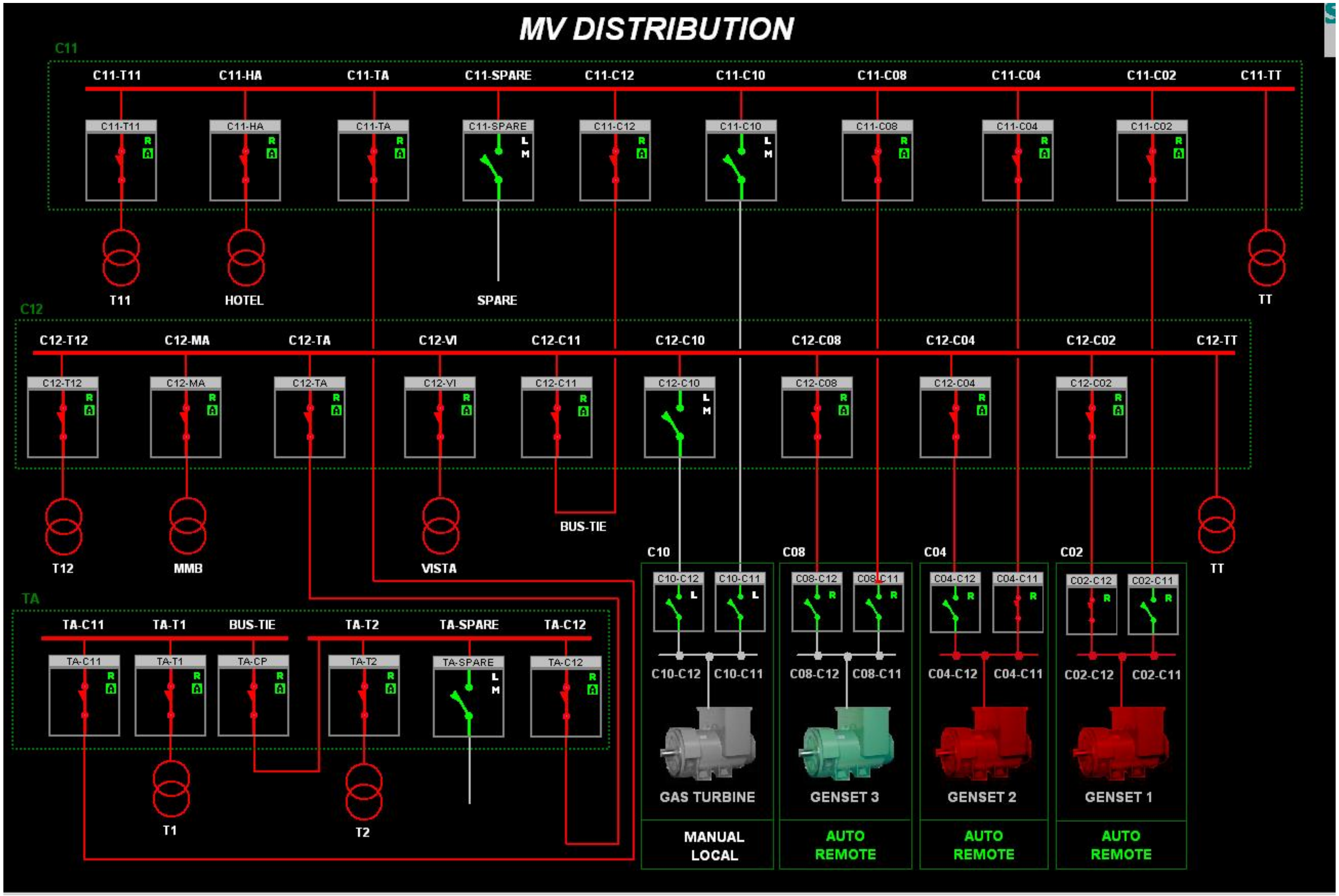
•Black-out hourly operational cost within 5.000 and 40.000 US$.

•Primary distribution grid realized by underground cables at 10 kV nominal voltage and extended for 6 kms all around the site. A set of 27 MV Switchboards is part of the grid.

•Secondary distribution grid realized after local step-down transformers and operated at 230 and 400 V.

•Before 2007 power production realized by means of 3 diesel units, 800 kW each.

# Paranal Power Grid



# Paranal MF Turbine

## ***The New Solution:***

•Due to urgent needs to improve reliability in 2007 it has been decided to install a multi-fuel turbine generator. The choice was a result of an accurate investigation in the market, finding the best product.

•The final choice remarked the need to maintain an isolated system from the Chilean grid, far and weak in this area.

•The new MF Turbine allows independence in fuel operation strategy, being able to run 5 types of fuels without stopping the machine.

•The new MF Turbine allows possibility of cogeneration and heat recovery.

•The MF Turbine minimize the maintenance stops and improves the reliability of the system.

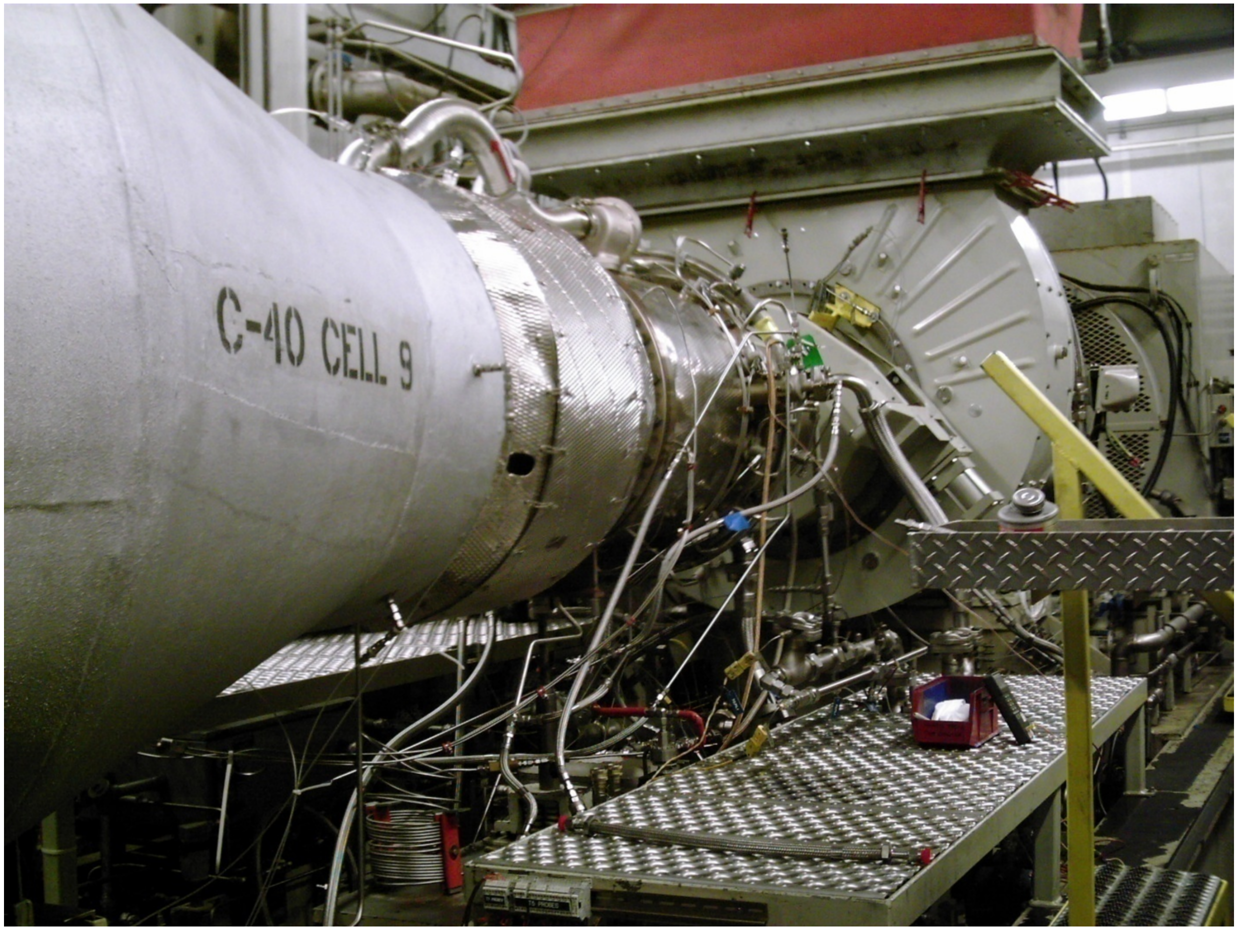
# Paranal MF Turbine

## The C40 choice was due to:

- The size and design, 2600 kW.
- Wide number of unit in operation worldwide.
- Multi-fuel operation possibility.
- Fast manufacturing time in compliance with project schedule.
- Limited inversion cost.
- Cogeneration possibility.

| | GT Gas Natural USD/kWh | GT LPG Butano USD/kWh | GT Diesel USD/kWh |
|---|---|---|---|
| 2005 | 0.15 | 0.17 | 0.21 |
| 2008 | 0.23 | 0.34 | 0.39 |

# Paranal MF Turbine



# Paranal MF Turbine

## ***General Description: Design Data***

| | | |
|---|---|---|
| **Power** | kWe | 2615 (3515@ISO) |
| **Gear Box Ratio** | -- | 14944:1500 |
| **Heat rate** | kJ/kW-hr | 12910 |
| **Exhaust flow rate** | kg/hr | 67000 |
| **Exhaust temperature** | ºC | 435 (a FL) |
| **NOx reduction** | -- | No |
| **Generator Voltage** | V | 10000 |
| **Turbine weight** | Kg | 2175 |

# Paranal MF Turbine

## ***General Description: Emissions***

This is one of the most important requirements, even if the Chilean Law does not apply in Paranal territory. Nevertheless EU standards and EED 2001/80/CE have been applied.

With LPG the following values are guaranteed (15% Oxygen):

| Measured | Limits |
|---|---|
| • $CO_2$ 1.8 % | --- |
| • CO 25 $mg/Nm^3$ | 100 $mg/Nm^3$ |
| • NO 351 $mg/Nm^3$ | --- |
| • $NO_x$ 373 $mg/Nm^3$ | 400 $mg/Nm^3$ |

# Paranal MF Turbine

## ***The Cogeneration:***

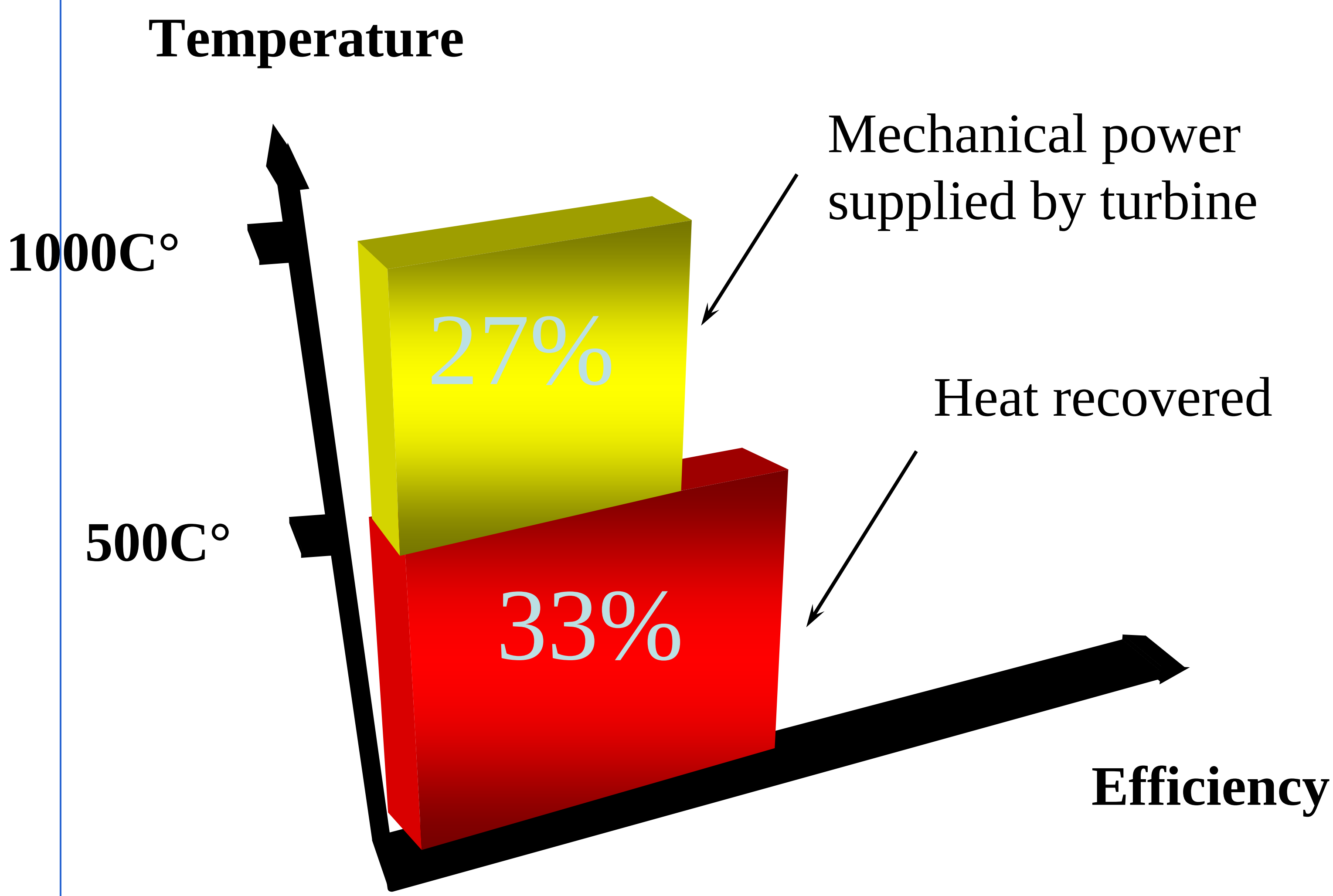
By definition Cogeneration means simultaneous production of heat and mechanical power. In this case

→ Heat is a thermal energy consumed at site, estimated 500 kWt max.

→ Mechanical energy is converted in electrical energy to be used at site, 2600 kWe max.

Both types of energy are available in the gas turbines, and in our application heat recovery has been used to heat domestic water.

# Paranal MF Turbine

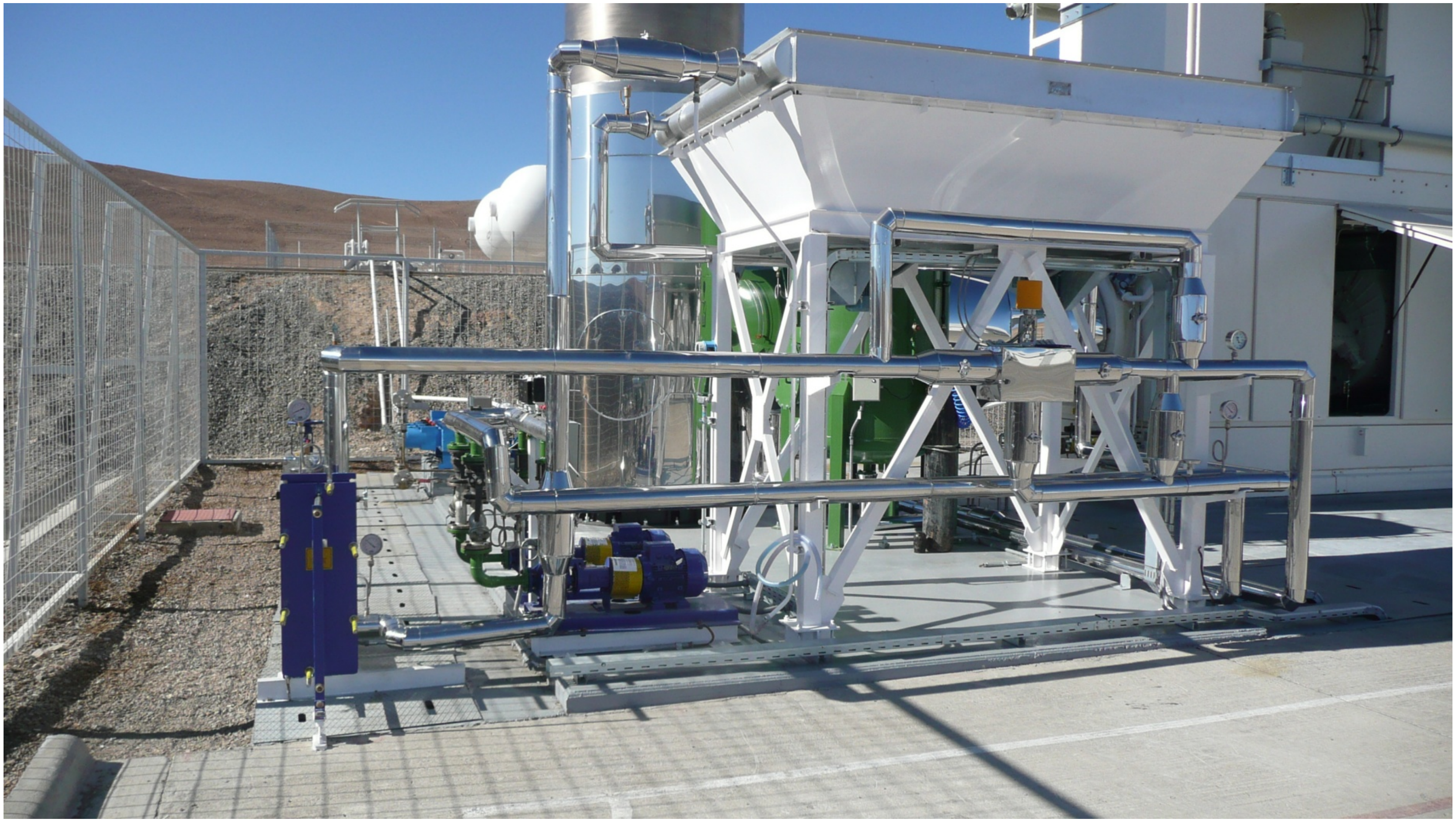


# Paranal MF Turbine

## ***General Description: Package and Stack***


# Paranal MF Turbine

## ***General Description: HR and Exchanger***

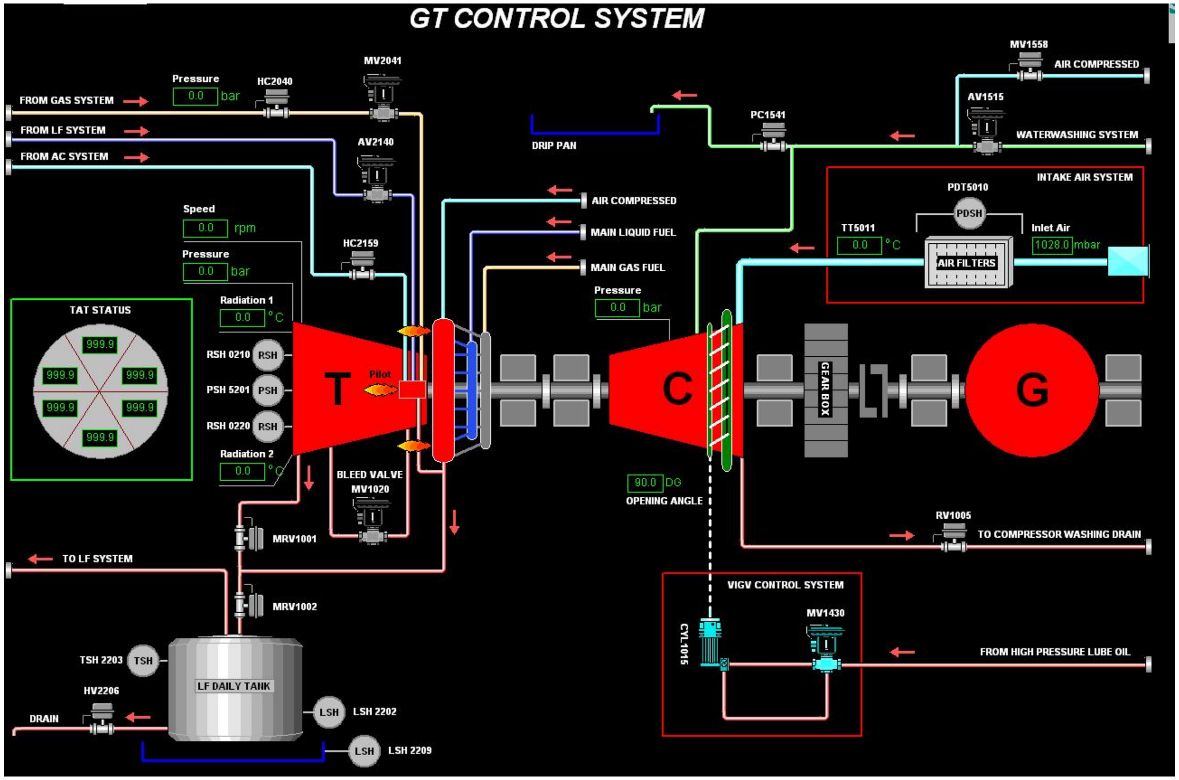


# Paranal MF Turbine

## ***General Description: Alternator & Air Filters***

Paranal MF Turbine

## *General Description: Control System*




# Paranal MF Turbine

***General Description: construction & manpower***

It started in early 2007 with contract signature and with detailed engineering. Civil works started in April 2007 with the following resources:

- 50000 kg concrete
- 10000 kg steel
- 50 workers & technicians
- 500 mt extension for earthing grid
- 130 mt extension for double-wall trench
- Use of heavy machinery and cranes
- EU Atex standard for electrical installation

# Paranal MF Turbine

## ***General Description: construction's overview***

Digging works…

..Basement completed…

# Paranal LPG Plant

## ***Fuel supply & stowage: 5 types of fuels***

Fuels allowed to be burnt in the turbine are:

- LPG in whatever mix (butane-propane)
- Diesel # B
- Kerosene
- Natural Gas
- Naphtha

# Paranal LPG Plant

***General Description: Design Data***

- 227.000 liters nominal capacity, 193.000 liters operational capacity (factor 0.85)
- Double feeder pumps to tanks
- Double feeder pumps to turbine
- Independent return line to tanks
- Redundant pressure monitor in all lines by means of Siemens Sitrans P
- On-line tank level measurement

# Paranal LPG Plant

# Paranal LPG Plant

# ENERGY SUPPLY AT REMOTE LOCATIONS

## A Case of Study:
## ALMA Observatory in Chile

# ALMA Power Plant

***Site Characteristics:***

•Isolated location, 160 kms far from Calama, at 2900/5200 m a.s.l.

•Power demand estimated in the range 5000 kW to 7000 kW.

•High Black-out hourly operational cost.

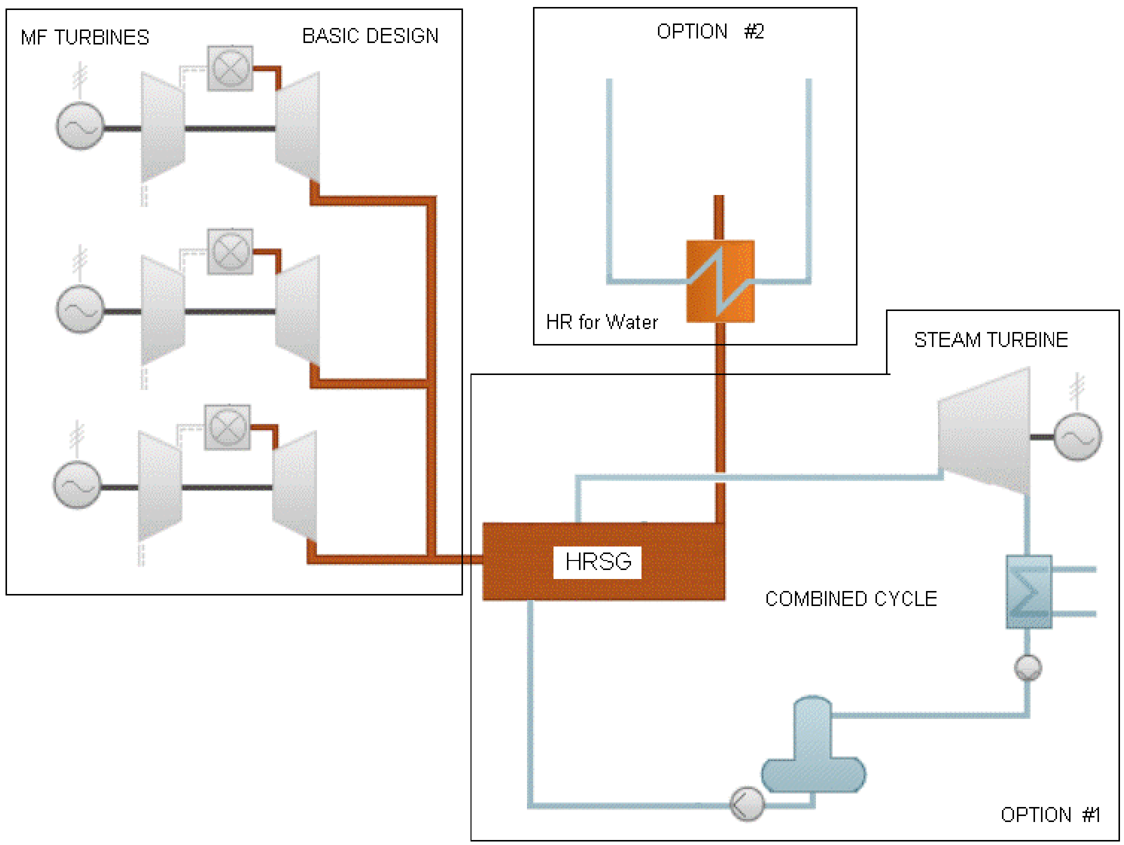
•Primary distribution grid realized by underground cables at 23 kV nominal voltage and extended for 50 kms all around the site. A set of 42 MV Switchboards is part of the grid.

•Secondary distribution grid realized after local step-down transformers and operated at 230 and 400 V.

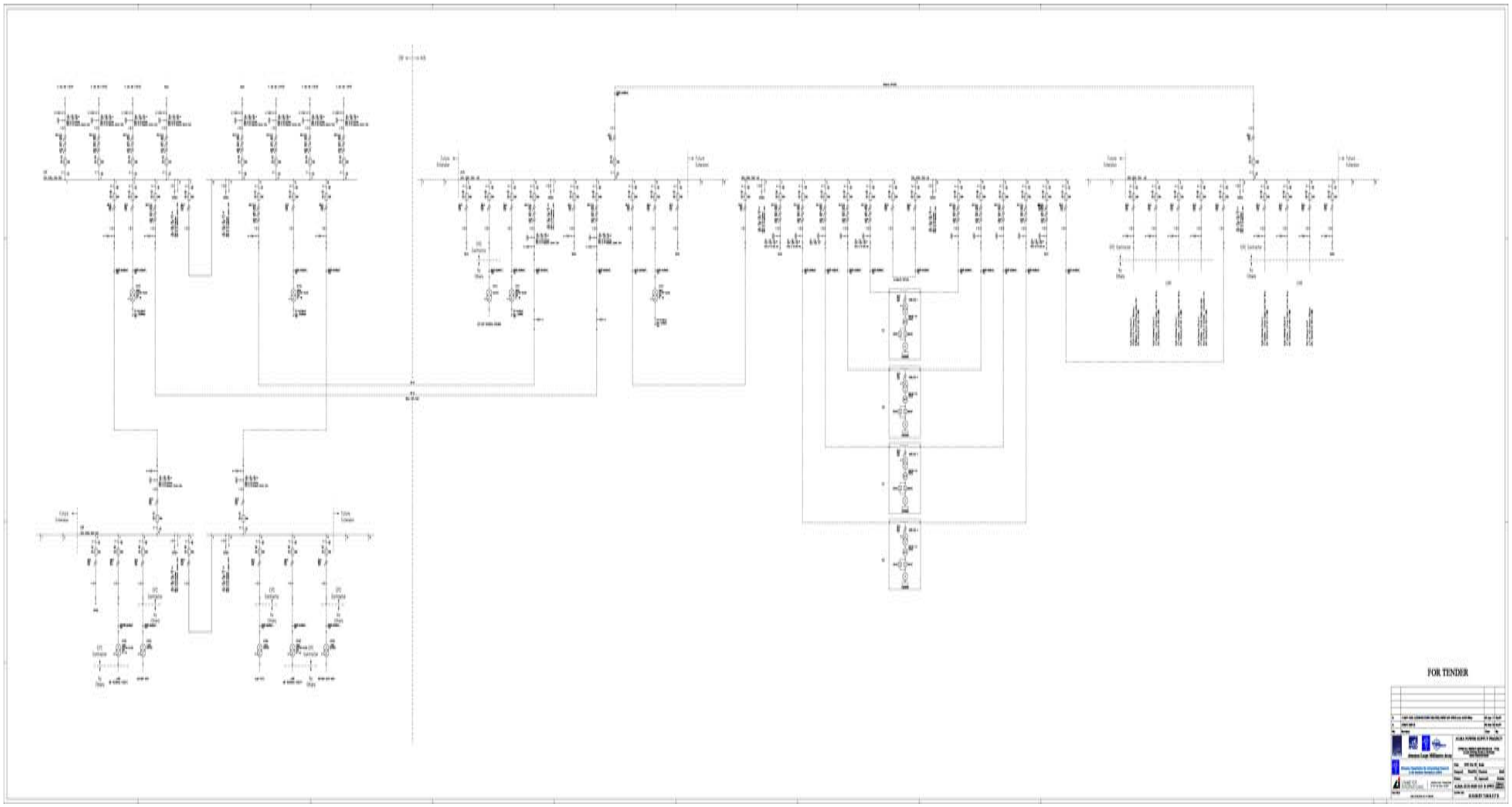
•Actual temporary power production realized by means of 11 diesel units, different size, 3800 kW total.

# ALMA Power Plant

## ***Basic design & future options***



# ALMA Power Grid



# ALMA MF Turbine

***The New Solution:***

•Due to urgent power needs in 2009 has been decided to install a multi-fuel turbine generator. The choice was a result of an accurate investigation in the market, finding the best product.

•The final choice remarked the need to maintain an isolated system from the Chilean grid, far and weak in this area.

•The new MF Turbine allows independence in fuel operation strategy, being able to run 5 types of fuels without stopping the machine.

•The new MF Turbine allows possibility of future combined cycle as well as cogeneration and heat recovery.

•The MF Turbine minimize the maintenance stops and improves the reliability of the system.

# ALMA MF Turbine

## ***<u>The T60 option was due to:</u>***

•The size and design, 4000 kW (at ALMA site).

•Wide number of unit in operation worldwide.

•Multi-fuel operation possibility (5 types).

•Fast manufacturing time in compliance with project schedule.

•Limited inversion cost.

•Combined cycle & cogeneration possibility.

| | GT Gas Natural USD/kWh | GT LPG Butano USD/kWh | GT Diesel USD/kWh |
|---|---|---|---|
| 2010 | 0.21 | 0.23 | 0.27 |
| 2013 (No CC) | 0.13 | 0.27 | 0.31 |
| 2013 (CC) | 0.11 | 0.15 | 0.17 |

Foreseen

# ALMA MF Turbine

## ***General Description: Design Data***

| | | |
|---|---|---|
| **Power** | kWe | 4000 (5959@ISO) |
| **Gear Box Ratio** | -- | 14944:1500 |
| **Heat rate** | kJ/kW-hr | 11800 |
| **Exhaust flow rate** | kg/hr | 77000 |
| **Exhaust temperature** | ºC | 510 (a FL) |
| **NOx reduction** | -- | No |
| **Generator Voltage** | V | 10500 |
| **Turbine weight** | Kg | 3275 |

# ALMA MF Turbine

## ***General Description: construction & manpower***

It will start in june 2010 after contract signature and with detailed engineering. Civil works started in April 2009 with the following resources:

- 250.000 kg concrete
- 92.000 kg steel
- 50 workers & technicians
- 1.300 mt extension for earthing grid
- 130 mt extension for double-wall trench
- Use of  heavy machinery and cranes
- EU Atex standard for electrical installation

# ALMA MF Turbine

## ***General Description: construction's overview***

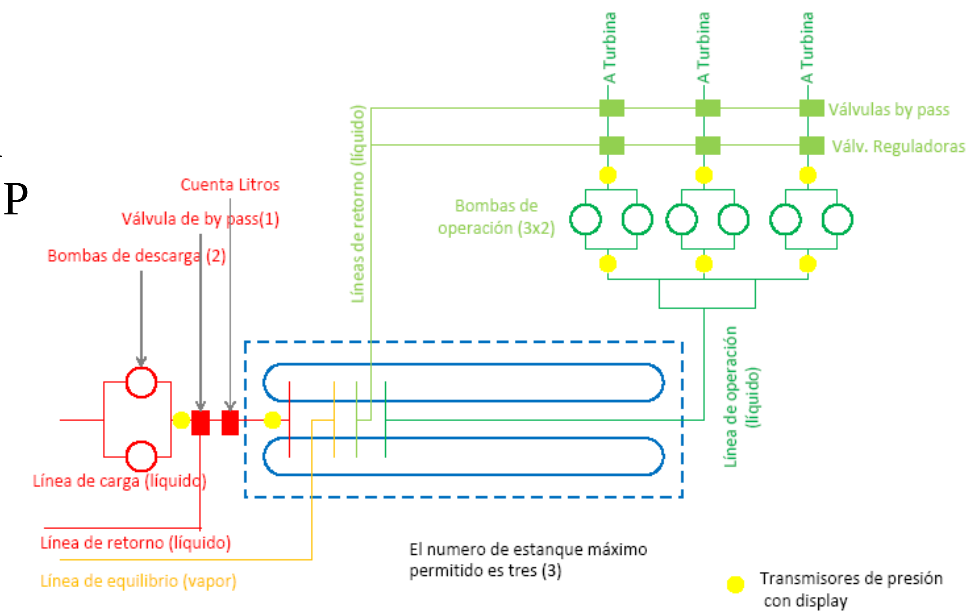
Concrete works…

..Basement completed…

# ALMA LPG Plant

## ***General Description: Design Data***

- 684.000 liters nominal capacity, 595.000 liters operational capacity (factor 0.85)
- Double feeder pumps to tanks
- Double feeder pumps to turbine
- Independent return line to tanks
- Redundant pressure monitor in all lines by means of Siemens Sitrans P
- On-line tank level measurement
- 9 days autonomy

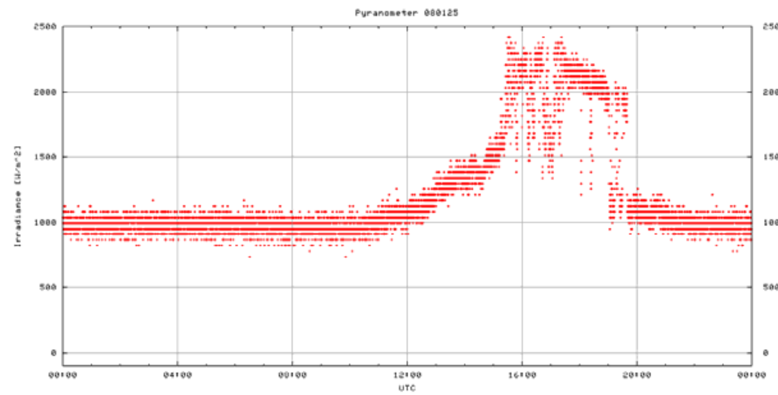


# ALMA & Renewable Energies

## ***Green Solution: Solar PV***

•The new system is compatible with solar PV integration. In fact Photo Voltaic plant can be designed to supply up to 30% of the total power without any problem. To achieve the max efficiency with an average solar radiation of 1600W/sqm, a sun-follower criteria has to be used as well as last technology silicon cells.

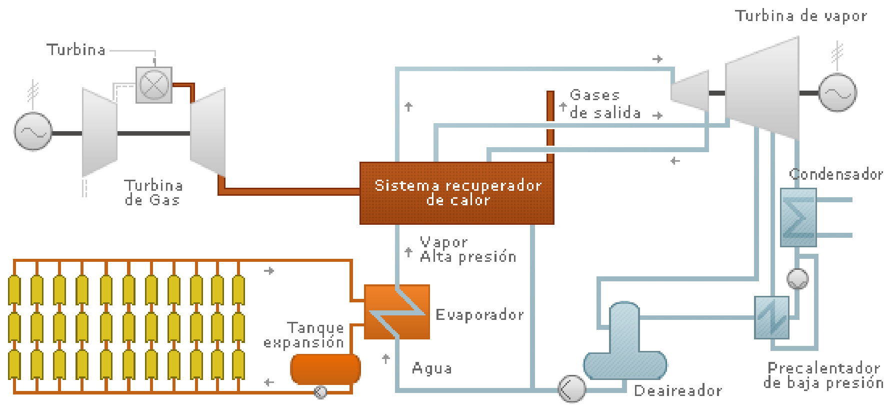
A 3 phase inverters convert electricity to 400V AC and later by means a transformer, to 23kV AC and then to the grid. An estimated construction cost for a 2 MW plant is around 3ML USD.




# ALMA & Renewable Energies

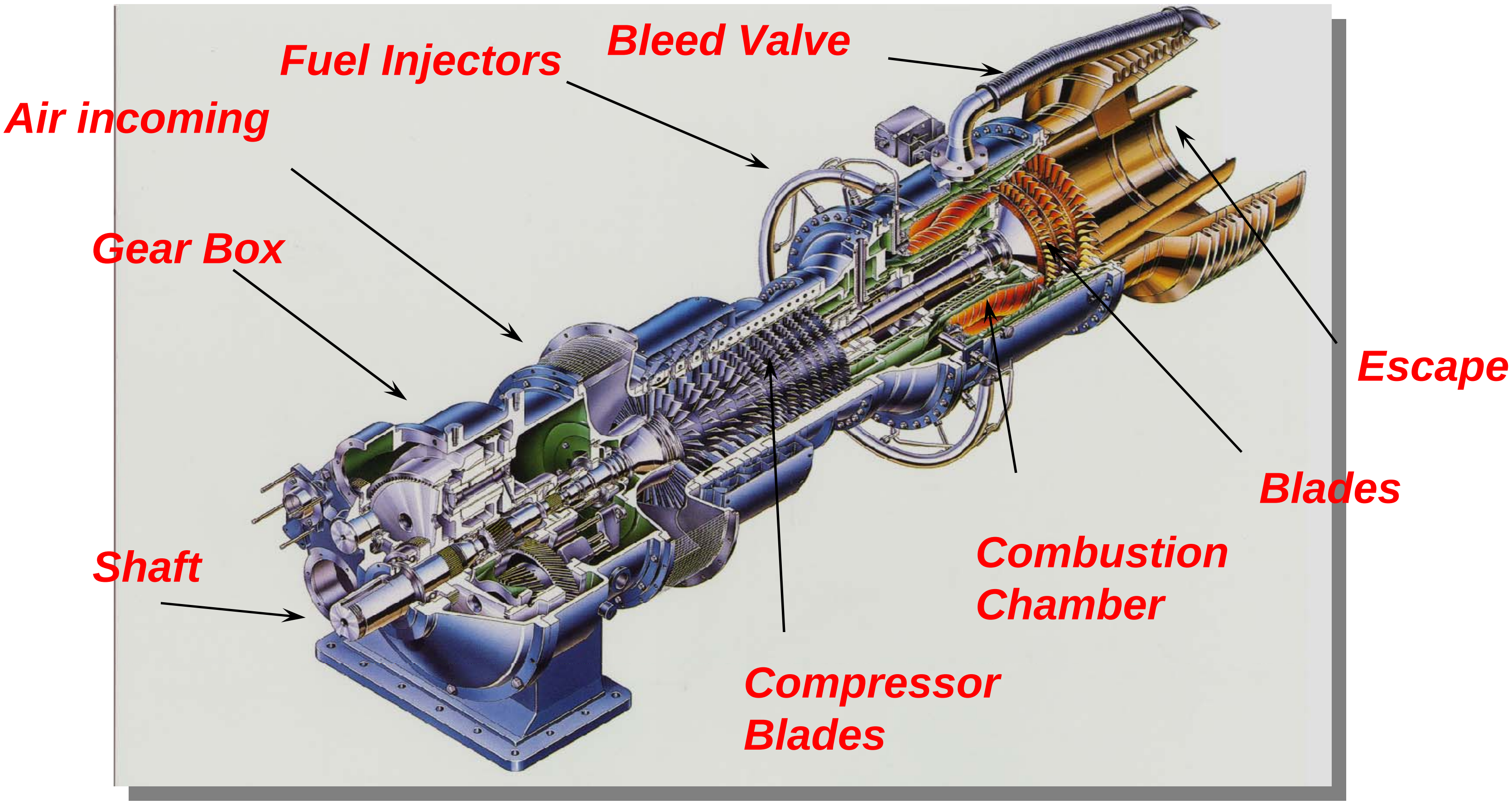
## ***Green Solution: Solar CSV***

•The new system is compatible with CSV integration, if installed associated to a Combined Cycle. In fact Solar CSV plant can be designed to supply up to 25% of the total thermal energy to the Combined Cycle closed loop. Using parabolic mirrors and vacuum pipes, the exchange fluid (liquid salt) can reach up to 550 Celsius, and give its heat to the steam cycle allowing an oversized steam turbine (estimated 1 MW more).




# ALMA Final User

# Technical Informations: The Gas Turbine



# MF Turbine Components

***History of the gas turbine:***

→ *first patent for a gas machine: John Barner, in 1791*

→ *beginning of the 20th century: first realisation attempts. Multiple failures due to technological delay on the materials (specially the compressor blades have to resist to high temperatures under strong speed efforts).*

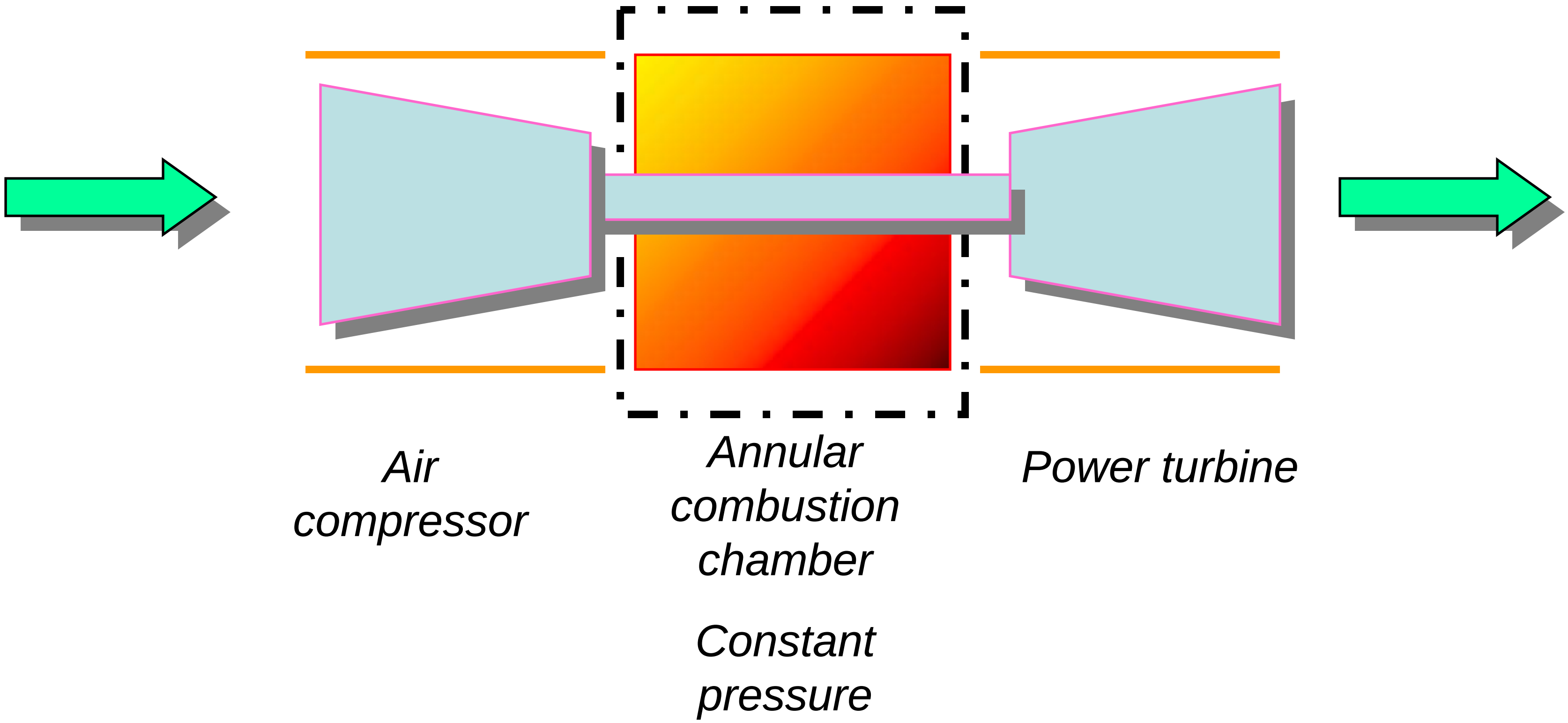
→ *first really operating GT appears in the 30's: in this period the first works on the axial compressors start.*

→ *big development since the world war of 1940 when the fighter engines  replaced the piston engine.*

→ *since then, the turbine continued to progress and important technical efforts allowed to develop less powerful units.*

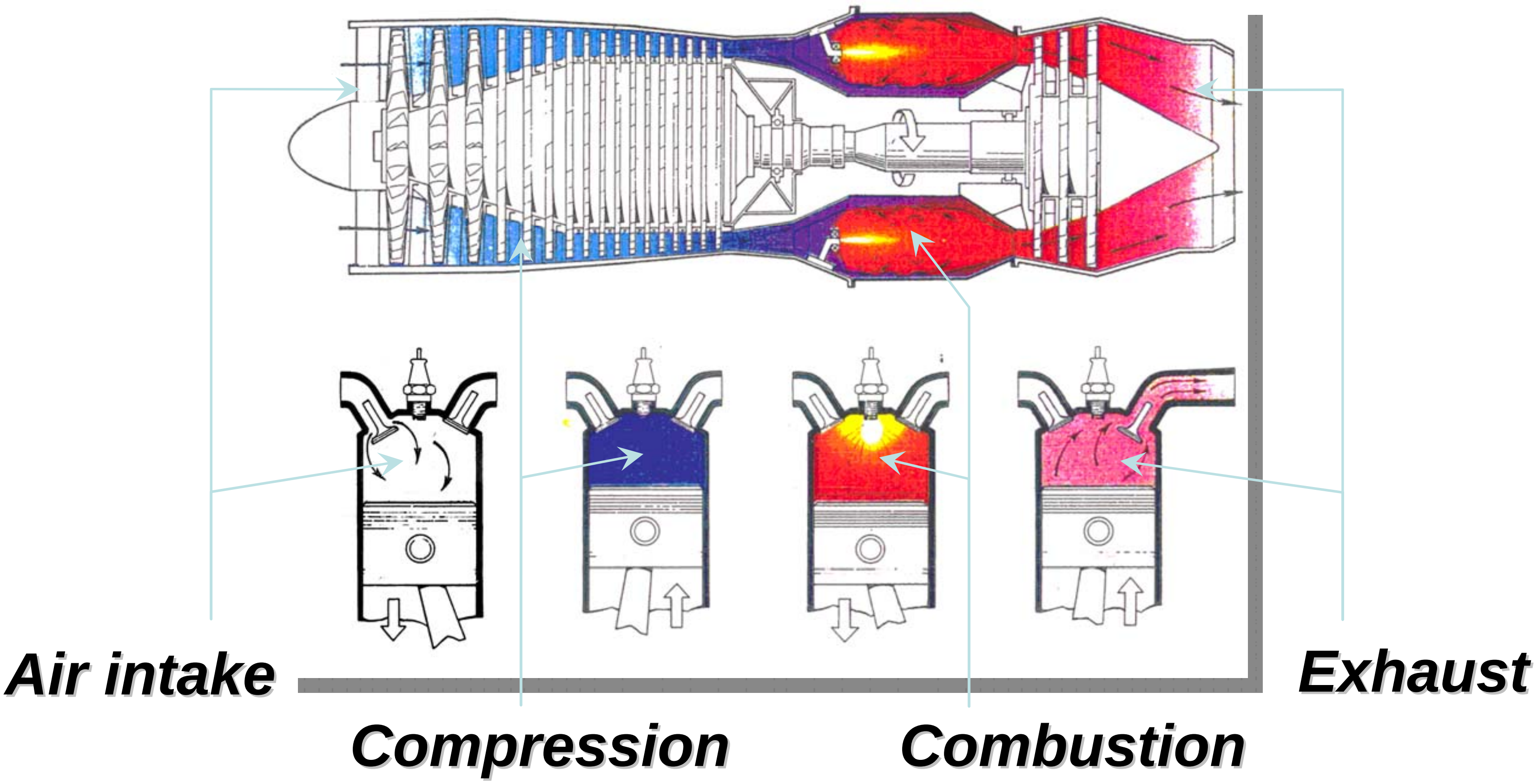
# MF Turbine Components

## ***The combustion turbine: operation***



# MF Turbine Components

*It is possible to compare the operation of a turbine (continuous cycle) with a four-cycle engine (intermittent cycle):*



# MF Turbine Components

## ***The Main Components:***

The three main components are:

•the **compressor**, used to compress the incoming air (increase the pressure).

•the **combustion chamber** where a proper mix air/fuel is burnt incrementing the kinetic energy.

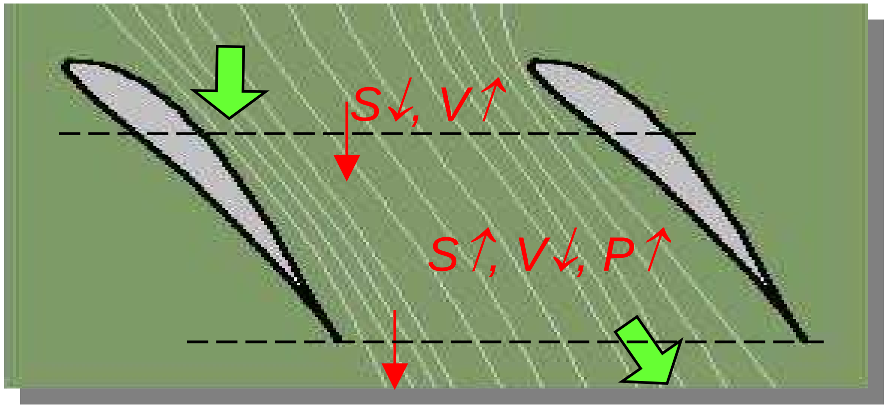
•the **power turbine**, where the kinetic energy of exhaust gases is transformed into mechanical energy and by means of its shaft into electric energy.

# MF Turbine Components

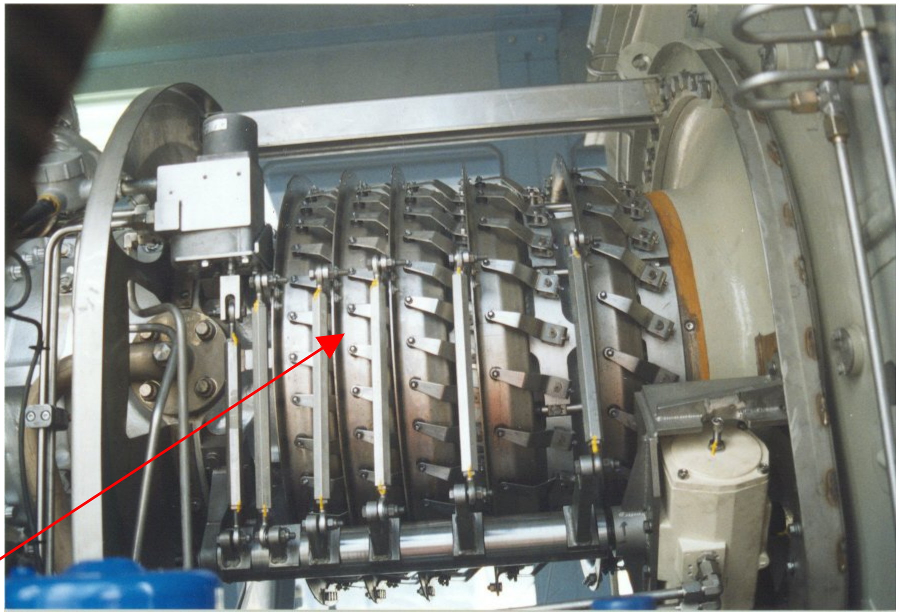
## ***The compressor:***

*The speed gain is due to mass flow conservation. On the opposite diagram you can recognise that the stream lines are closing at the rotor inlet. For the mass flow conservation, this causes a speed increase. Inversely, at the rotor outlet, and specially at the stator inlet, the section area of the blade increases. This produces a speed decrease accompanied by a pressure increase.*

*Mass flow equation: Q=rSV (r density, S section and V speed)*

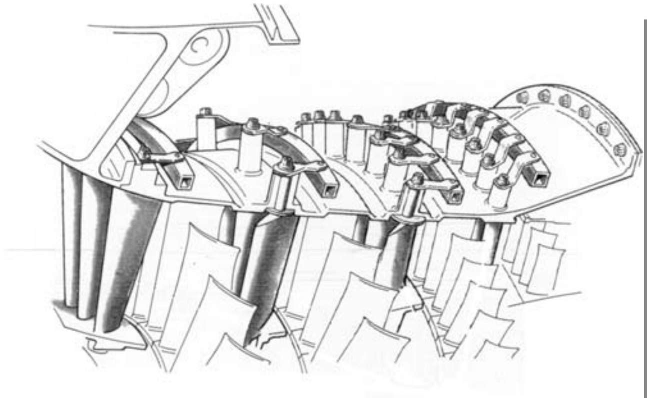


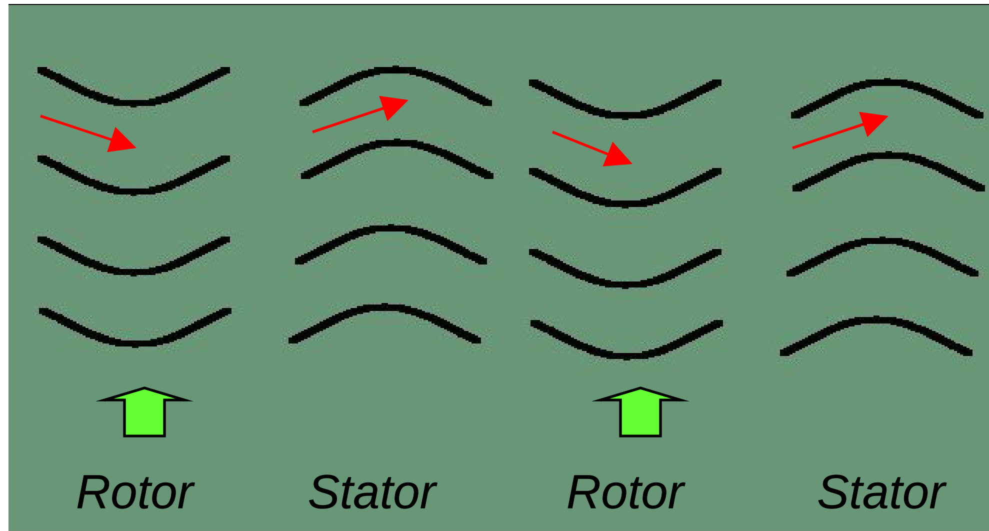

*Outer view of a compressor: adjustable stator blades (IGV)*



# MF Turbine Components

***The compressor:***



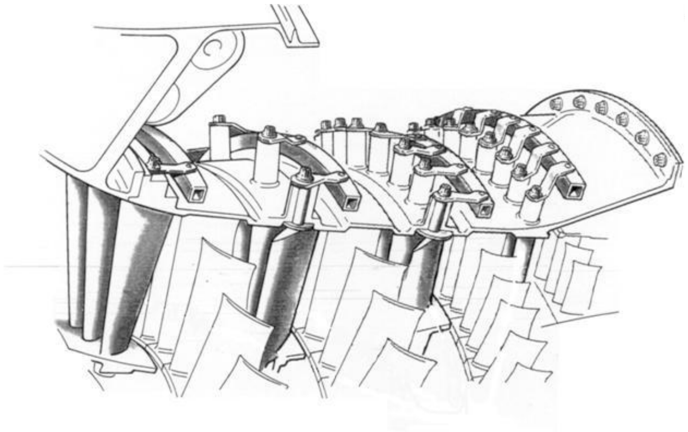



*The compressor compresses the air by accelerating and then decelerating it, since the pressure and the air speed are inversely proportional.*

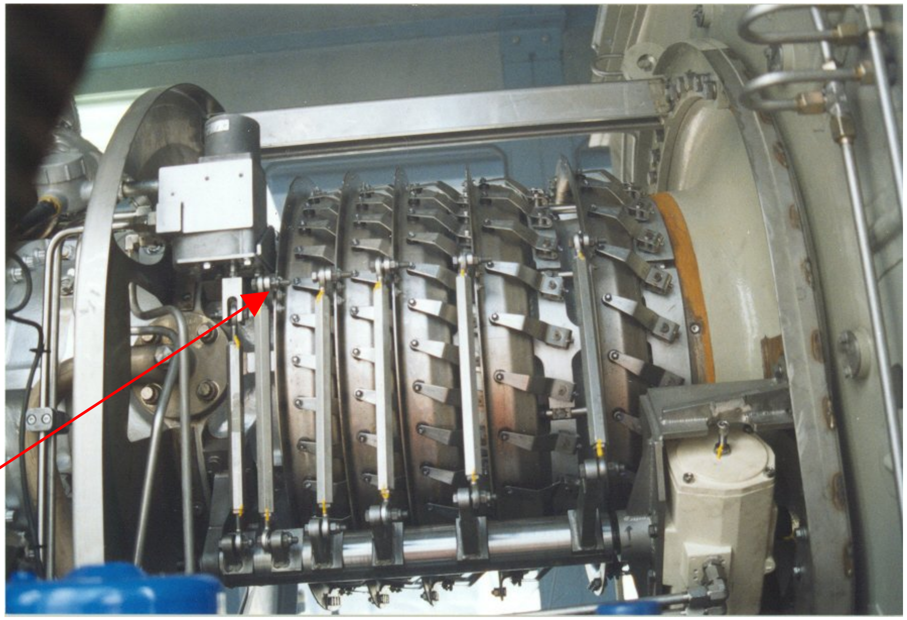
*A first row of rotors (turning) sucks the air and speeds it up. The air enters at this speed the stators row (fix) and by means of its geometry, the air is slowed down and then compressed. In order to achieve the wanted pressure, more stages of blades are necessary.*

# MF Turbine Components

***The Compressor:***



Compressor view: adjustable stator blades (IGV)

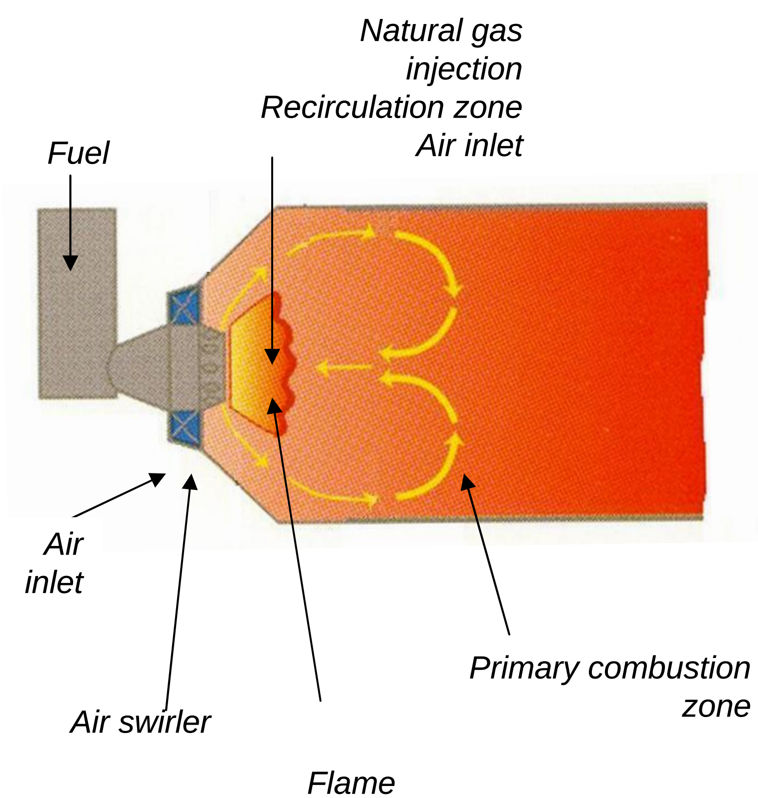


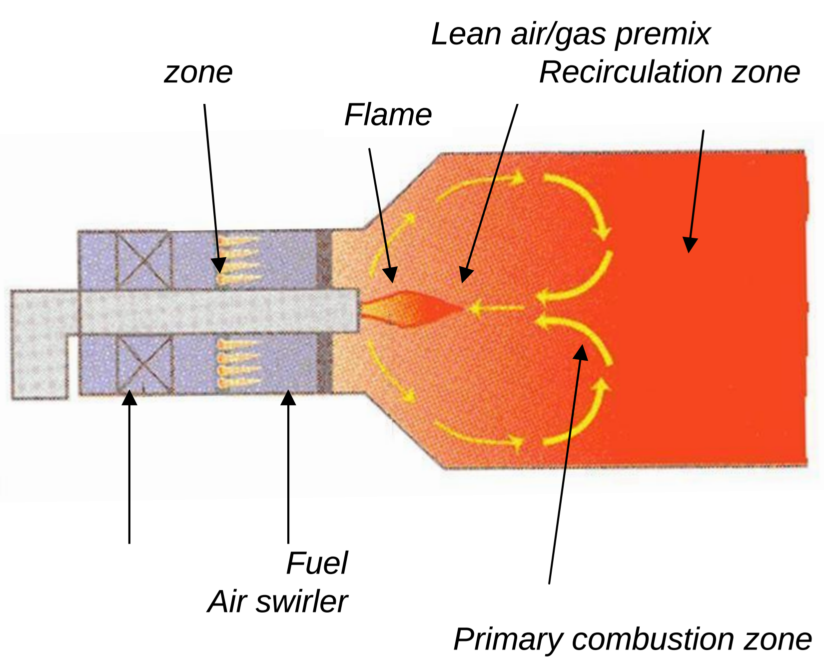
The Compressor compresses air by acceleration and deceleration, being pressure and air speed with inverted law.

The first row (moving) takes and speeds up air. The air comes into the stator row where due to the geometry speeds down increasing its pressure. This is repeated many times each compressor row, and at the end the air is compressed.

# MF Turbine Components

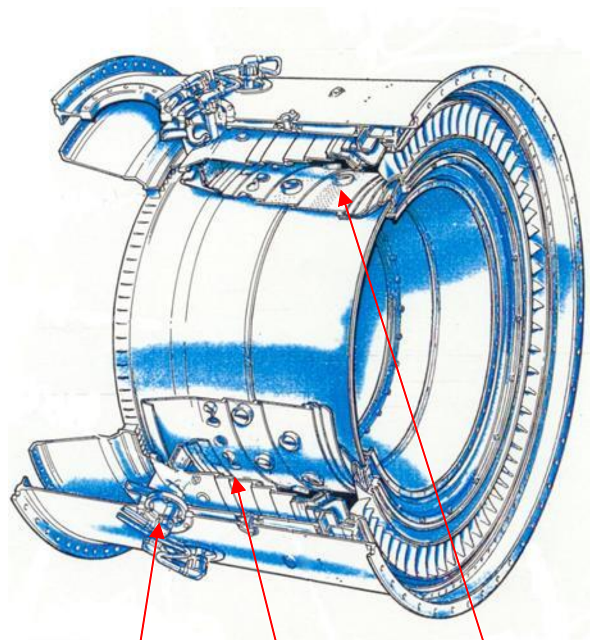
## *The Combustion Chamber:*



# MF Turbine Components

## ***The Combustion Chamber:***

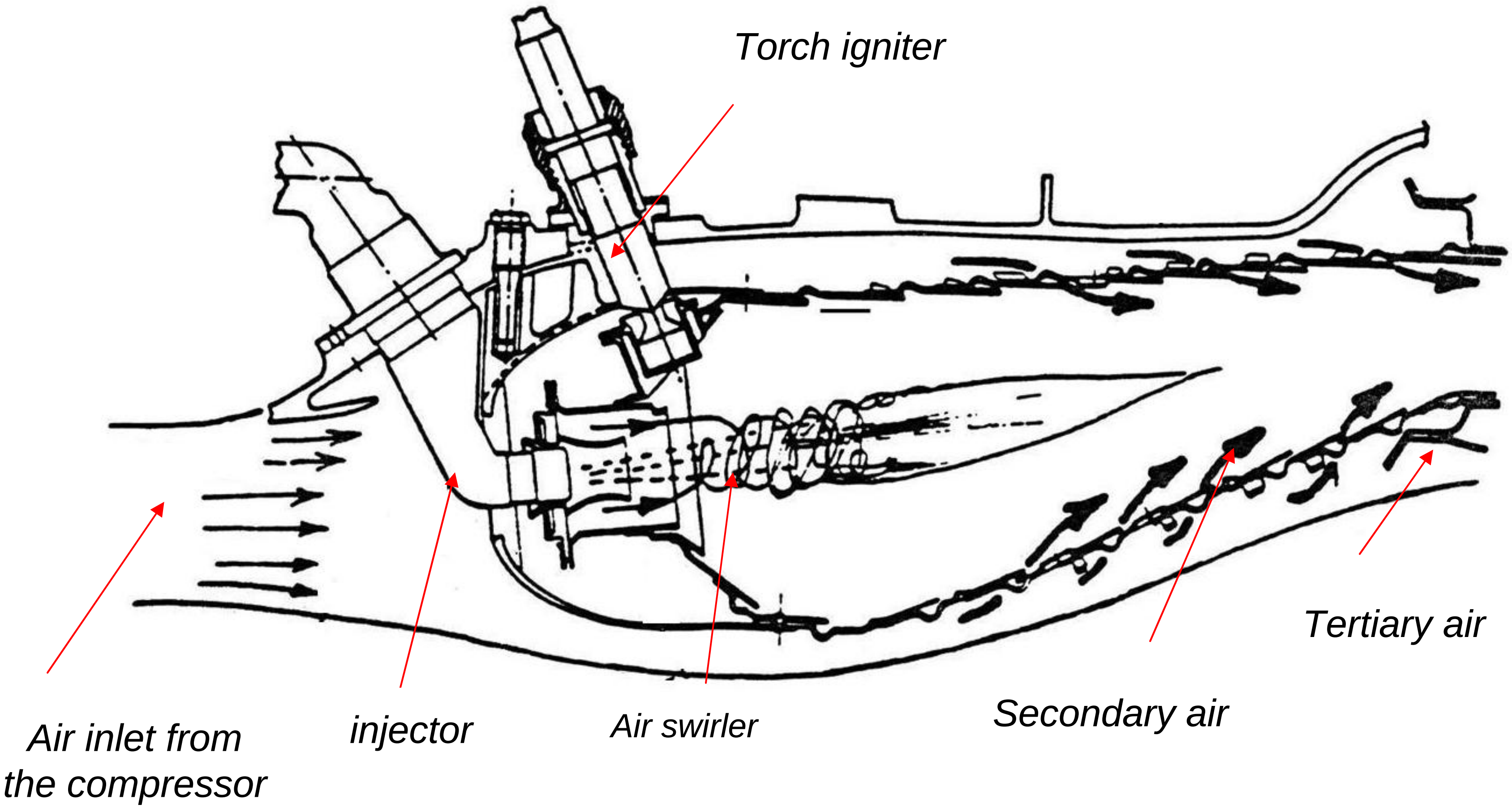



In the combustion chamber a mix of fuel coming from the injectors and air coming from the compressor is burnt at constant pressure.

In the combustion chamber is also realized the emission reduction by acting on the flame temperature.

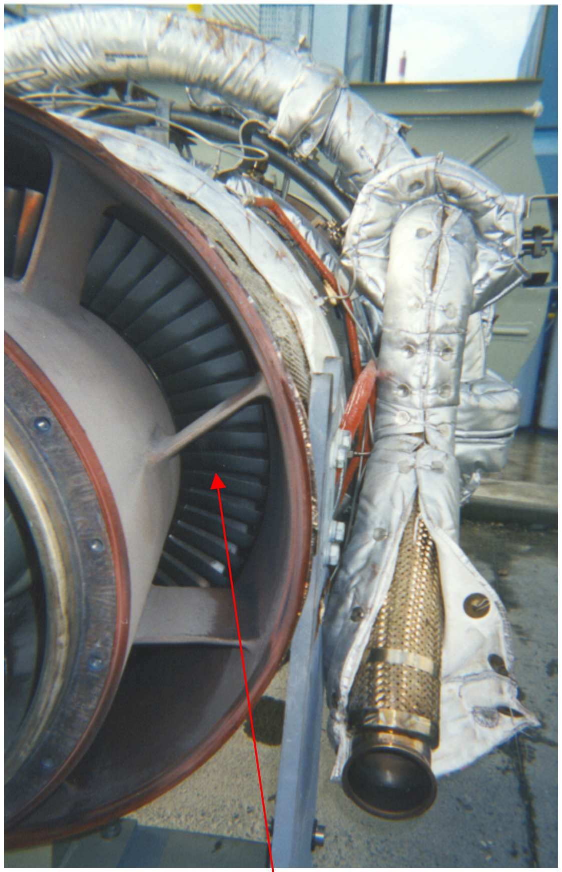
# MF Turbine Components

## ***The Combustion Chamber:***

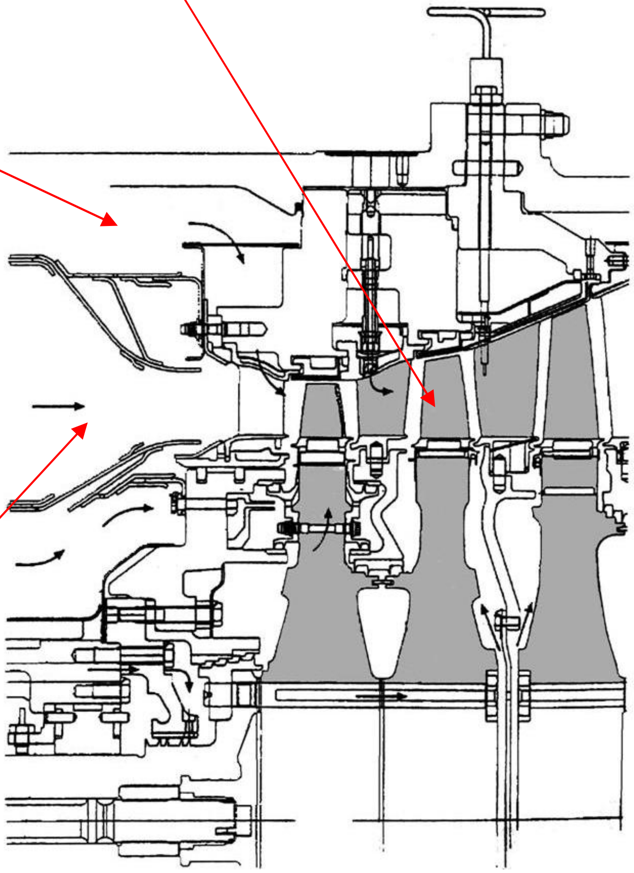


# MF Turbine Components

***The Power Turbine:***



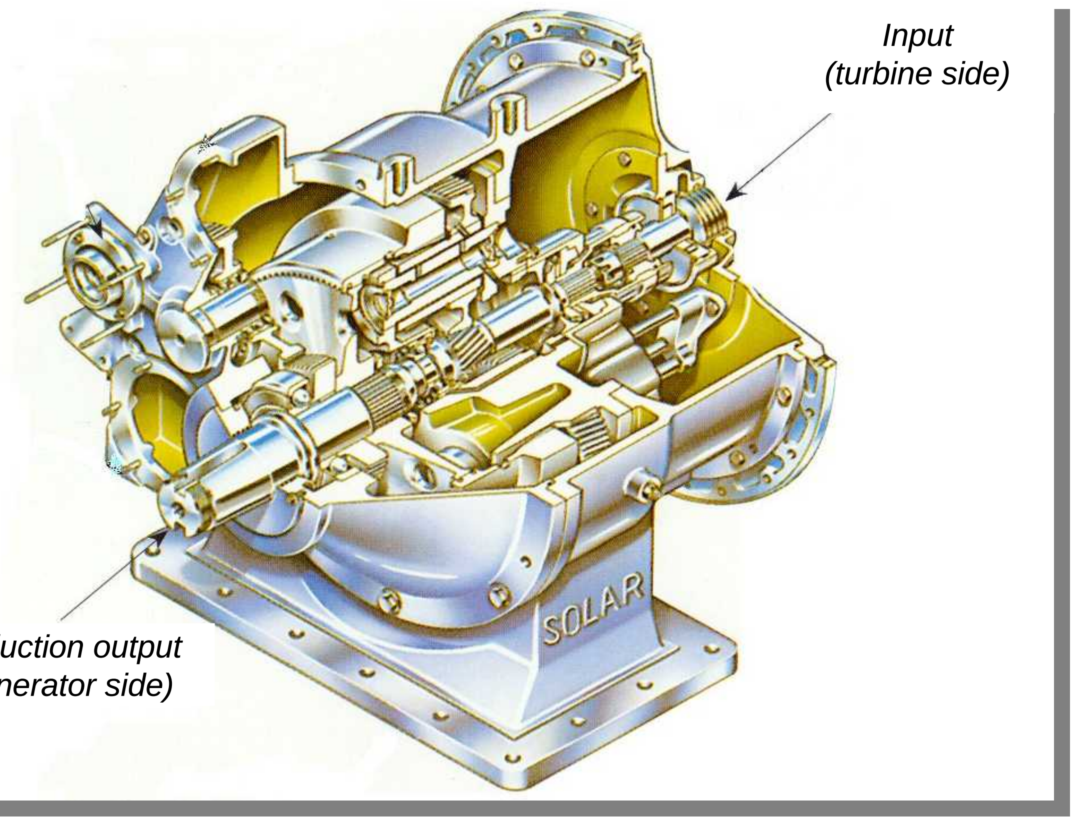

Hot exhausts give their pressure energy to the turbine's power blades moving the rotor: this last one is directly connected through a gear box to the alternator.



# MF Turbine Components

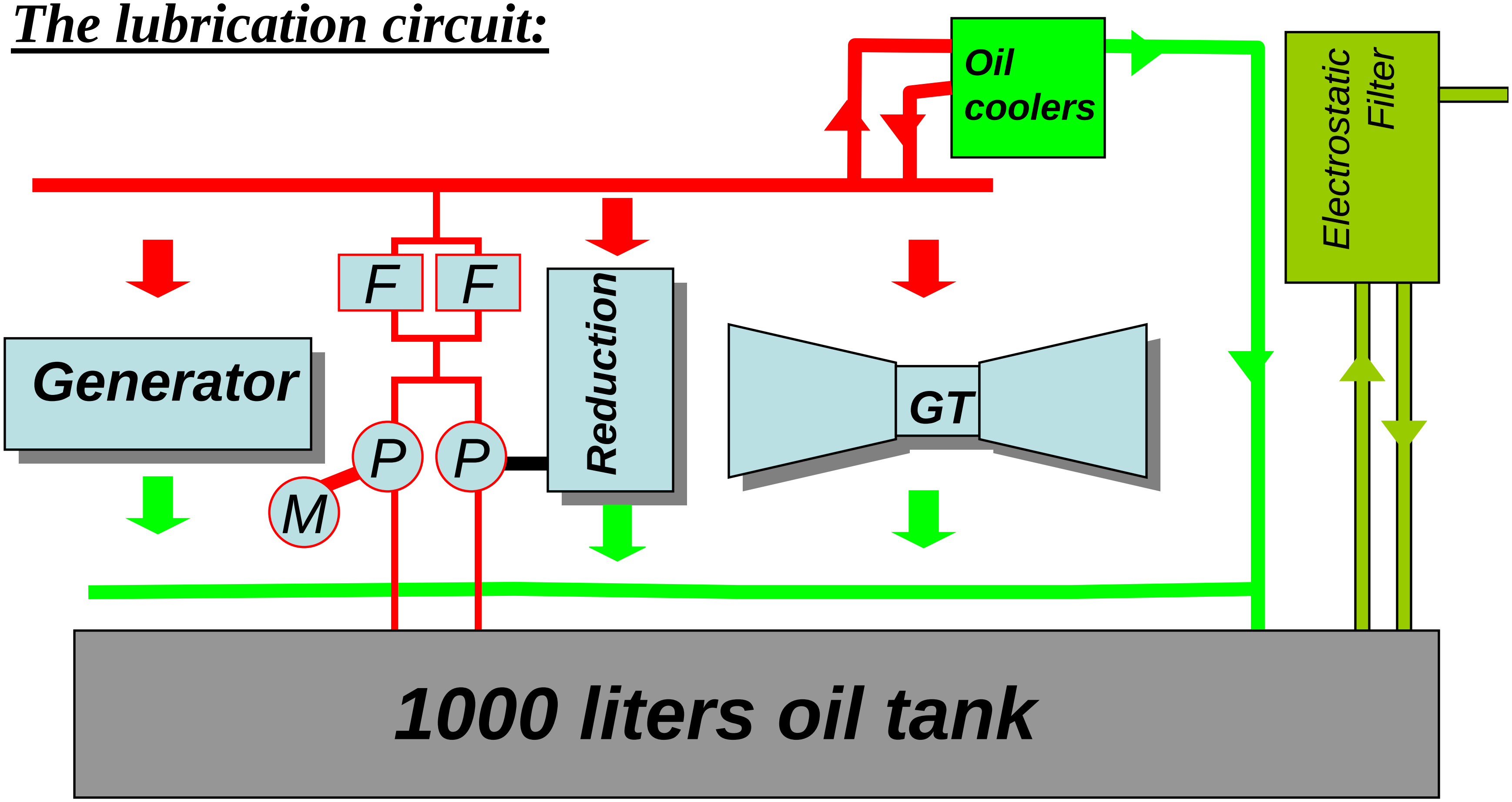
***<u>The reduction gear box:</u>***

- *Two stages reduction, star and epicyclic compound*
- *Reduced output speed : 1500 rpm*
- *Efficiency 98,20%*



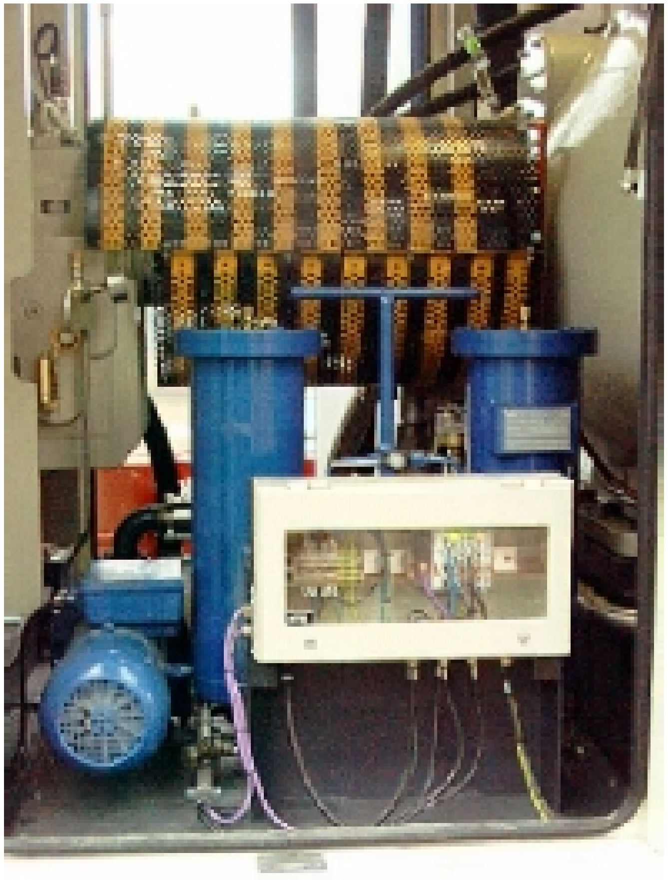
# MF Turbine Components

***The lubrication circuit:***

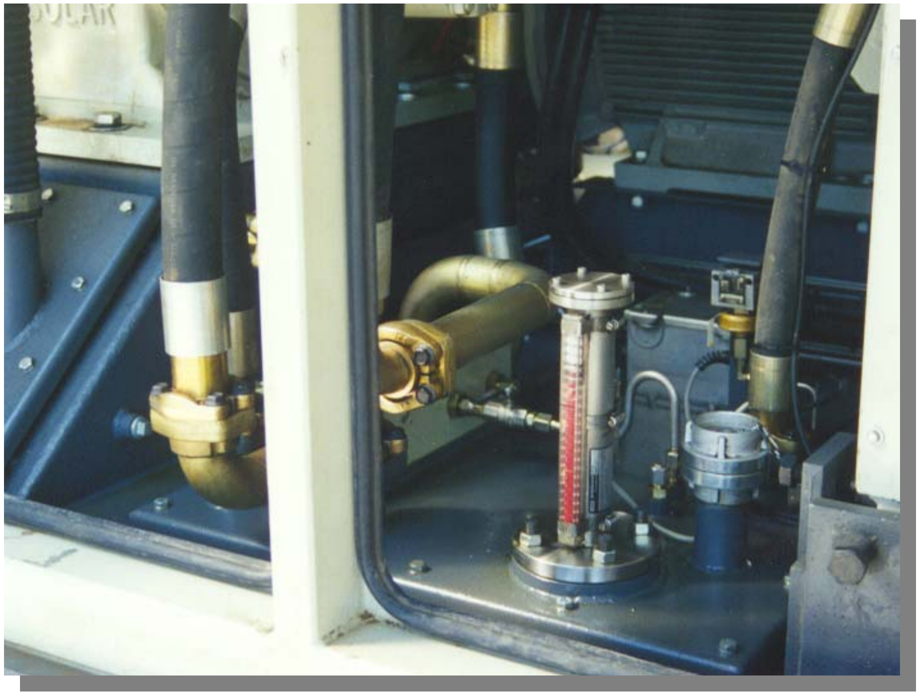


# MF Turbine Components

## ***The lubrication circuit:***



***View of the duplex oil filter***



***Lube oil tank***

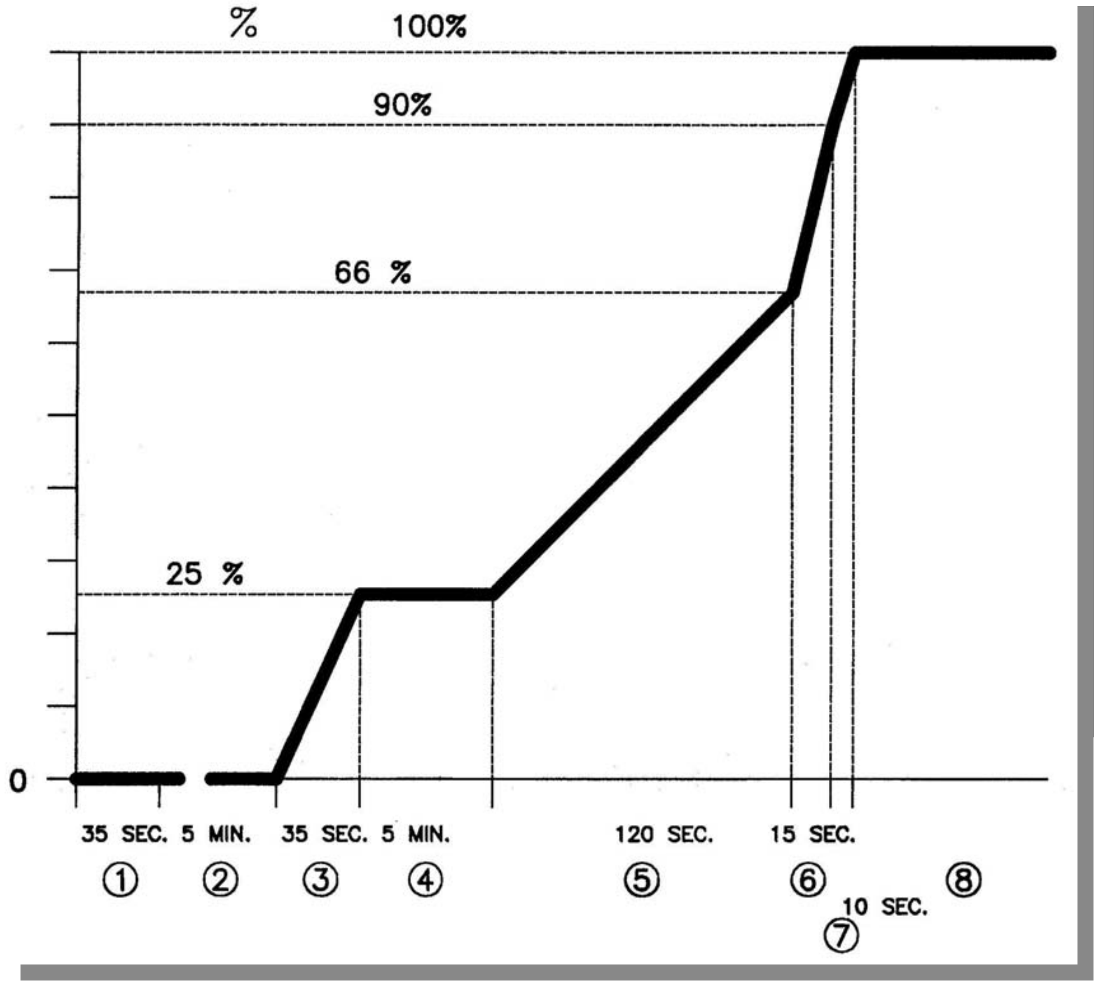
# MF Turbine Components

***<u>The Operation:</u>***

- *Starting cycle*
- *Shut-down cycle of the turbine*
- *Synchronisation*
- *Checks during operation*
- *Maintenance*

# MF Turbine Components

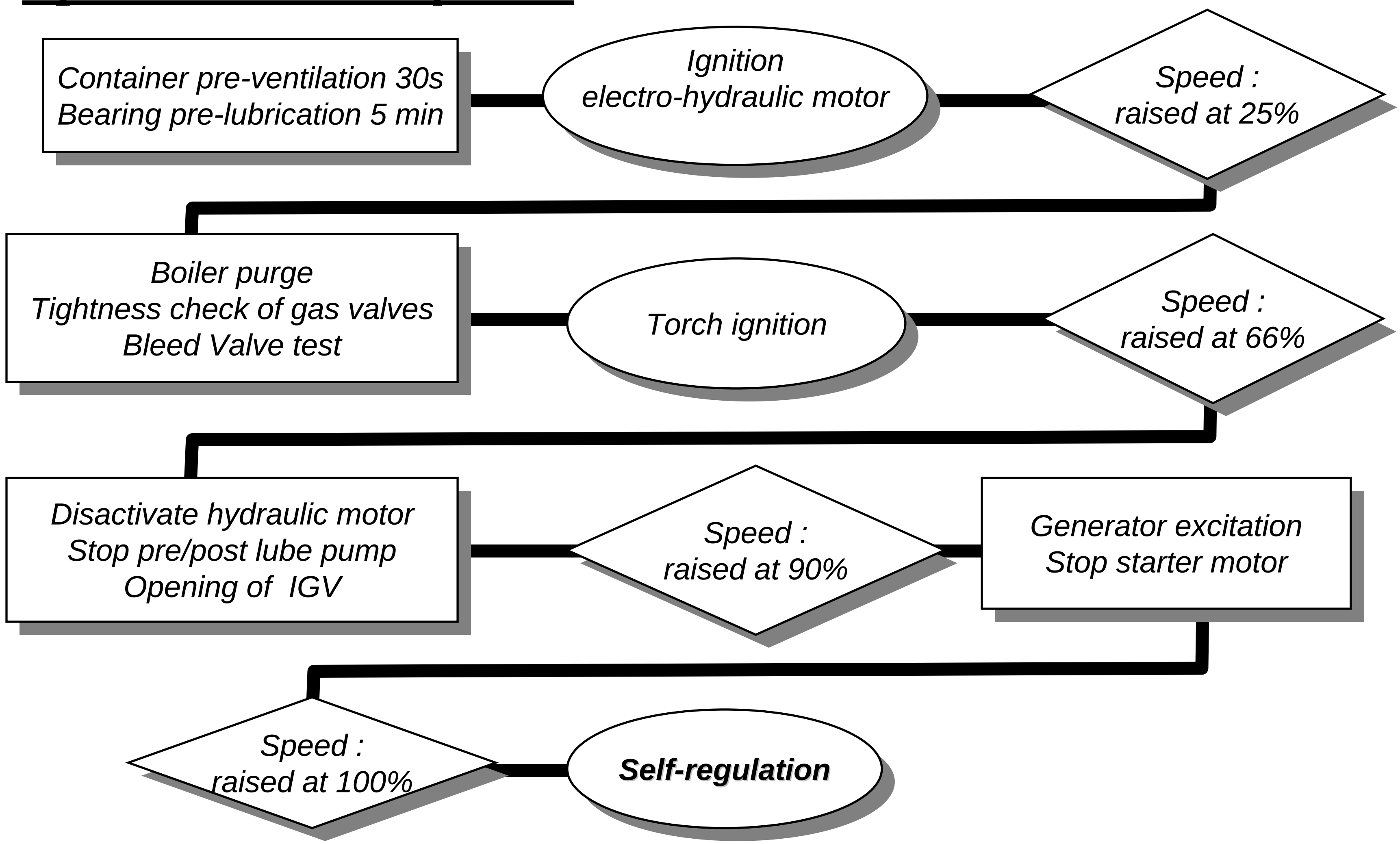
## ***Operation: start sequence***




- *1 Pre-ventilation*
- *2 Pre-lubrication*
- *3 Starter motor*
- *4 Control gas valves, boiler purge, bleed valve*
- *5 Acceleration at 60%*
- *6 Acceleration at 90%*
- *7 Reaching of the operating speed*
- *8 Synchronisation sequence*

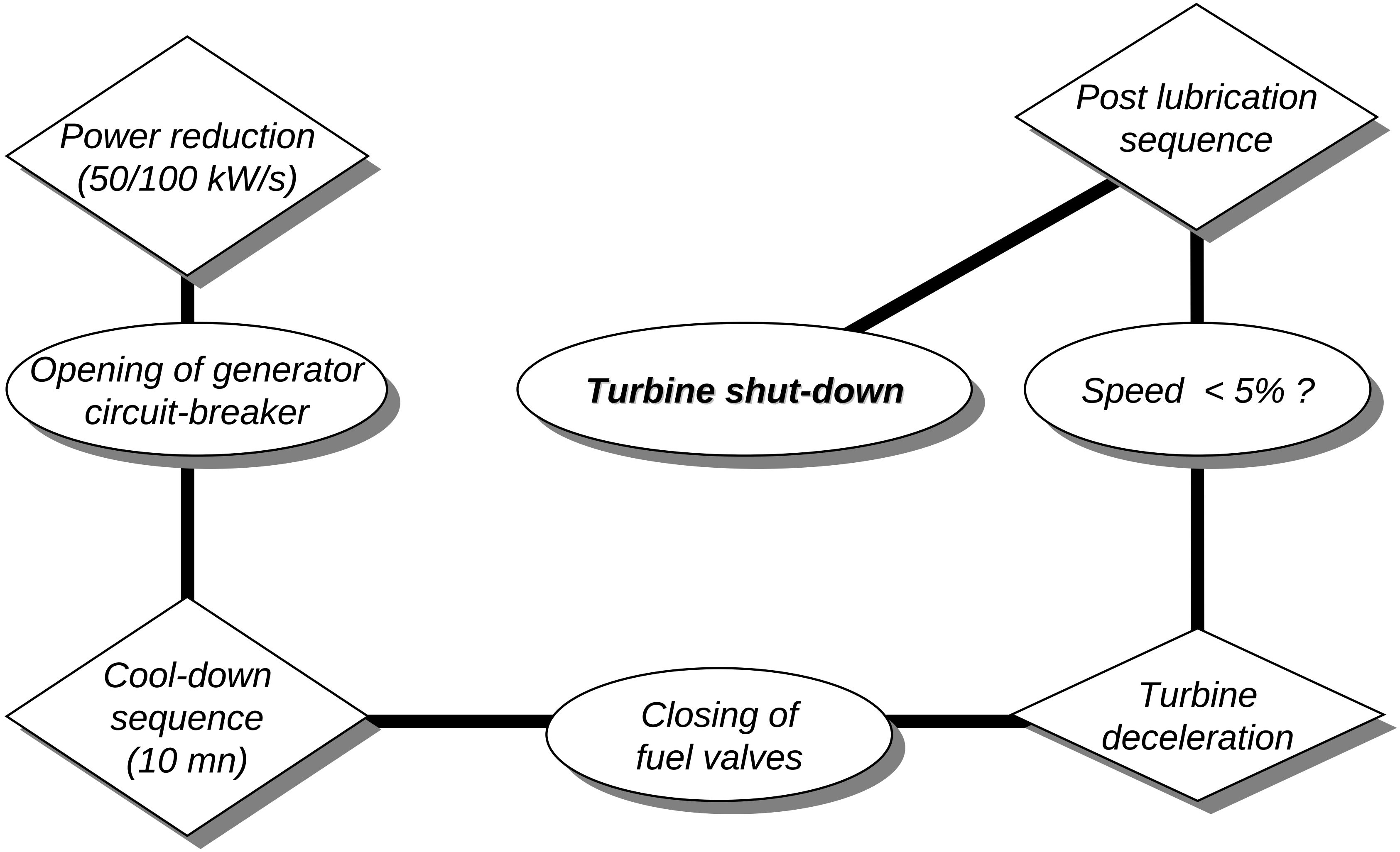
# MF Turbine Components

## ***Operation: start sequence***



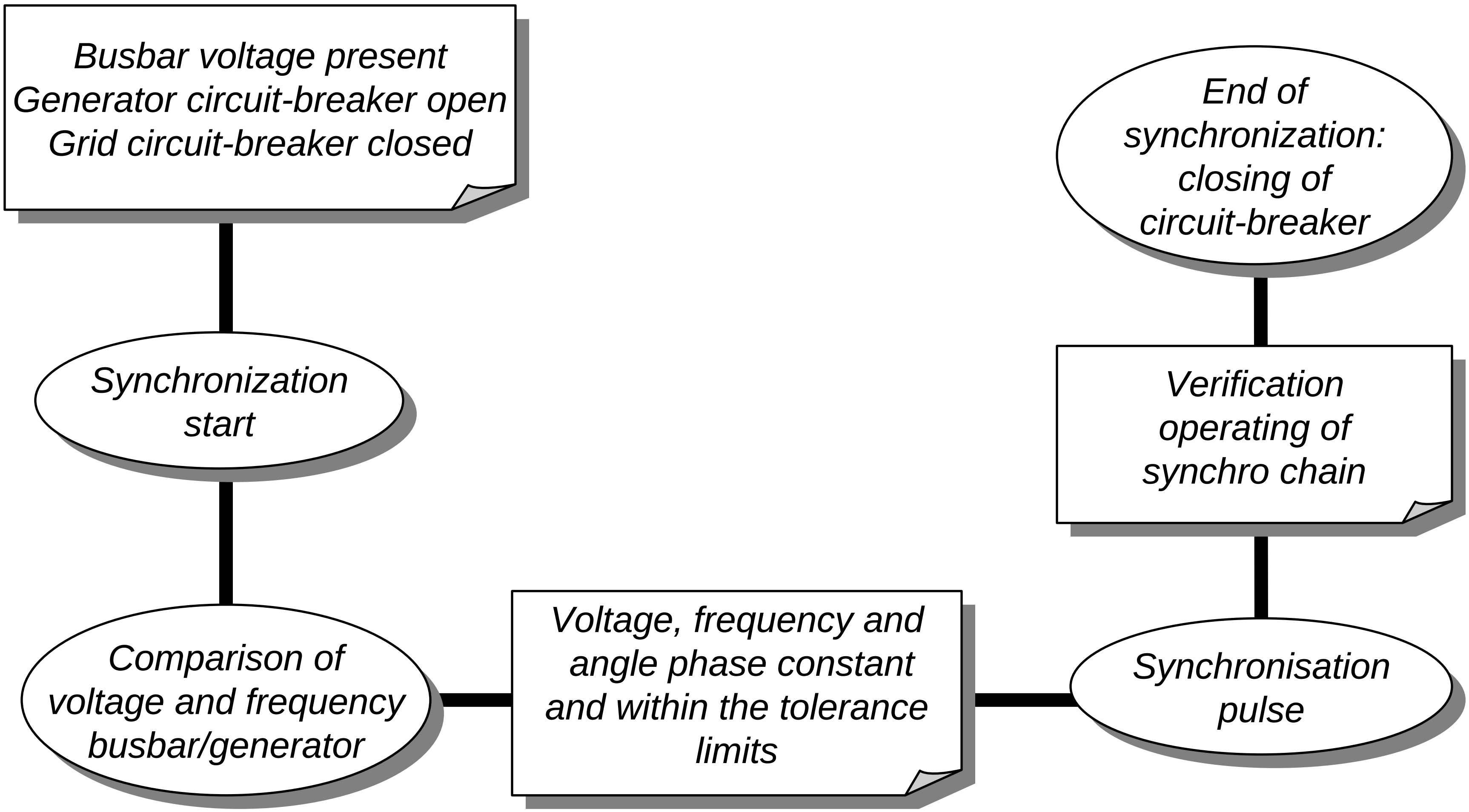
# MF Turbine Components

## ***Operation: stop sequence***



# MF Turbine Components

## ***Operation: syncronization sequence***



# MF Turbine Components

***<u>Control during operation:</u>***

*When the power of the turbogenerator is stabilised, the control and monitoring systems verify the operating parameters of the whole turbine. These systems react automatically to any changes in the parameters by either readjusting the turbine or by activating an alarm.*

*However, for the smooth running of the turbine, **it is essential for the operator to check the operation of all the turbine components,** in order to prevent any system failure. To accomplish this, it is preferable to record the system parameters every 24 hours, and have the data analysed by qualified operator.*

# MF Turbine Components

## ***The different maintenance levels:***

*Turbine → exposed to thermal, mechanical and vibratory charges.*

***Maximise the life duration ⇔ carry out a regular maintenance***

| Level | I | II | III | IV | V |
|---|---|---|---|---|---|
| Nature | Operational maintenance | Simple maintenance | Complete maintenance | Major maintenance | Package revision |
| Periodicity | Weekly | 4 months | 12 months | 30/35 000 hours | 40 000 hours |
| Duration | 1 hour | 1 day | 4 days | 5 days | |
| Shut-down time | 0 hours | 6 hours | 96 hours | 120 hours | 15/30 days |
| Expenses | Client | Provider | Provider | Provider | Provider |

*These indications can differ according to the use of the machine.*

# MF Turbine Components

## ***<u>Level I : inspection</u>***

***Turbine*** *: report of the functioning parameters, measuring of the differential pressure of the fuel/air filters, batteries visual check, oil level check, piping check, filter check of the air inlet.*

***Generator****: lubrication check of the bearings and general cleaning of the generator.*

***«On-line» washing****.*

***General works****: check and supervision in order to look for malfunctions (leaks), general cleaning of the installation, report on extraordinary events.*

# MF Turbine Components

## ***Level II: simple maintenance***

***Turbine****: replacement of oil filter, gas filter and ignition plug. Check of the air filter, oil level, compressed air quality, ventilation fans functional test, leaks, compressor cleanness.*

***Generator****: check of the bearings lubricant level.*

***Cubicles****: check of batteries, batteries charger, terminals, cleaning.*

***Operating verification*** *and synchronisation check.*

***General works****: maintenance protocol.*

# MF Turbine Components

## ***Level III: complete maintenance***

*In addition to the simple maintenance steps, it contains:*

***Turbine****: replacement of gas sensors, of the electro-hydraulic actuator filter, of the oil pump suction filter, oil vapours separator, gas pressure regulator. Cleaning. Disassembly and check of the injectors, temperature measurement probes of the exhaust gas, bleed valve, speed measurement probes, gas valve. Endoscopy. Various checks.*

***Generator****: inspection of the power cables connections, diodes and screws on the basement. Verification of the exciter, connection cables to the regulators.*

***Cubicles****: verification of the speed measure, exhaust gas temperature measure. Verification of the complete functioning of the fire extinguishing system, gas detection and vibrations.*

***General works****: emission of a boroscopy report and of an intervention report.*

# MF Turbine Components

***Level IV: major maintenance***

*If required by the boroscopy check, revision of the turbine in the workshop (duration about 3 months). There are two possibilities:*

- *on request, a hired turbine is put at the client's disposal. As per the client's wishes, the maintenance will include either the simple revision and the updating of the turbine to the latest technology.*
- *or the turbine is replaced by a «0 operating hours» turbine (new), adapted to the latest technological progress and the customer will become the owner of it.*

*The revision includes the complete disassembling and the inspection of the turbo generator group.*

# MF Turbine Components

## ***Level V: revision***

- *The replacement of the power module (turbine + compressor + gear box) is finished at the client's plant*
- *Auxiliaries: interventions on*
    - *generator bearings*
    - *cleaning and lubrication of the generator rotor*
    - *replacement or revision of the auxiliary AC motors*
    - *replacement of the carbon brushes on the DC motors*
    - *replacement of batteries, etc.*