CLIENT

GT6 Life Extension Assessment

City , March - June 2023

Rev	Author	Date	Reviewed	Document no	Status
00	Xx	08 March 2023	Xx	R20230308-1	Concept
01	Xx	14 June 2023	Xx	R20230308-2	For client review

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1. Preface

[redacted]

CLIENT operates a combined heat and power installation in order to provide the energy required for the production process in an economically and environmental responsible manner. The rotating part of the CHP consists of two powertrains (Gas turbine GT5 / Generator 5 and Gas turbine GT6 / Generator 6 / Steam turbine ST6)

Xx is requested to support [redacted] in determining the current condition of the GT6 unit, the theoretical remaining lifetime on the engine and the minimum amount of maintenance needed to ensure backup availability of the unit until year 2030. One year of continuous operation in case of GT5 failure must be provided by GT6.

Additionally part of the assessment different scenarios will be examined in more detail:

1. No action
2. Minimum repair existing unit
3. Overhaul existing unit
4. Minimum repair Australian engine
5. Overhaul Australian engine
6. Used SGT600 engine from market
7. Replace existing unit with alternative engine

Within the scope of this assessment the following Key Performance Indicators are the analytical basis for decision making toward the intended result:

- Scope
- Maintenance and operational costs
- Risks
- Safety
- Steam production
- Efficiency
- Emissions
- Availability

2. Summary

Please find below a visual summary of the 7 options. A detailed context of the various options can be found in the report.

	OPTION 1 No action	OPTION 2 Minimum repair existing unit	OPTION 3 Overhaul existing unit	OPTION 4 Minimum repair Australian engine	OPTION 5 Overhaul Australian engine	OPTION 6 Used SGT600 engine from market	OPTION 7 Replace exist. unit with alt. engine
SCOPE	Bad	Average	Good	Average	Good	Average	Excellent
ESTIMATED INVESTMENT COST	€ 0,00	€ 1.974.875,00	€ 2.774.125,00	€ 2.887.375,00	€ 3.686.625,00	€ 2.331.250,00	€ 16.250.000,00
RISKS	Bad	Average	Good	Average	Good	Average	Good
SAFETY	Bad	Good	Good	Good	Good	Good	Good
STEAM PRODUCTION	Average	Average	Good	Average	Good	Good	Good
EFFICIENCY	Poor	Average	Good	Average	Good	Good	Excellent
EMISSIONS	Poor	Average	Good	Average	Good	Good	Excellent
AVAILABILITY	Bad	Average	Good	Average	Good	Good	Excellent

3. Background

3.1. History CHP client

CLIENT has had a small Combined Heat and Power Plant since 1983. It was primarily intended for CLIENT site power generation but the heat released was also used effectively. The gas consumption that time at CLIENT was approximately 70 million nm³ per year.

The current Combined Heat and Power Plant (1994) was original designed as shown in figure 1. Natural gas is supplied and by meaning of the use of two gas turbines, a steam boiler and a steam turbine , electricity and steam are generated. Steam and electricity will be used for local site requirement and the surplus of electricity will be exported to [redacted] interconnected system. Compared to previous small CHP the annual consumption of natural gas was reduced by 35 million nm³. This means a reduction of national emissions of nitric oxide and dioxide of 432 tons per year. The carbon dioxide emissions (greenhouse effect) footprint was reduced by 115,000 tons per year.

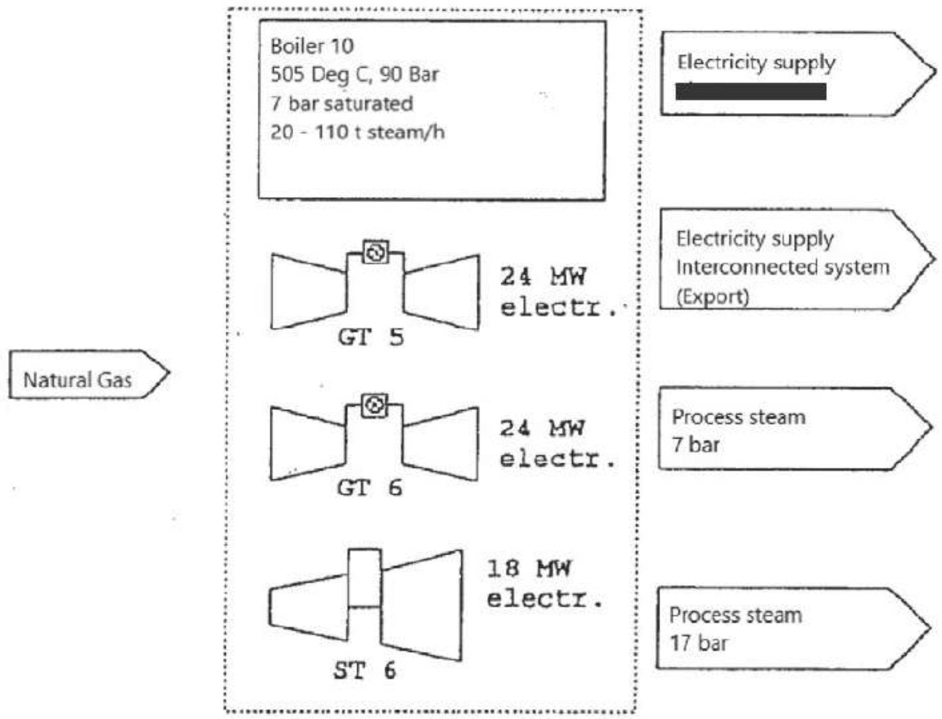


Figure 1: Schematic overview CHP [redacted] client

3.2. Current configuration CHP

Over the years the need for increased operational flexibility, reduced emissions, backup availability the CHP has been evolved to below configuration:

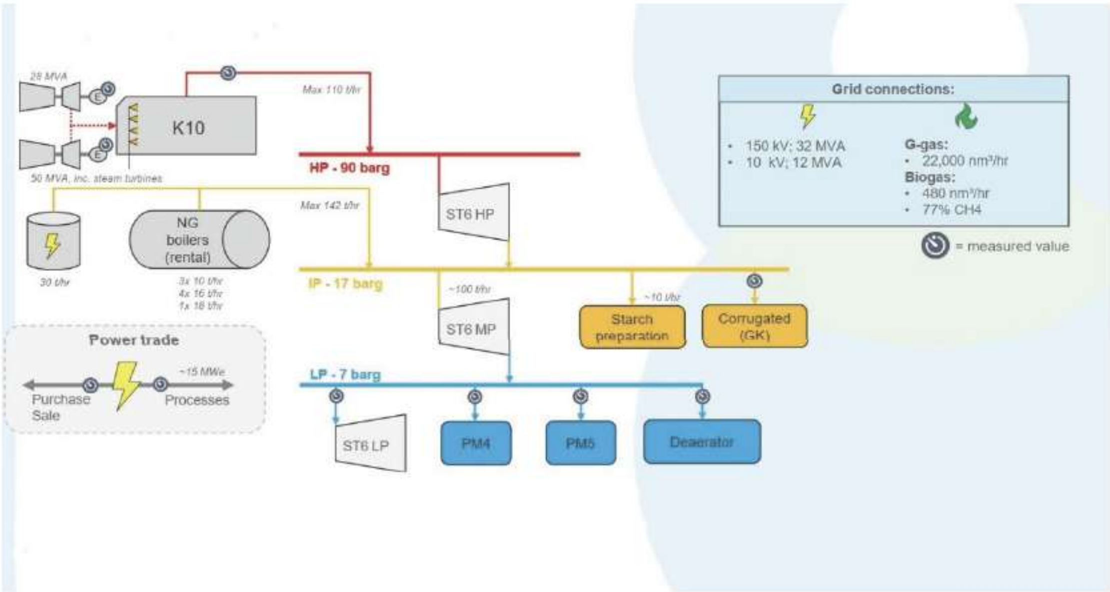


Figure 2: Current configuration CHP

The heat demand for the CLIENT processes is primarily provided by a 110 t/hr Combined Heat and Power plant with natural gas boilers as back-up facility.

CLIENT has an active power trade and varies the utilization of CHP and E-boiler depending on the day-ahead and intraday power markets.

3.3. Gas turbines

The rotating equipment consists of two ABB supplied powertrains. One train is a combination of one gas turbine, generator and one steam turbine. The other powertrain consists of a gas turbine and a generator. The gearboxes of the first unit (with steam turbine) are equipped with overrunning clutches in case of failure of either the gas turbine or the steam turbine to continue producing E-power.

The gas turbines, type Siemens SGT600 (Former ABB GT10B) is a low weight industrial gas turbine designed and developed to incorporate size and weight advantages of the aircraft derivative gas turbine while at the same time maintaining the robustness, flexibility and long life advantages of the traditional heavy duty industrial gas turbine.

Figure 3: Siemens SGT600 (Former ABB GT10B)

The gas generator section consists of a ten stage axial air compressor which is built up from a number of fully electron beam welded discs and onto which the intermediate shaft also is welded. The two gas generator turbine discs are bolted onto the intermediate shaft.

The low pressure section of the compressor and intermediate shaft are manufactured in low alloy steel. Inconel 718 is used for the discs in the high pressure section of the compressor.
The cooled gas generator turbine stator and rotor blades are precision cast.

While the compressor section is of conventional horizontally split design, the remainder of the unit makes use of vertically split, single piece, circular stator components. By this means the loss of circularity experienced with split casings is eliminated, hence running clearances and, thereby aerodynamic losses can be reduced to a minimum.
These sections can be removed as modules which permits easy access and fast simple maintenance. The combustion chamber is of straight through annular design and suitable for both liquid and gaseous fuels.

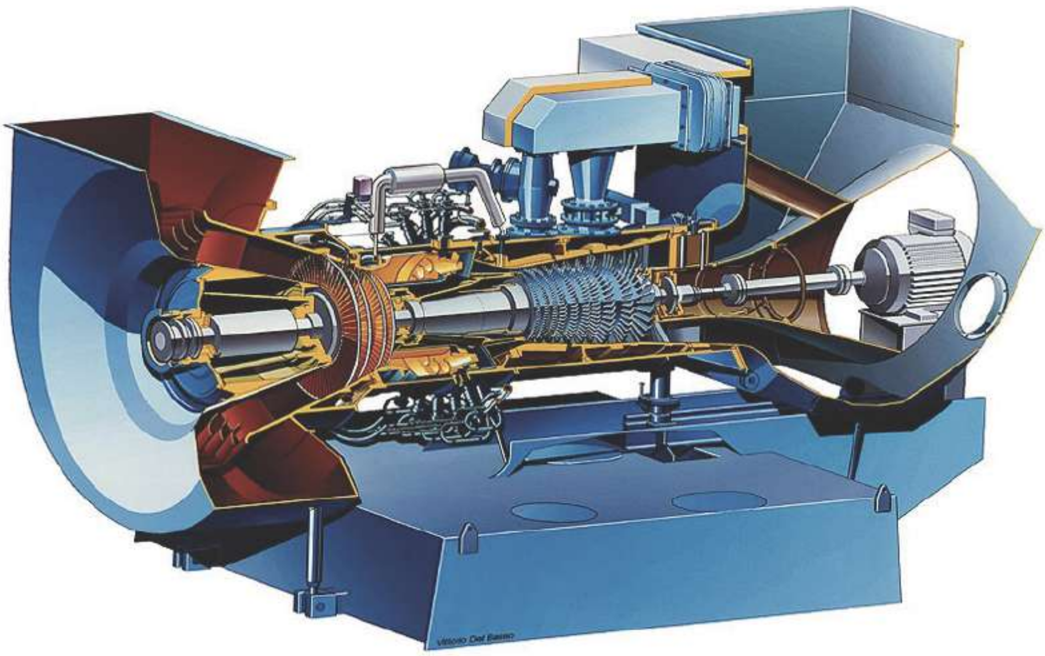


Figure 4: SGT600 Engine cutaway view

4. Starting point

A gas turbine consists of thousands of components, most of them do not requiring any regular replacement or checks. For a few components the conditions are quite different due to the potential consequences with respect to risks to humans, surrounding equipment and the environment.

For Siemens SGT600 engine these “critical components” are subject to specific maintenance requirements due to operation environment and operation profile of the individual gas turbine. Damaged mechanisms affecting the life of critical components can be split into four different categories, each with its specific characteristics:

- Time dependent damage
- Cycle dependent damage
- Vibration related damage
- Wear and tear

To be able to investigate the different scenario’s as stated in chapter one we have to determine the “As Known” current condition of the unit. This condition can be derived from follow criteria:

1. OEM maintenance schedules
2. OEM replacement schedules
3. Operating profile GT6
4. Running log GT6
5. Borescope inspection GT6

4.1. OEM Maintenance schedule

Economical operation of the power plant is affected by the operational performance and also by the availability and the reliability of the plant as a whole. The overall availability, however, is not guaranteed simply because the owner has originally invested in quality reliable equipment, with provision to operate without disturbances. Successful and profitable power plant operation also requires a well-prepared maintenance concept together with well-trained operation personnel.

Maintenance can be divided into two categories:

- ***Preventive maintenance***
- ***Corrective maintenance***

The ***Preventive maintenance*** is divided into two main categories:

- **Operation maintenance**
- **Maintenance Plan**

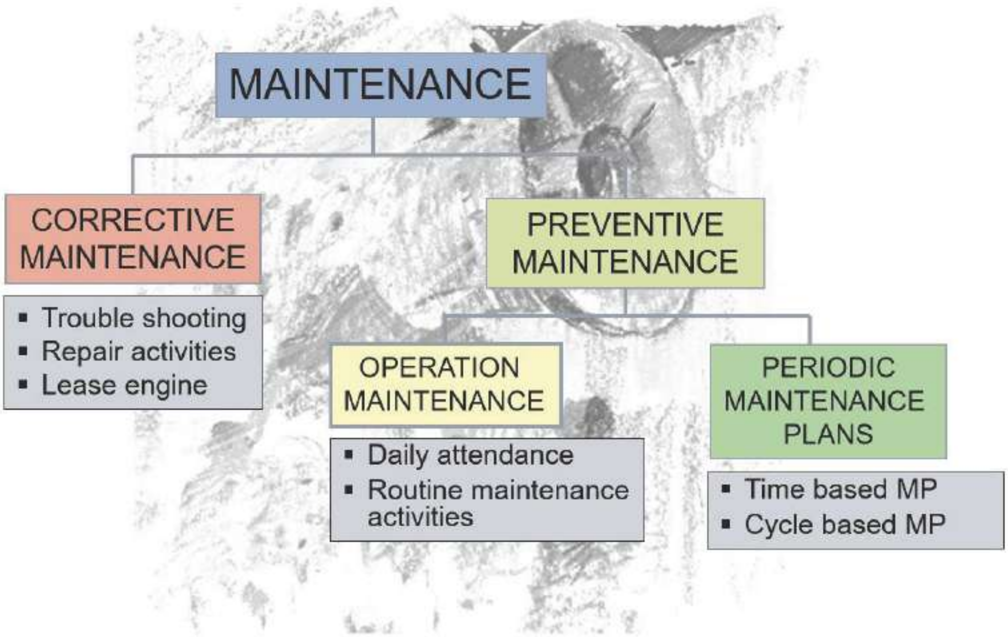


Figure 5: Maintenance concept

4.1.1. Operation Maintenance

The Gas turbine requires regular attention in order to detect trends and to determine abnormalities at an early stage. Operation maintenance is to be carried out according to the operation maintenance manual, which is included in the plant documentation. Operation maintenance activities are performed on a daily, weekly and monthly basis. These consist mainly of daily checks which include instrument readings, visual inspection for general condition i.e. check for leakage, abnormal noise, etc. and also routine maintenance activities such as replacement of filter,cleaning, etc.

4.1.2. Equivalent Operating Hours

The critical parts determining the time between overhaul are the hot section parts, which are exposed to:

- Creep due to high stresses in combination to high temperatures
- Low cycle fatigue = thermal stresses at transient conditions (start and stop)
- Hot oxidation or corrosion

The creep and LCF exposition is recalculated to an equivalent operating time for simplicity. The corrosion effect is basically fuel dependent, but also air quality dependent in heavily polluted areas. For each type of gas turbine there's a formula for calculating the Equivalent Operating Hours / Equivalent Operating Cycles. The formula for the SGT600 is:

EOH = Equivalent operating hours

$$EOH = \Sigma (C_x \times C_f \times C_w \times H) + 5 \times EOC$$

C_X = Stress factor
C_f = Fuel factor
C_w = Water and steam injection factor
H = Operating hours

C_x = 0.5 - 10 depending on running condition
C_f =1.0 for gas (see GTI J241003E)
C_f =1.2 for liquid fuel (see GTI J242003E)
C_W =1.0 when no water or steam injection is used
C_W =1.25 when water or steam injection is used

EOC = Equivalent Operating Cycles

$$EOC = C_n \times N$$

C_n = Start and stop factor
N = Number of start/stop cycles

Figure 6: EOH and EOC formula

4.1.3. Maintenance Plan

The maintenance plan used for GT6 is a time-based standard maintenance plan, which is designed to optimise the overall maintenance cost and availability during the lifetime of the gas turbine.

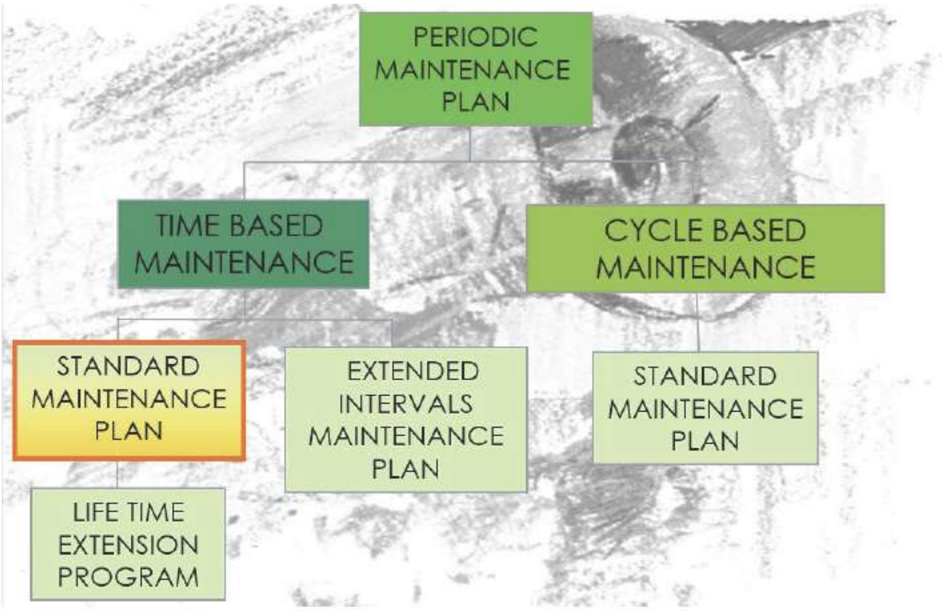


Figure 7: SGT600 Maintenance strategies

The maintenance plan can also be Cycle based or a mix between both concepts depending on the operating regimes.

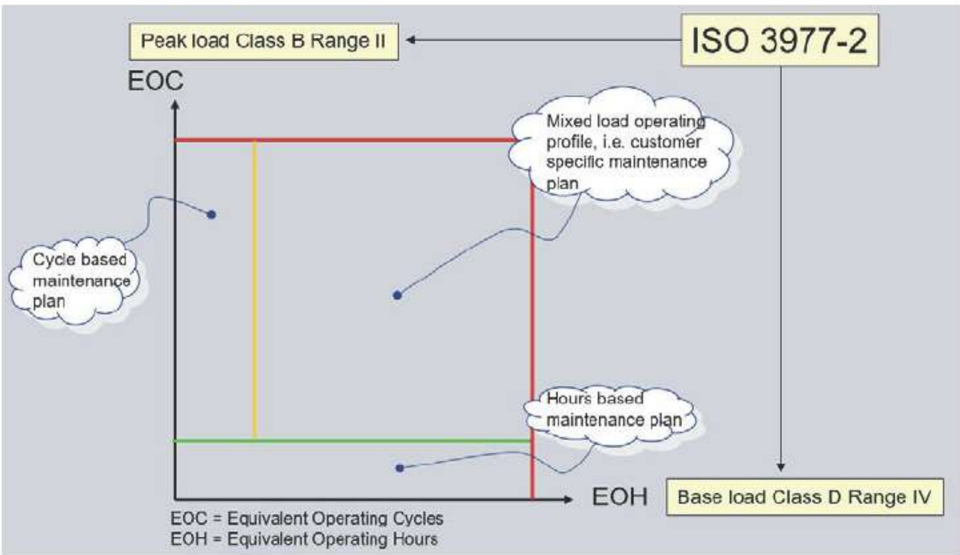


Figure 8: EOH vs EOC

The overall turbine/alternator availability is not only determined by forced outages, but also by planned outages. Therefore such outages must be managed efficiently.

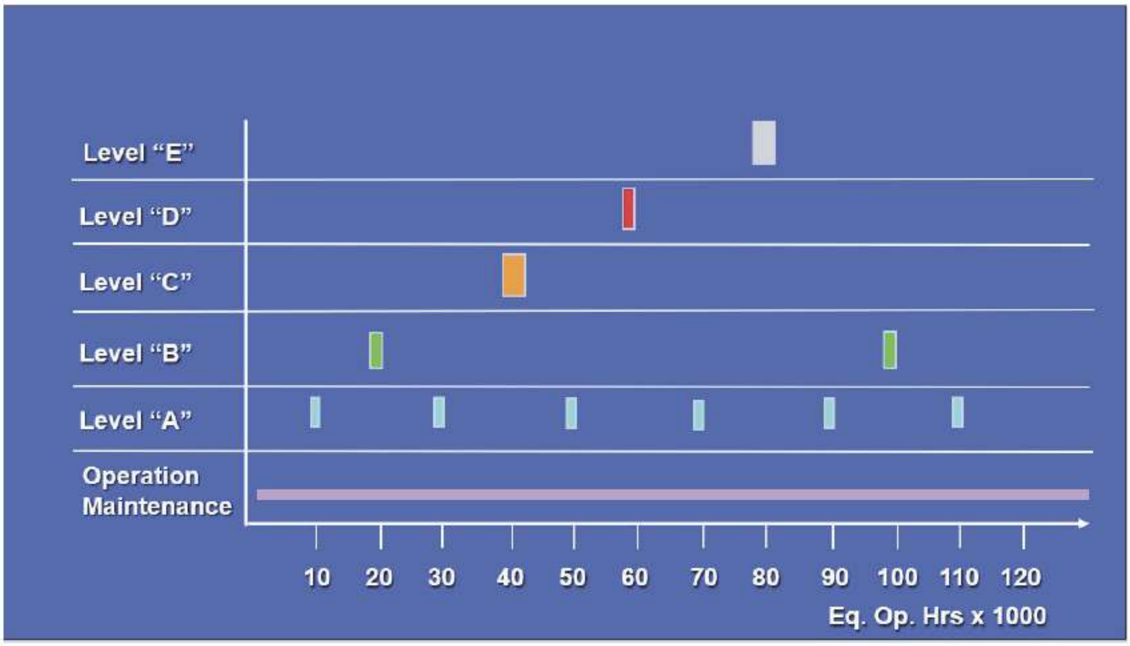


Figure 9: Time based standard maintenance plan

4.1.4. OEM Maintenance schedule Life time extension program

The standard base load maintenance plan is valid for operation up to 120 000 EOH. In order to allow operation up to 160000 EOH, a Life Time Extension program is available for the SGT-600/GT10. The LTE program consists of three parts.

- Life Time Assessment (LTA)
- Life Time Extension (LTE)
- Optimized Replacement Schedule.

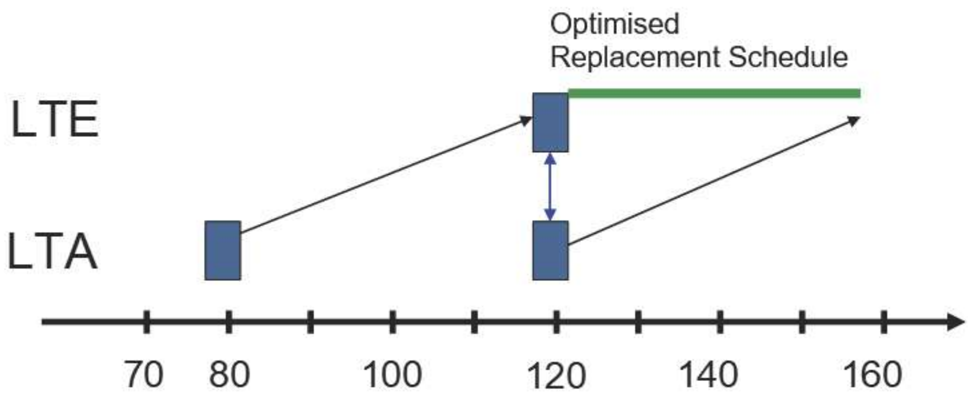


Figure 10: Life Time Extension program

For units planning to operate beyond 120 000 EOH a status determination has to be done and implementation of the LTE program.

Life Time Assessment:

- Performed at 80.000 E.O.H
- Level E inspection, with significant additional analysis and evaluation
- Inspections to determine state of major components before LTE:
    - Non-destructive and
    - Destructive tests
- Cost optimization of operation beyond 120.000 E.O.H.

Life Time Extension:

- 120,000 E.O.H. level C inspection with add-ons:
    - Recommended replacements as agreed with customer
    - Upgrade packages as agreed with customer

Optimised Replacement Schedule:

- Operation maintenance with reference to:
    - Previous experience
    - Customer's available spare parts
    - Replacement history
    - Future needs

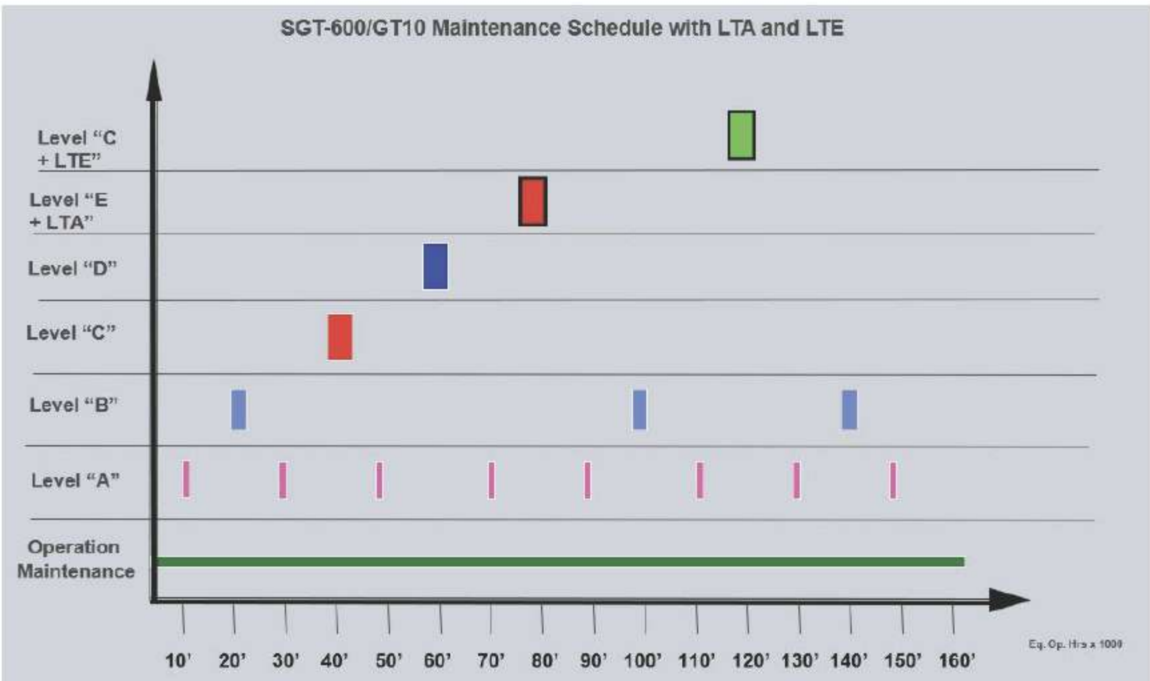


Figure 11: SGT600 Maintenance schedule with LTA and LTE

4.1.5. Maintenance Levels

The various planned maintenance plan activities are based on a level system. The maintenance levels are:

Level A (10.000, 30.000, 50.000, 70.000, 90.000, 110.000 Equivalent Operating Hours):

- Cleaning the compressor (off-line), by customer
- Borescope inspection:
  - Compressor blading
  - Combustion chamber
  - Fuel injectors
  - Turbine blading
- Check of the auxiliary system
- Check of the control system
- Test run

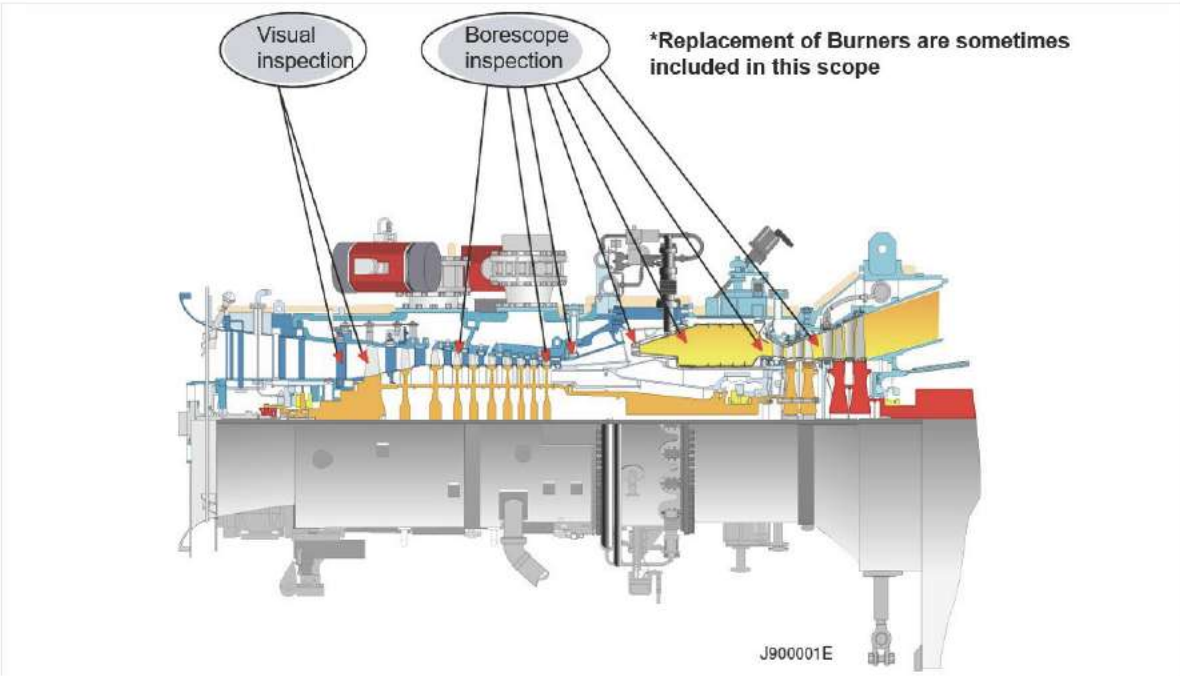


Figure 12: Borescope inspection

Level B (20.000, 100.000 Equivalent Operating Hours)

- Cleaning the compressor (off-line), by customer
- Boroscope inspection of compressor stage 4 and 10
- Inspection of:
  - Compressor
  - Turbine blading
  - Fuel injectors
  - Couplings and gear
  - Visual inspection of the generator
- Replacement of the combustion chamber at 20' EOH
- Replacement of compressor turbine guide vane 1 at 20' EOH
- Reconditioning of the combustion chamber at 100' EOH
- Reconditioning of compressor turbine guide vane 1 and 2 at 100' EOH
- Check of the auxiliary system
- Check of the control system
- Test run

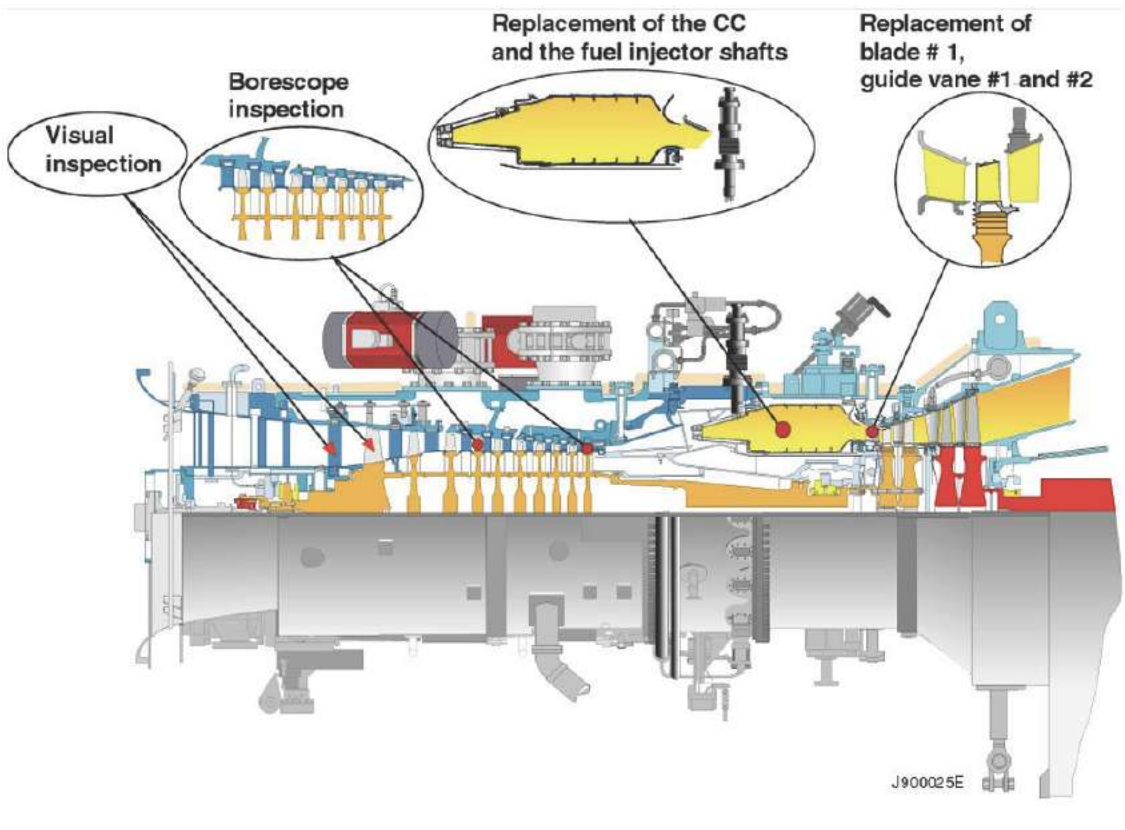


Figure 13: Hot section inspection

Level C (40.000 Equivalent Operating Hours)

- Cleaning the compressor (off-line), by customer
- NDT-test of compressor blading
- NDT-test of turbine blading
- Inspection of:
  - Fuel injectors
  - Couplings and gear
  - Auxiliaries
- Replacement of compressor turbine blades stage 1
- Replacement of compressor turbine guide vane 2
- Reconditioning of the combustion chamber
- Reconditioning of compressor turbine guide vane 1
- Visual inspection of generator
- Check of the auxiliary system
- Check of alarms and shutdowns
- Test run

Level C + LTE (40.000 Equivalent Operating Hours + Life Time Extension)

- Level E
- LTE for:
  - Compressor rotor
  - Flange / bolt connection
  - Casing position
  - Roundness Measurements
  - Exhaust parts
  - Destructive evaluation:
    - PT vanes 3 and 4
    - PT blades 4

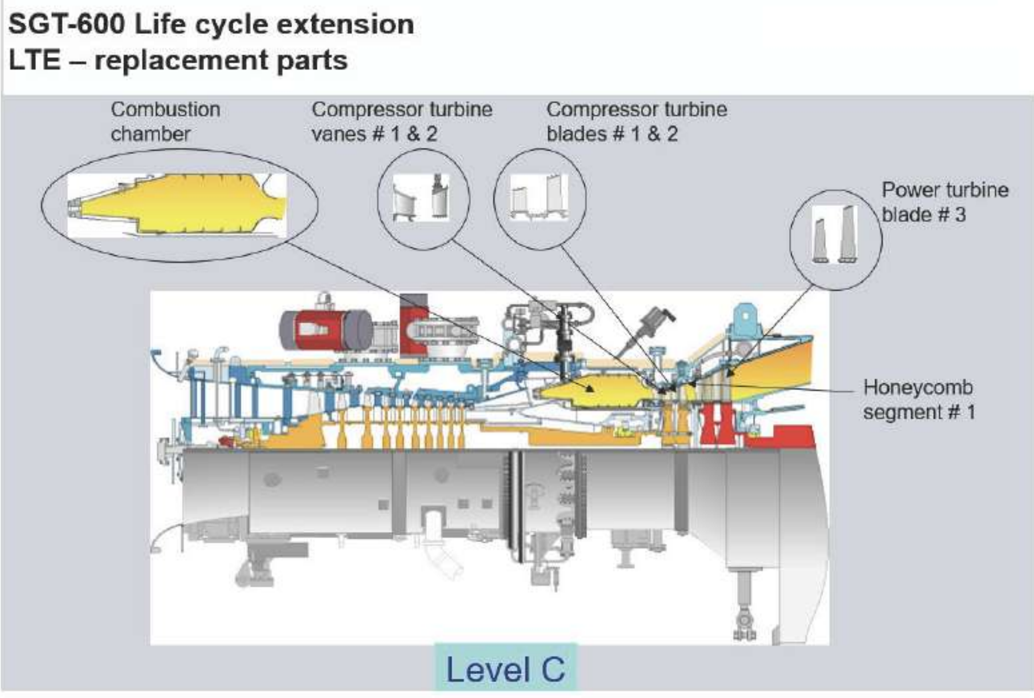


Figure 14: Level C + LTE

Level D (60.000 Equivalent Operating Hours)

- Cleaning the compressor (off-line), by customer
- Borescope inspection of compressor stage 4 and 10
- Inspection of:
  - Compressor
  - Turbine blading
  - Fuel injectors
  - Couplings and gear
- Visual inspection of the generator
- Replacement of compressor turbine blades stage 2 and 3
- Replacement of compressor turbine guide vane 1
- Reconditioning of the combustion chamber
- Visual inspection of generator
- Check of the auxiliary system
- Check of alarms and shutdowns
- Test run

Level E (80.000 Equivalent Operating Hours)

- Cleaning the compressor (off-line), by customer
- NDT-test of compressor blading
- NDT-test of turbine blading
- Overhaul of the generator
- Inspection of:
  - Fuel injectors
  - Couplings and gear
  - Auxiliaries
- Replacement of compressor turbine blades stage 1
- Reconditioning of the combustion chamber
- Reconditioning of compressor turbine guide vane 1 and 2
- Check of the auxiliary system
- Check of alarms and shutdowns
- Test run

Level E + LTA (80.000 Equivalent Operating Hours + Life Time Assessment)

- Level E
- LTA for:
  - Compressor rotor
  - Flange / bolt connection
  - Casing position
  - Roundness Measurements
  - Exhaust parts
  - Destructive evaluation:
    - PT vanes 3 and 4
    - PT blades 4

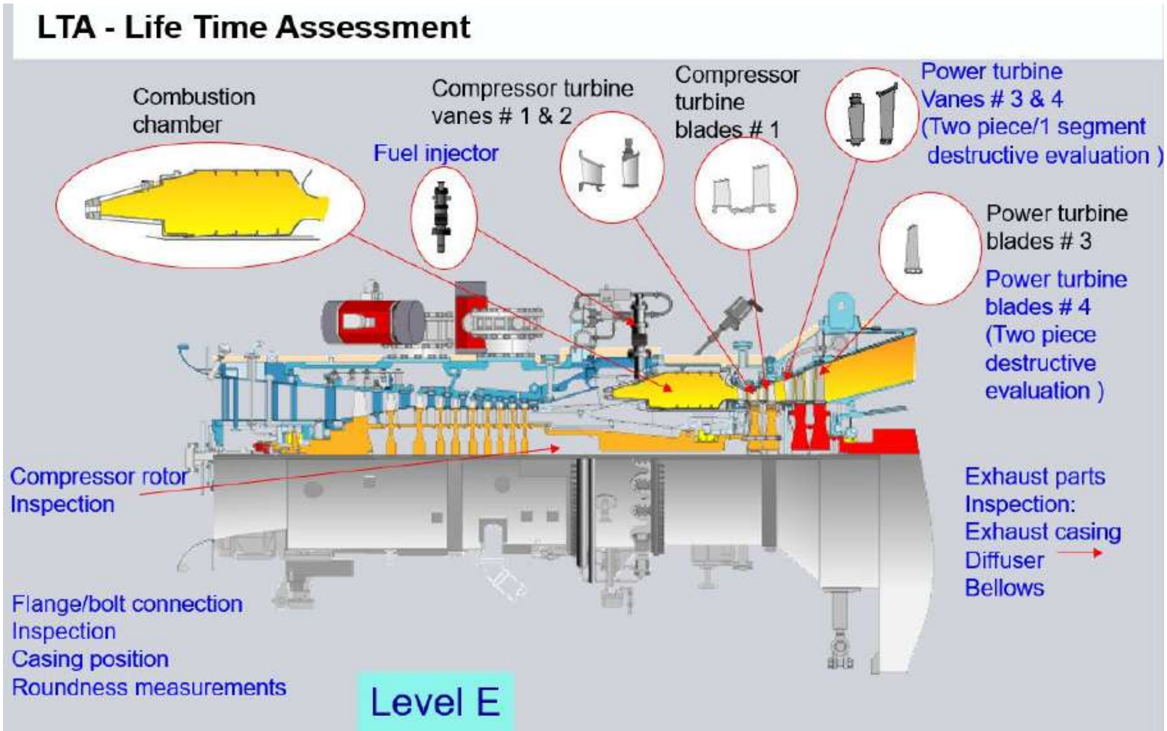


Figure 15: Level E + LTA - Life Time Assessment

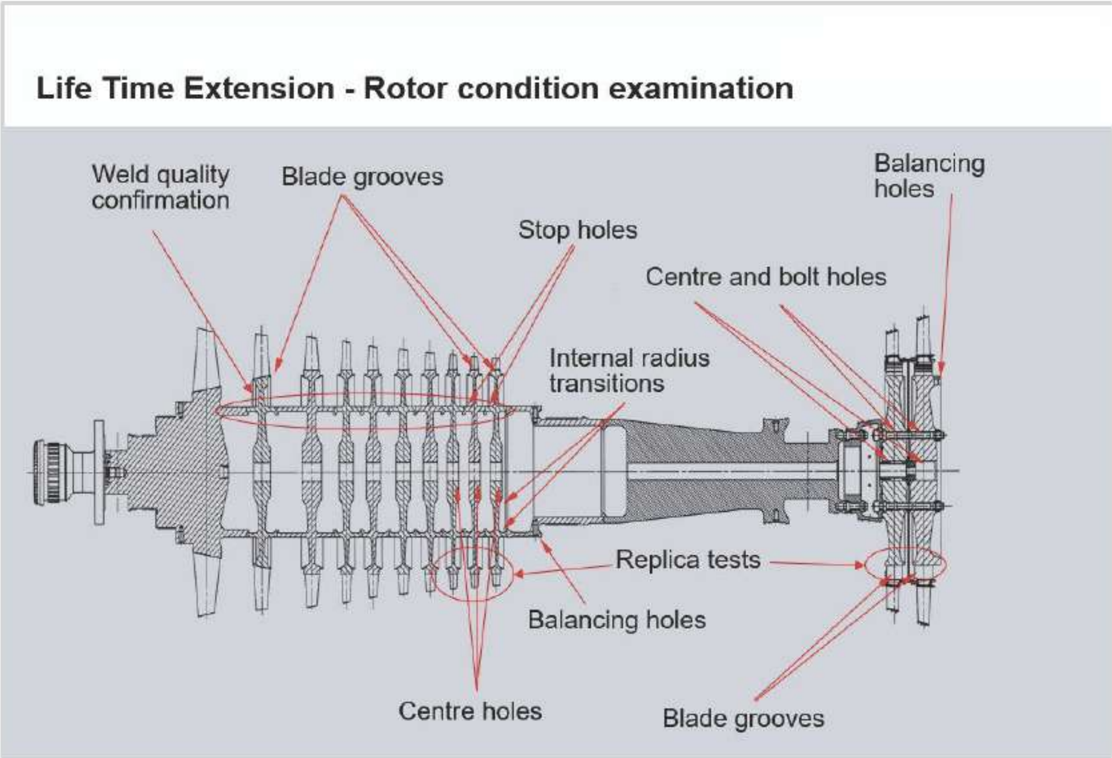


Figure 16: LTE rotor condition examination

4.2. OEM replacement schedule

The replacement schedule is an overview from all identified components in the gas turbine Maintenance Plan to be replaced after a certain number of equivalent operation hours. Examples are turbine blading, heat segments and combustion chambers.

OEM RECOMMENDED EOH REPLACEMENT SCHEDULE

EQUIVALENT OPERATING HOURS	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000	110000	120000
MAINTENANCE LEVEL	Level A	Level B	Level A	Level C	Level A	Level D	Level A	Level E + LTA	Level A	Level B	Level A	Level C + LTE
TURBINE SECTION												
Combustion chamber:	BSI	replace	BSI	replace	BSI	replace	BSI	replace	BSI	replace	BSI	replace
Guide vanes 1	BSI	replace	BSI	replace	BSI	replace	BSI	replace	BSI	replace	BSI	replace
Running blades 1	BSI	inspect	BSI	replace	BSI	inspect	BSI	replace	BSI	inspect	BSI	replace
Guide vanes 2	BSI	-	BSI	replace	BSI	-	BSI	replace	BSI	-	BSI	replace
Running blades 2	BSI	-	BSI	-	BSI	replace	BSI	-	BSI	-	BSI	replace
Guide vanes 3	BSI	-	BSI	-	BSI	-	BSI	inspect	BSI	-	BSI	(replace)
Running blades 3 (power)	BSI	-	BSI	replace	BSI	-	BSI	replace	BSI	-	BSI	replace
Running blades 3 (mech drive)	BSI	-	BSI	-	BSI	replace	BSI	-	BSI	-	BSI	replace
Guide vanes 4	BSI	-	BSI	-	BSI	-	BSI	inspect	BSI	-	BSI	(replace)
Running blades 4	BSI	-	BSI	-	BSI	-	BSI	inspect	BSI	-	BSI	(replace)
Honey combs 1		inspect		replace		inspect		replace		inspect		replace
Honey combs 2		-		-		replace		-		-		replace
Honey combs 3 (power)		-		replace		-		replace		-		replace
Honey combs 3 (mech drive)		-		-		replace		-		-		replace
Turbine disc 1 (OLD Design) material Ni901		-		-		-		NDT		NDT		NDT
Turbine disc 1 (NEW design) material In718 standard since 2010		-		-		-		NDT		-		NDT
Turbine disc 2 (OLD Design) material Ni901		-		NDT		(NDT) if EOC < 600		NDT		NDT		NDT
Turbine disc 2 (NEW design) material In718 standard since 2010												NDT
Power Turbine disc 3		-		-		-		NDT		-		NDT

Power Turbine disc 4		-		-		-		NDT		-		NDT
COMPRESSOR SECTION												
Compressor rotor OLD Design (serial < B0928) material stage 6-10 Ni901		-		-		-		NDT		-		NDT
Compressor rotor NEW Design (serial >B0928) material stage 6-10 In718 Change of geometry of blades #1 and #2 attachments		-		-		-				-		NDT
IGV overhaul		-		overhaul		-		overhaul		-		overhaul
IGV stage 0	BSI	BSI	BSI	(replace)	BSI	BSI	BSI	(replace)	BSI	BSI	BSI	(replace)
IGV stage 1	BSI	BSI	BSI	inspect	BSI	BSI	BSI	NDT	BSI	BSI	BSI	NDT
Guide vane 2	BSI	BSI	BSI	inspect	BSI	BSI	BSI	NDT	BSI	BSI	BSI	NDT
Compressor blades 1-10	BSI	BSI	BSI	inspect	BSI	BSI	BSI	NDT	BSI	BSI	BSI	NDT
Compressor vanes 3-10	BSI	BSI	BSI	inspect	BSI	BSI	BSI	NDT	BSI	BSI	BSI	NDT
Compressor stator rings 6 - 10	BSI	BSI	BSI	(replace)	BSI	BSI	BSI	(replace)	BSI	BSI	BSI	(replace)
Comp. rotor sealing edges 3 - 5	BSI	BSI	BSI	inspect	BSI	BSI	BSI	(replace)	BSI	BSI	BSI	(replace)
BEARINGS												
Gearbox pinion NDE bearing		-		inspect		-		inspect		-		inspect
Gearbox pinion DE bearing		-		inspect		-		inspect		-		inspect
Thrust bearing no.1		-		inspect		-		inspect		-		inspect
Radial bearing no.1		-		inspect		-		inspect		-		inspect
Turbine radial bearing no.2		-		inspect		-		inspect		-		inspect
Front PT bearing no.3		-		inspect		-		inspect		-		inspect
Rear PT bearing no.4		-		inspect		-		inspect		-		inspect
Thrust bearing no.4		-		inspect		-		inspect		-		inspect

Table 1: OEM recommended EOH replacement schedule

4.3. Operating profile GT6

We have created an operating profile from GT6 by using all available operating data and historical maintenance documentation received from CHP management. This profile together with the running log will help us determine the amount of service hours of the different components.

OPERATING PROFILE GT6

Date	Hours	Starts	EOH's	EOH's SCA	Reason
17 March 2023	186104	1462	193414	175779	Borescope Inspection
31 May 2022	183595	1451	190850	173656	T7 verification, Replace burner restriction
15 October 2021	178663	1445	185888	169920	Flowtest CC, Calibration PT speedcard, Adjustment T7 spread alarm
30 September 2020	170580	1404	177600	163087	TIT spread, synchronizing issues, High T7 and failed starts
22 May 2019	164716	1367	171551	158295	Semi-Annual inspection
07 April 2015	146203	1187	150357	141228	Level D inspection
02 November 2011	123383	1060	127073	121773	Level C inspection
04 October 2011	Unknown	Unknown	Unknown	Unknown	IGV inspection
18 April 2010	112145	994	117115	112131	Level A inspection
01 March 2008	98012	760	101812	99548	Level E inspection + LTA ?
18 September 2006	90777	685	94202	92821	High vibration bearing #2
13 March 2006	87239	665	90564	89545	Compressor Damage
03 October 2004	75518	623	78633	Unknown	Follow-up Level D Inspection
06 June 2004	73977	615	77052	Unknown	Level D Inspection
08 February 2004	71248	612	74308	Unknown	BSI CC
27 December 2003	70555	606	73585	Unknown	Level A inspection + CC replacement
12 May 2002	57147	555	59922	Unknown	Level A inspection
19 November 2001	53881	547	56616	Unknown	Bearing Damage
10 September 2001	53274	529	55915	Unknown	Level C Inspection

27 October 1998	30573	372	32433	Unknown	Level A Inspection
21 May 1998	27095	364	28915	Unknown	IGV Repair
01 July 1997	19901	328	21541	Unknown	Level B Inspection

Table 2: Operating Profile GT6

4.3.1. Running log GT6

From the information derived from the operating profile and the available maintenance reports we compiled an overview of the service hours per component in the so called ‘Running Log’.

RUNNING LOG

COMPONENT	INSTALLATION DATE	ENGINE EOH'S SCA INSTALLATION	CONDITION @INSTALLATION	OEM RECOMMENDED REPLACEMENT SCHEDULE	CONSUMED EOH'S SCA SINCE INSTALLATION
COMPRESSOR INLET					
SSS Clutch Start Motor	01 November 1994	0	New	Inspect	175779-0 = 175779
Compressor Inlet Casing	01 November 1994	0	New	Inspect	175779-0 = 175779
COMPRESSOR					
Front Compressor casing	07 April 2015	141228	Reconditioned	Inspect	175779-141228 = 34551
IGV overhaul	07 April 2015	141228	Reconditioned	Overhaul @40000 EOH	175779-141228 = 34551
IGV stage 0	07 April 2015	141228	New	Replace @40000 EOH	175779-141228 = 34551
IGV stage 1	06 June 2004	77052	New	NDT > 40000 EOH	175779-77052 = 98727
Guide vane 2	01 November 1994	0	New	NDT > 40000 EOH	175779-0 = 175779
Compressor blades 1-10	01 November 1994	0	New	NDT > 40000 EOH	175779-0 = 175779
Compressor vanes 3-10	01 November 1994	0	New	NDT > 40000 EOH	175779-0 = 175779
Compressor stator rings 6 - 10	01 November 1994	0	New	Replace > 40000 EOH	175779-0 = 175779
Comp. rotor sealing edges 3 - 5	01 November 1994	0	New	Replace > 40000 EOH	175779-0 = 175779
Central Compressor casing	01 November 1994	0	New	Inspect	175779-0 = 175779
Rear Compressor casing	01 November 1994	0	New	Inspect	175779-0 = 175779
COMBUSTION CHAMBER / EV BURNERS / FUEL INJECTORS					
Central Casing	01 November 1994	0	New	Inspect	175779-0 = 175779
Ejectors	01 November 1994	0	New	Overhaul > 20000 EOH	175779-0 = 175779
Ignition System	01 November 1994	0	New	Overhaul > 20000 EOH	175779-0 = 175779

Combustion chamber	07 April 2015	141228	Reconditioned	Replace > 20000 EOH	175779-141228 = 34551
COMPRESSOR TURBINE					
Guide vanes 1	07 April 2015	141228	Reconditioned	Replace > 20000 EOH	175779-141228 = 34551
Running blades 1	07 April 2015	141228	Reconditioned	Replace > 40000 EOH	175779-141228 = 34551
Guide vanes 2	07 April 2015	141228	Reconditioned	Replace > 40000 EOH	175779-141228 = 34551
Running blades 2	02 November 2011	121773	Used	Replace > 60000 EOH	175779-121773 = 54006
Honey Combs Seal 1	07 April 2015	141228	New	Replace > 40000 EOH	175779-141228 = 34551
Honey Combs Seal 2	01 March 2008	99548	Reconditioned	Replace > 60000 EOH	175779 - 99548 = 76231
POWER TURBINE					
Guide vanes 3	02 November 2011	121773	New	Inspect > 80000 EOH	175779-121773 = 54006
Running blades 3	07 April 2015	141228	New	Replace > 40000 EOH	175779-141228 = 34551
Guide vanes 4	02 November 2011	121773	New	Inspect > 80000 EOH	175779-121773 = 54006
Running blades 4	01 November 1994	0	New	Replace > 120000 EOH	175779-0 = 175779
Honey Combs Seal 3	07 April 2015	141228	Reconditioned	Replace > 40000 EOH	175779-141228 = 34551
Honey Combs Seal Ring 4	01 March 2008	99548	New	Inspect	175779 - 99548 = 76231
Power Turbine Diffuser	01 November 1994	0	New	Inspect	175779-0 = 175779
Turbine Casing	01 November 1994	0	New	Inspect	175779-0 = 175779
Exhaust Channel	01 November 1994	0	New	Inspect	175779-0 = 175779
COMPRESSOR ROTOR					
Flexible Coupling	01 November 1994	0	New	Inspect	175779-0 = 175779
Turbine disc 1 (OLD Design)	01 November 1994	0	New	NDT > 20000	175779-0 = 175779
Turbine disc 2 (OLD Design)	01 November 1994	0	New	NDT > 20000	175779-0 = 175779
Power Turbine disc 3	01 November 1994	0	New	NDT > 40000	175779-0 = 175779
Power Turbine disc 4	01 November 1994	0	New	NDT > 40000	175779-0 = 175779
Compressor rotor OLD Design	01 November 1994	0	New	NDT > 40000	175779-0 = 175779

TURBINE BEARINGS					
Bearing 1 Thrust	07 April 2015	141228	New	Inspect > 40000 EOH	175779-141228 = 34551
Bearing 1 Radial	07 April 2015	141228	New	Inspect > 40000 EOH	175779-141228 = 34551
Bearing 2 (Radial)	07 April 2015	141228	New	Inspect > 40000 EOH	175779-141228 = 34551
Bearing 3 (Radial)	07 April 2015	141228	New	Inspect > 40000 EOH	175779-141228 = 34551
Bearing 4 Radial	07 April 2015	141228	New	Inspect > 40000 EOH	175779-141228 = 34551
Bearing 4 Thrust	07 April 2015	141228	New	Inspect > 40000 EOH	175779-141228 = 34551
GEARBOX BEARINGS					
Gearbox pinion NDE bearing	01 November 1994	0	New	Inspect > 40000 EOH	175779-0 = 175779
Gearbox pinion DE bearing	01 November 1994	0	New	Inspect > 40000 EOH	175779-0 = 175779

Table 3: Running log GT6

4.4. Borescope inspection

On March 17th 2023 unit GT6 was borescope inspected by Xx. The general condition of the unit was better than expected from time in service perspective.

The “full open” position of the IGV’s deviates from expected position. It is recommended to perform a calibration check on the IGV system as it could be the reason of limited power.

Compressor inlet section is dirty. It is recommended to clean the compressor inlet section and perform multiple compressor washes prior to next start-up.
Turbine guide vane 1 have sustained considerable burning, cracking, discoloration and erosion, but expected with amount of hours consumed. Due to the extent of damage and consumed hours and start it is recommended to re-inspect the guide vanes 1 within 1.000 EOH or 25 starts

Oil leakage is present originating from the no 2 bearing bolts/seal plate. Check if tank sub-pressure is sufficient during operation. Check oil leakage at next BSI inspection

For more details please see borescope inspection report R20230317-1.

5. Option 1 - No action

Not having a maintenance strategy is the simplest "strategy" to have for asset maintenance. The absence of a strategy eliminates the need to plan ahead for maintenance. When the equipment is non-critical and does not pose any safety risk, this strategy may be ideal. A "no maintenance strategy" approach is unsuitable in most other situations. The risk of equipment unavailability, or safety issues should prompt some level of thought about a maintenance strategy.

5.1. Scope for no action

Scope for no action will be determined by corrective maintenance. Components that will break down will be replaced.

5.2. Maintenance and operational costs

Without maintenance strategy the maintenance costs will be unpredictable and depending on corrective maintenance. Corrective maintenance is the process of restoring assets after unplanned downtime. It includes troubleshooting, disassembling, re-adjusting, repairing, replacing and re-aligning equipment. Since the unit is used as back-up unit, corrective maintenance will mean that both engines are not available and alternative sources must secure the delivery obligations. The lead time and cost of the repair depends on the availability of spare parts and skilled personnel.

5.3. Risk assessment

[illegible]	RISK NAME	RISK DESCRIPTION	CAUSE / RISK FACTOR / RISK DRIVER	IMPACT	LIKELIHOOD	IMPACT	Max Loss (MEUR)	Expected Loss (MEUR)
	[illegible]	Risk description including Cause, Event and Impact. (One full sentence)	[illegible]	[illegible]	Likelihood Ranking [illegible]	Impact Ranking [illegible]	[illegible]	[illegible]
OPTION NO ACTION	Low efficiency of the unit	Reduced efficiency due to lack of maintenance resulting in high fuel consumption	[illegible]	High fuel costs	Frequently (6)	[illegible]	[illegible]	[illegible]
OPTION NO ACTION	[illegible]	Crash of unit due to lack of maintenance resulting in unit being out of operation	[illegible]	[illegible]	Frequently (6)	[illegible]		
OPTION NO ACTION	Reduced power output of the unit	Reduced power output due to lack of maintenance resulting in higher operational cost per MW	[illegible]	High electricity costs	Frequently (6)	[illegible]		
OPTION NO ACTION	[illegible]	[illegible]	[illegible]	Environmental impact exceeds permit limit, image damage	Frequently (6)	[illegible]		
OPTION NO ACTION	[illegible]	[illegible]	[illegible]	Low operational flexibility, single source dependency	Frequently (6)	[illegible]		

Table 4: Risk assessment GT6 – No action

5.4. Safety

From OEM point of view the unit B00613 has reached end of life conditions and safe operation beyond this state will not be guaranteed. For safety reasons, OEM personnel are no longer allowed to work on the unit.
Due to the high operating speeds mechanical failure can occur, in particular with turbine and compressor blades and discs. Such failures can lead to a loss of containment, mechanical damage, and fire and explosion risks from plant disruption.

5.5. Steam production

Operational use of the engine without maintenance strategy will not have a major impact on the steam production as long as the engine is available. Without the availability of the back-up engine it is not possible to operate the boiler and the steam turbine.

5.6. Efficiency

In current state the engine is running with reduced efficiency which will lead to higher fuel consumption and costs. Collateral damage of running with reduced efficiency is the increased thermal load needed for equivalent performance. So reduced efficiency will decrease hot-parts component service life.
In case the backup unit is not available, operations is forced to run the backup boilers to fulfill the delivery obligations. If running solo on the backup boilers the powerplant is not complying with the applicable efficiency standards and can be fined by local government.

5.7. Emissions

The increased fuel consumption due to reduced efficiency will lead to higher total emissions.

5.8. Availability

Operational use of the engine without maintenance strategy can have major influence on the operational flexibility.
Data from the operating profile, running log and replacement schedule shows that most identified components are due for inspection or replacement. Data from the latest borescope inspection indicates that the general condition of the unit is better than expected for time in service. Turbine guide vane 1 and 2 have sustained considerable burning, cracking, discoloration and erosion, but expected with amount of hours consumed. Due to the extent of damage and consumed hours and starts it is recommended to re-inspect the guide vanes 1 within 1.000 EOH or 25 starts.
Basically the unit is suitable to use for short running periods like off-line washing or regular maintenance of unit GT5. For longer running periods the unit is not reliable.

Without the availability of the unit (assuming GT5 is out of service) :

- No K10/K11 boiler operation possible
- No E-boiler operation possible
- No steam turbine operation possible
- No power generation possible
- No benefit CHP generation.
- Increased energy costs per ton of paper (average 180 %)

6. Option 2 – Minimum repair existing unit

For option 2 the starting point is to minimize the maintenance costs on the unit to the lowest acceptable level. This level must fulfill the minimum requirement of safety and availability of the unit. The most necessary work will be executed to keep the unit safe and available during maintenance work or failure of the GT5 unit. With this minimum repair the unit will maximize the use of remaining operating hours on the components and will be available for another 5500 EOH before next inspection / overhaul.

6.1. Scope for minimum repair existing unit

The table below shows the scope and associated estimated budget costs for the minimum repair of the existing engine.

SCOPE FOR MAXIMUM 5500 EOH

COMPONENT	INCLUDED IN SCOPE	STATUS / COMMENTS	COST ESTIMATION
COMPRESSOR			
IGV overhaul	Yes	Stuck during start	€ 25.000,00
Compressor stator rings 6 - 10	No	Worn out, replace	-
Comp. rotor sealing edges 3 - 5	No	Worn out, replace	-
COMBUSTION CHAMBER / EV BURNERS / FUEL INJECTORS			
Ejectors	Yes	T7 spread issues, recondition	In CC pricing
Ignition system	Yes	T7 spread issues, recondition	In CC pricing
Combustion chamber	Yes	T7 spread issues, recondition	€ 350.000,00
COMPRESSOR TURBINE			
Guide vanes 1	Yes	Cracks, replace set	€ 323.400,00
Running blades 1	No	5500 remaining EOH, no replacement	-
Guide vanes 2	Yes	Cracks, replace set	€ 326.700,00
Running blades 2	No	6000 remaining EOH, no replacement	-
POWER TURBINE			
Guide vanes 3	No	No replacement	-
Running blades 3	No	5500 remaining EOH, no replacement	-
Guide vanes 4	No	No replacement	-
Running blades 4	Yes	Service life > 160.000 EOH, replace set	€ 204.800,00
COMPRESSOR ROTOR			
Compressor turbine disc 1	Yes	Life Time Assessment by DEKRA	In LTA pricing
Compressor turbine disc 2	Yes	Life Time Assessment by DEKRA	In LTA pricing
Compressor rotor	Yes	Life Time Assessment by DEKRA	In LTA pricing
POWERTURBINE ROTOR			
Power turbine disc 3	Yes	Life Time Assessment by DEKRA	In LTA pricing
Power turbine disc 4	Yes	Life Time Assessment by DEKRA	In LTA pricing
Power turbine rotor	Yes	Life Time Assessment by DEKRA	In LTA pricing
MISCELLANEOUS			
Revision / Inspection hours	Yes	Revision hours	€ 225.000,00
Materials	Yes	Revision material	€ 80.000,00
LTA Inspection	Yes	Life Time Assessment by DEKRA	€ 45.000,00
TOTAL			
TOTAL			€ 1.579.900,00
INCL. 25% BUDGET MARGIN			€ 1.974.875,00

Table 5: Budget cost estimation option 1

6.2. Maintenance and operational costs

Option 2 is focusing on eliminating direct issues like cracks, burning, discoloration, erosion et cetera which reduces the risk for collateral damage and increases the availability of the unit. To reduce the maintenance costs on the recommended replacement parts one can opt for used parts with a left minimum of approximately 12000 equivalent operating hours. Operational costs will be higher comparing to unit GT5 due to reduced efficiency, limited power output and higher fuel consumption.

6.3. Risk assessment

Risks to consider for option 2:

- 10 months delivery time after order
- 5-7 weeks lead time for installation and commissioning
- Limited operating hours (maximum 5500 EOH's)
- Risk for findings during inspection (spare rotor and disks available for 10.000 EOH's)

6.4. Safety

From safety point of view it is strongly recommended to perform a rotor condition examination by DEKRA or similar agency. Last rotor examination was done in 2008 (Level E LTA inspection) by [redacted]

6.5. Steam production

Limited maintenance vs no maintenance strategy will increase the availability of the back-up unit and therefore the ability to produce steam in cogeneration mode.

6.6. Efficiency

The option 2 scenario is focusing on eliminating direct issues like cracks, burning, discoloration, erosion et cetera which reduces the risk for collateral damage and increases the availability of the unit. Efficiency is not part of the scope in this scenario. To increase the efficiency of the unit it is necessary to replace all sealings, abradables, honeycombs etc..
Due to lower efficiency the unit is limited in power output and exposed to higher thermal load needed for equivalent performance which will reduce the service life time of the hot part components.

6.7. Emissions

Reduced component efficiency is the error with the largest impact on the flame temperature calculation. This calculation is used to determine the optimum flame temperature in part load to reduce emissions. Reduced efficiency will lead to higher emissions due to calculation errors. In part load the system will keep de flame temperature stable around 1400 °C (1673 K).

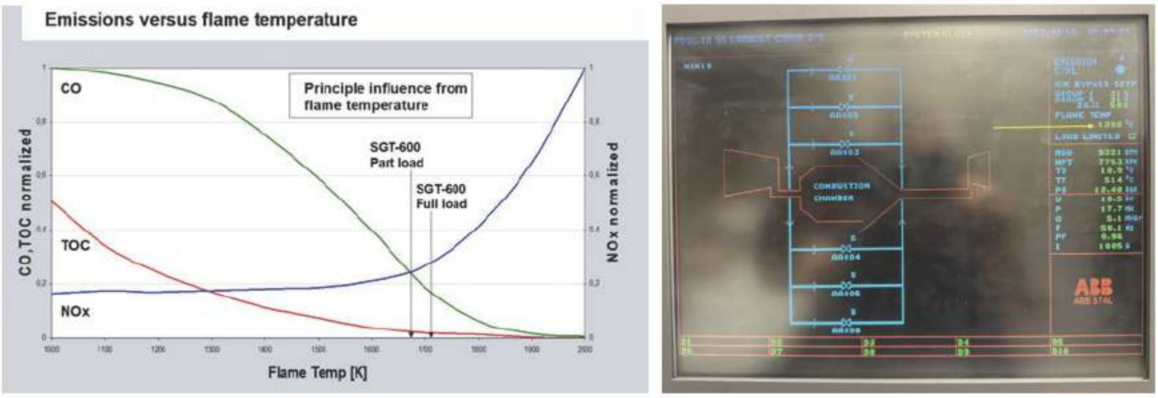


Figure 17: Emissions vs flame temperature

The increased fuel consumption due to reduced efficiency will lead to higher total emissions.

6.8. Availability

To increase the availability rate over a longer period to an acceptable level, a minimum of maintenance activity is required. Data from latest borescope inspection indicates that it is necessary to replace the combustion chamber, CT guide vane 1 and CT guide vane 2 due to considerable burning, cracking, discoloration and erosion. With this minimum repair the unit will maximize the use of remaining operating hours on the components and will be available for another 5500 EOH before next inspection / overhaul. Operations will have the flexibility and availability for:

- Backup operation
- K10/11 boiler operation
- K12 E-boiler operation
- Steam turbine operation
- Power generation (with reduced efficiency)
- Benefit CHP generation.
- Decreased energy costs per ton of paper (average 180 %) comparing to solo NG boiler operation.

7. Option 3 - Overhaul existing unit

For option 3 the starting point is to overhaul the existing unit to increase power output, availability, efficiency and decrease emissions and fuel consumption. To reach that status the engine needs a level E maintenance inspection plus a Life Time Assessment. This kind of maintenance level will restore full availability, safety and efficiency of the unit.

7.1. Scope for overhaul existing unit

SCOPE FOR MAXIMUM 20.000 EOH

COMPONENT	INCLUDED IN SCOPE	STATUS / COMMENTS	COST ESTIMATION
COMPRESSOR			
IGV overhaul	Yes	Stuck during start	€ 25.000,00
Compressor stator rings 6 - 10	Yes	Worn-out, replace	€ 35.000,00
Comp. rotor sealing edges 3 - 5	Yes	Worn-out, replace	€ 20.000,00
COMBUSTION CHAMBER / EV BURNERS / FUEL INJECTORS			
Ejectors	Yes	T7 spread issues, recondition	In CC pricing
Ignition system	Yes	T7 spread issues, recondition	In CC pricing
Combustion chamber	Yes	T7 spread issues, recondition	€ 350.000,00
COMPRESSOR TURBINE			
Guide vanes 1	Yes	Cracks, replace set	€ 323.400,00
Running blades 1	Yes	Replace with AU set 20k remaining EOH	-
Guide vanes 2	Yes	Cracks, replace set	€ 326.700,00
Running blades 2	No	6000 remaining EOH, replace set	€ 382.800,00
POWER TURBINE			
Guide vanes 3	No	No replacement	-
Running blades 3	Yes	5500 remaining EOH, replace set	€ 201.600,00
Guide vanes 4	No	No replacement	-
Running blades 4	Yes	Service life > 160.000 EOH, replace set	€ 204.800,00
COMPRESSOR ROTOR			
Compressor turbine disc 1	Yes	Life Time Assessment by DEKRA	In LTA pricing
Compressor turbine disc 2	Yes	Life Time Assessment by DEKRA	In LTA pricing
Compressor rotor	Yes	Life Time Assessment by DEKRA	In LTA pricing
POWERTURBINE ROTOR			
Power turbine disc 3	Yes	Life Time Assessment by DEKRA	In LTA pricing
Power turbine disc 4	Yes	Life Time Assessment by DEKRA	In LTA pricing
Power turbine rotor	Yes	Life Time Assessment by DEKRA	In LTA pricing
MISCELLANEOUS			
Revision / Inspection hours	Yes	Revision hours	€ 225.000,00
Materials	Yes	Revision material	€ 80.000,00
LTA Inspection	Yes	Life Time Assessment by DEKRA	€ 45.000,00
TOTAL			
TOTAL			€ 2.219.300,00
INCL. 25% BUDGET MARGIN			€ 2.774.125,00

Table 6: Budget cost estimation option 2

7.2. Maintenance and operational costs

Option 3 is focusing on restoring the engine parameters back to almost original values like safety, performance, emissions, fuel consumption et cetera. To reduce the maintenance costs on the recommended replacement parts one can opt for used parts with a left minimum of approximately 12.000 equivalent operating hours. Operational costs will be similar comparing to unit GT5 due to similar availability, efficiency, power output and fuel consumption.

7.3. Risk assessment

Risks to consider:

- 10 months delivery time after order
- 5-7 weeks lead time for installation and commissioning
- Risk for findings during inspection (spare rotor and disks available for 10.000 EOH's)

7.4. Safety

It is strongly recommended to perform a rotor condition examination by DEKRA or similar agency. Last rotor examination was done in 2008 (Level E LTA inspection) by [redacted] Inspection program 50[redacted] report [redacted]

7.5. Steam production

Overhauling the existing unit will restore full availability of the CHP and therefore the ability to produce steam in cogeneration mode.

7.6. Efficiency

Overhauling the existing unit with new components, sealings, abradables, honeycombs etc.. will restore the efficiency of the unit. Due to the increased efficiency the unit is able to produce increased power output and is exposed to lower thermal load needed for equivalent performance which will increase the service life time of the hot part components.

7.7. Emissions

Increased efficiency will lower the emissions due to more accurate flame temperature calculation in part load operation. The lower fuel consumption due to increased efficiency will lead to lower total emissions.

7.8. Availability

Overhauling the existing unit will restore original operational availability and flexibility for :

- Backup operation
- Part load operation with emission control
- K10/11 boiler operation
- K12 E-boiler operation
- Steam turbine operation
- Power generation possible (with increased efficiency)
- CHP generation with turbines in primary, backup or parallel mode.
- Decreased energy costs per ton of paper (average 180 %) comparing to solo NG boiler operation.

8. Option 4 – Minimum repair Australian engine

In option 4 the existing unit will be replaced with the available Australian SGT600 engine from [redacted] workshop in [redacted]. Since the unit is used as a donor engine for unit GT5 during the repair process the Australian unit must be completed to be operational ready. Starting point in option 3 is to minimize the maintenance costs on the unit to the lowest acceptable level. This level must fulfill the minimum requirement of safety and availability of the unit. The most necessary work will be executed to keep the unit safe and available during maintenance work or failure of the GT5 unit. With this minimum repair the unit will maximize the use of remaining operating hours on the components and will be available for another 5500 EOH before next inspection / overhaul.

8.1. Scope for minimum repair Australian engine

SCOPE FOR MAXIMUM 5500 EOH

COMPONENT	INCLUDED IN SCOPE	STATUS / COMMENTS	COST ESTIMATION
USED AUSTRALIAN ENGINE			
Used Engine	Yes	Australian engine, partially used for GT5	€ 800.000,00
COMPRESSOR			
IGV overhaul	Yes	Worn out, overhaul	In engine pricing
Compressor stator rings 6 - 10	No	Worn out, replace	-
Comp. rotor sealing edges 3 - 5	No	Worn out, replace	-
Compressor blades 1-10	Yes	Replace running blade stage 7 and 8	In engine pricing
COMBUSTION CHAMBER / EV BURNERS / FUEL INJECTORS			
Ejectors	Yes	T7 spread issues, recondition	In CC pricing
Ignition system	Yes	T7 spread issues, recondition	In CC pricing
Combustion chamber	Yes	T7 spread issues, recondition	€ 350.000,00
COMPRESSOR TURBINE			
Guide vanes 1	Yes	Replace set	€ 323.400,00
Running blades 1	No	20.000 remaining EOH	-
Guide vanes 2	Yes	Replace set	€ 326.700,00
Running blades 2	Yes	Transfer set from GT6, 6000 remaining EOH	-
POWER TURBINE			
Guide vanes 3	Yes	Transfer set from GT6	-
Running blades 3	Yes	Transfer set from GT6, 5500 remaining EOH	-
Guide vanes 4	Yes	Transfer set from GT6	-
Running blades 4	Yes	Service life > 160.000 EOH, replace set	€ 204.800,00
COMPRESSOR ROTOR			
Compressor turbine disc 1	No	Life Time Assessment by DEKRA	-
Compressor turbine disc 2	No	Life Time Assessment by DEKRA	-
Compressor rotor	No	Life Time Assessment by DEKRA	-
POWER TURBINE ROTOR			
Power turbine disc 3	No	Life Time Assessment by DEKRA	-
Power turbine disc 4	No	Life Time Assessment by DEKRA	-
Power turbine rotor	No	Life Time Assessment by DEKRA	-
MISCELLANEOUS			
Revision / Inspection hours	Yes	Revision hours	€ 225.000,00
Materials	Yes	Revision material	€ 80.000,00
LTA Inspection	No	Life Time Assessment by DEKRA	-
TOTAL			
TOTAL			€ 2.309.900,00
INCL. 25% BUDGET MARGIN			€ 2.887.375,00

Table 7: Budget cost estimation option 3

8.2. Maintenance and operational costs

In option 4 the maintenance cost will be the price of the used engine in current state plus the minimum amount of necessary maintenance estimated to fulfill the lowest acceptable level of safety and availability. The used engine together with this minimum repair will maximize the use of remaining operating hours on the available components for another 5500 EOH before next inspection / overhaul. To reduce the maintenance costs on the recommended replacement parts one can opt for used parts with a left minimum of approximately 12000 equivalent operating hours.
Operational costs will be higher comparing to unit GT5 due to reduced efficiency, limited power output and higher fuel consumption.

8.3. Risk assessment

Risks to consider:

- 10 months delivery time after order
- 3-4 weeks unit down time including commissioning
- Limited operating hours (maximum 5500 EOH's)
- Risk for findings during NDT inspection running blades

8.4. Safety

Engine history is known, compressor rotor and compressor turbine disk 1 and 2 are replaced for new type. No life time assessment needed for these components.

Unit:	
GT Model:	SGT600
Serial number:	[redacted]
Total operating hours:	17.277
Total starts:	1.820
Total EOH	27.112
TSLI	11.670 EOH

Date	Hours	Starts	EOH's	Reason
July 2020	17.277	1.820	27.112	Removal of unit
Jun 2010	9791	983	15.442	Level II inspection, GG rotor and disc 1&2 exchange

Table 8: Running hours Australian engine

8.5. Steam production

Limited maintenance vs no maintenance strategy will increase the availability of the back-up unit and therefore the ability to produce steam in cogeneration mode.

8.6. Efficiency

The option 4 scenario is getting the Australian engine ready for operation with minimum amount of maintenance. Key indicators are safety and availability, efficiency is not part of the scope. To increase the efficiency of the unit it is necessary to replace all sealings, abradables, honeycombs etc.. Due to lower efficiency the unit is limited in power output and exposed to higher thermal load needed for equivalent performance which will reduce the service life time of the hot part components.

8.7. Emissions

Increased efficiency will lower the emissions due to more accurate flame temperature calculation in part load operation. The lower fuel consumption due to increased efficiency will lead to lower total emissions.

8.8. Availability

After recommended minimum maintenance for unit GT6, operations have the flexibility and availability for:

- Backup operation
- K10/11 boiler operation
- K12 E-boiler operation
- Steam turbine operation
- Power generation (with reduced efficiency)
- Benefit CHP generation.
- Decreased energy costs per ton of paper (average 180 %) comparing to solo NG boiler operation.

9. Option 5 - Overhaul Australian engine

For option 5 the starting point is to replace the existing unit with an completely overhauled Australian unit to increase power output, availability, efficiency and decrease emissions and fuel consumption. This kind of maintenance level will restore full power output, availability, safety and efficiency of the unit.

9.1. Scope for overhaul Australian engine

SCOPE FOR MAXIMUM 20.000 EOH

COMPONENT	INCLUDED IN SCOPE	STATUS / COMMENTS	COST ESTIMATION
USED AUSTRALIAN ENGINE			
Used Engine	Yes	Australian engine, partially used for GT5	€ 800.000,00
COMPRESSOR			
IGV overhaul	Yes	Worn out, overhaul	In engine pricing
Compressor stator rings 6 - 10	Yes	Worn out, replace	€ 35.000,00
Comp. rotor sealing edges 3 - 5	Yes	Worn-out, replace	€ 20.000,00
Compressor blades 1-10	Yes	Replace running blade stage 7 and 8	In engine pricing
COMBUSTION CHAMBER / EV BURNERS / FUEL INJECTORS			
Ejectors	Yes	T7 spread issues, recondition	In CC pricing
Ignition system	Yes	T7 spread issues, recondition	In CC pricing
Combustion chamber	Yes	T7 spread issues, recondition	€ 350.000,00
COMPRESSOR TURBINE			
Guide vanes 1	Yes	Replace set	€ 323.400,00
Running blades 1	Yes	20.000 remaining EOH	-
Guide vanes 2	Yes	Replace set	€ 326.700,00
Running blades 2	Yes	6000 remaining EOH, replace set	€ 382.800,00
POWER TURBINE			
Guide vanes 3	Yes	Transfer set from GT6	-
Running blades 3	Yes	5500 remaining EOH, replace set	€ 201.600,00
Guide vanes 4	Yes	Transfer set from GT6	-
Running blades 4	Yes	Service life > 160.000 EOH, replace set	€ 204.800,00
COMPRESSOR ROTOR			
Compressor turbine disc 1	No	Life Time Assessment by KEMA	-
Compressor turbine disc 2	No	Life Time Assessment by KEMA	-
Compressor rotor	No	Life Time Assessment by KEMA	-
POWER TURBINE ROTOR			
Power turbine disc 3	No	Life Time Assessment by KEMA	-
Power turbine disc 4	No	Life Time Assessment by KEMA	-
Power turbine rotor	No	Life Time Assessment by KEMA	-
MISCELLANEOUS			
Revision / Inspection hours	Yes	Revision hours	€ 225.000,00
Materials	Yes	Revision material	€ 80.000,00
LTA Inspection	No	Life Time Assessment by KEMA	-
TOTAL			
TOTAL			€ 2.949.300,00
INCL. 25% BUDGET MARGIN			€ 3.686.625,00

Table 9: Budget cost estimation option 4

9.2. Maintenance and operational costs

Option 5 is focusing on restoring the engine parameters back to almost original values like safety, performance, efficiency, emissions, fuel consumption et cetera. To reduce the maintenance costs on the recommended replacement parts one can opt for used parts with a left minimum of approximately 12.000 equivalent operating hours. Operational costs will be similar comparing to unit GT5 due to similar availability, efficiency, power output and fuel consumption.

9.3. Risk assessment

Risks to consider:

- 10 months delivery time after order
- 3-4 weeks unit down time including commissioning

9.4. Safety

Engine history is known, compressor rotor and compressor turbine disk 1 and 2 are replaced for new type. No life time assessment needed for these components.

Unit:	
GT Model:	SGT600
Serial number:	[redacted]
Total operating hours:	17.277
Total starts:	1.820
Total EOH	27.112
TSLI	11.670 EOH

Date	Hours	Starts	EOH's	Reason
July 2020	17.277	1.820	27.112	Removal of unit
Jun 2010	9791	983	15.442	Level II inspection, GG rotor and disc 1&2 exchange

Table 10: Running hours Australian engine

9.5. Steam production

Overhauling the existing unit will restore full availability of the CHP and therefore the ability to produce steam in cogeneration mode.

9.6. Efficiency

Overhauling the Australian unit with new components, sealings, abradables, honeycombs etc.. will restore the efficiency of the unit. Due to the increased efficiency the unit is able to produce increased power output and is exposed to lower thermal load needed for equivalent performance which will increase the service life time of the hot part components.

9.7. Emissions

Increased efficiency will lower the emissions due to more accurate flame temperature calculation in part load operation. The lower fuel consumption due to increased efficiency will lead to lower total emissions.

9.8. Availability

Replacing the existing unit with an fully overhauled Australian unit will restore original operational availability and flexibility for :

- Backup operation
- Part load operation with emission control
- K10/11 boiler operation
- K12 E-boiler operation
- Steam turbine operation
- Power generation possible (with increased efficiency)
- CHP generation with turbines in primary, backup or parallel mode.
- Decreased energy costs per ton of paper (average 180 %) comparing to solo NG boiler operation.

10. Option 6 - Used SGT600 engine from market

In option 6 the existing unit will be replaced by a purchased SGT600 available from the market. The unit maintenance history must be clear and known and confirmed by a borescope inspection. Remaining equivalent running hours and cycles must be sufficient to continue running in backup operation until 2030

10.1. Scope for used SGT600 engine from market

SCOPE FOR MAXIMUM UNKNOWN EOH

COMPONENT	INCLUDED IN SCOPE	STATUS / COMMENTS	COST ESTIMATION
USED AUSTRALIAN ENGINE			
Used Engine	Yes	Australian engine still in operation	€ 1.700.000,00
COMPRESSOR			
IGV overhaul	No	As-found condition	-
Compressor stator rings 6 - 10	No	As-found condition	-
Comp. rotor sealing edges 3 - 5	No	As-found condition	-
COMBUSTION CHAMBER / EV BURNERS / FUEL INJECTORS			
Ejectors	No	As-found condition	-
Ignition system	No	As-found condition	-
Combustion chamber	No	As-found condition	-
COMPRESSOR TURBINE			
Guide vanes 1	No	As found condition	-
Running blades 1	No	As found condition	-
Guide vanes 2	No	As-found condition	-
Running blades 2	No	As-found condition	-
POWER TURBINE			
Guide vanes 3	No	As-found condition	-
Running blades 3	No	As-found condition	-
Guide vanes 4	No	As-found condition	-
Running blades 4	No	As-found condition	-
COMPRESSOR ROTOR			
Compressor turbine disc 1	No	Life Time Assessment by DEKRA	-
Compressor turbine disc 2	No	Life Time Assessment by DEKRA	-
Compressor rotor	No	Life Time Assessment by DEKRA	-
POWER TURBINE ROTOR			
Power turbine disc 3	No	Life Time Assessment by DEKRA	-
Power turbine disc 4	No	Life Time Assessment by DEKRA	-
Power turbine rotor	No	Life Time Assessment by DEKRA	-
MISCELLANEOUS			
Installation / Commissioning	Yes	Installation / Commissioning hours	€ 150.000,00
Materials	Yes	Installation material	€ 15.000,00
LTA Inspection	No	Life Time Assessment by DEKRA	-
TOTAL			
TOTAL			€ 1.865.000,00
INCL. 25% BUDGET MARGIN			€ 2.331.250,00

10.2. Maintenance and operational costs

Investing in a similar type used engine will be a significant initial investment. The amount of investment and maintenance budget will be depending on condition and the amount of operating hours / cycles left on the engine at time of purchase.

For example the engine operating hours are 125.000 EOH:

- Last inspection level C + LTE @120.000 EOH
- Next level A inspection is @130.000 EOH
- Next level B inspection is @140.000 EOH
- Next Level A inspection is @150.000 EOH

In this example the expected maintenance costs will be relative low for the next 15.000 operating hours.

Total equivalent operating hours '= x 1000	10'	20'	30'	40'	50'	60'	70'	80'	90'	100'	110'	120' LTE	130'	140'	150'	160'
Inspection levels Option LTA/LTE	A	B	A	C	A	D	A	E + LTA	A	B	A	C+ LTA	A	B	A	-

Figure 18: Expected maintenance schedule @125.000 EOH

In case the engine operating hours are 75.000 EOH:

- Last inspection level A @70.000 EOH
- Next level E inspection + LTA @80.000 EOH
- Next level A inspection is @90.000 EOH
- Next level B inspection is @100.000 EOH

In this example the maintenance costs will be relative high for the first next 15.000 operating hours.

Total equivalent operating hours '= x 1000	10'	20'	30'	40'	50'	60'	70'	80'	90'	100'	110'	120' LTE	130'	140'	150'	160'
Inspection levels Option LTA/LTE	A	B	A	C	A	D	A	E + LTA	A	B	A	C+ LTA	A	B	A	-

Figure 197: Expected maintenance schedule life cycle extension

Other points of attention for budget determination are:

- Available maintenance history
- Available operating history
- Engine finger print before it was taken out of service
- Engine configuration (Mechanical and instrumentation match)
- Local conditions (salt, sand, pollution, etc..)
- Control system (IGV- controller, Bleed valve 2 controller. Bypass valve controller, Fuel gas valves controller)
- Conservation of the engine
- Preservation of the engine
- Transport procedures

Expected operational costs for the engine in properly maintained condition will be similar to unit GT5 due to expected similar efficiency, power output and fuel consumption.

10.3. Risk assessment

Risks to consider:

- > 1 year before unit will be available (If owner is willing to sell)
- Unknown remaining components service life time
- 3-4 weeks unit down time including commissioning

10.4. Safety

From safety point of view it must be demonstrated that maintenance has been carried out in accordance with the manufactures instruction. The operating hours and origin of all installed turbine components must be available and within the permitted amount of equivalent operating hours c.q. equivalent operating cycles.

10.5. Steam production

Depending on used engine condition but expected to restore full availability of the CHP and therefore the ability to produce steam in continuously cogeneration mode.

10.6. Efficiency

Depending on used engine condition but expected to restore the efficiency of the unit. Due to the increased efficiency the unit is able to produce increased power output and is exposed to lower thermal load needed for equivalent performance which will increase the service life time of the hot part components.

10.7. Emissions

Increased efficiency will lower the emissions due to more accurate flame temperature calculation in part load operation. The lower fuel consumption due to increased efficiency will lead to lower total emissions.

10.8. Availability

Availability of the unit depends entirely on condition and the amount of operating hours / cycles left on the engine at time of purchase. If the engine is properly maintained and there are still enough operating hours left, the unit will be available for:

- Backup operation
- Part load operation with emission control
- K10/11 boiler operation
- K12 E-boiler operation
- Steam turbine operation
- Power generation possible (with increased efficiency)
- CHP generation with turbines in primary, backup or parallel mode.
- Decreased energy costs per ton of paper (average 180 %) comparing to solo NG boiler operation.

11. Option 7 – LM2500 DLE

In option 7 the existing engine will be replaced with a General Electric LM2500 Base DLE. The engine is slightly lower in ISO Base Load Power Rating but has the advantage to be able to run deep in part load within acceptable emission values.

Introduction to LM2500

The GE Energy LM2500 is an axial flow, gas generator/gas turbine engine designed to power a wide variety of marine and industrial applications. Its development stems from a combination of the GE TF39 turbofan engine, which powers the Air Force C-5A/B, and the CF6-6, which powers a number of commercial aircraft (DC10)

Figure 20: GE LM family

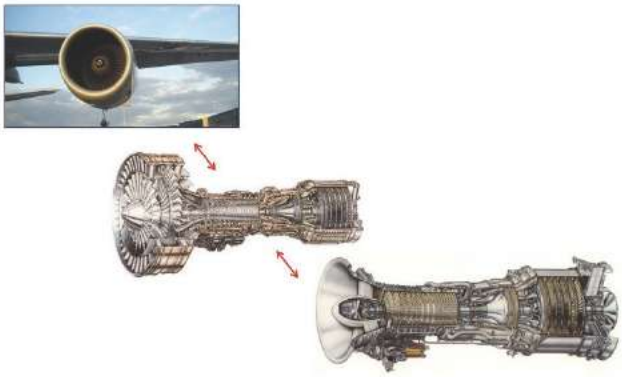


Figure 21: GE TF39 derivatives

The following components have been changed to convert the CF6 into a LM2500 engine:

- Front fan removed (1)
- LP compressor removed (2)
- Front frame adapted (3)
- New industrial fuel system added (4)
- Exhaust nozzle CF6 replaced by exhaust diffuser (5)
- Output shaft added to the rear (6)

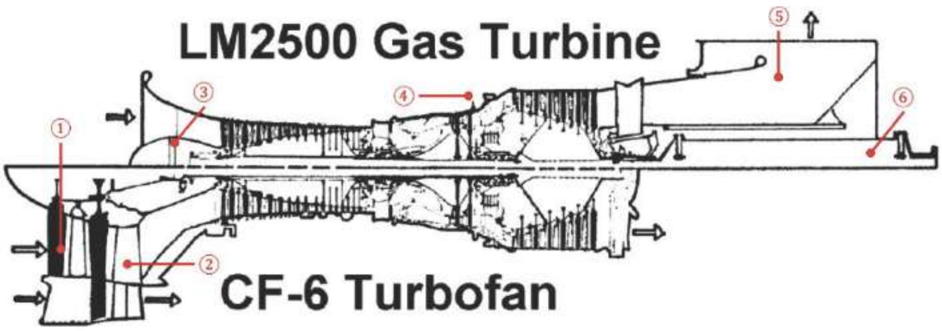


Figure 22: CF-6 Turbofan vs LM2500 Gas turbine

The components between compressor front frame and the turbine rear frame are identical for the LM2500 and the jet engine. This comprises the HP axial flow compressor, the combustion chamber, the HP turbine and the LP turbine. These major components are also the most critical parts of a gas turbine, so that experience with the jet engine is of great importance. The LM2500 load can be an electrical generator, a gas compressor or ship's propeller.

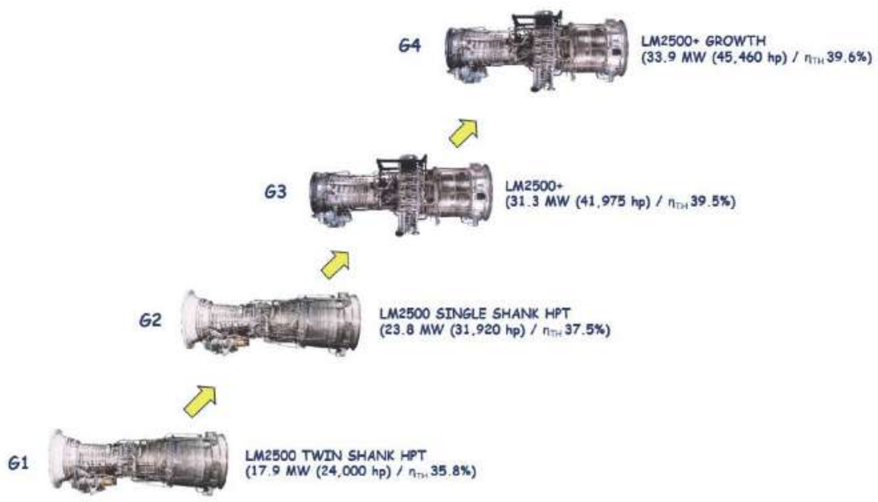


Figure 23: LM2500 Gas turbine heritage

Principle of operation

The principle of operation of the LM2500 gas turbine is the same as that of any gas turbine. Air is compressed by a axial compressor, heated in a combustion chamber and it expands in a turbine, thereby developing mechanical power. This power is partly used to drive the compressor, the remaining shaft power is available to drive a load. The LM2500 gas turbine consists of two major parts: the gas generator and the power turbine

De gas generator is of the "single spool" type, meaning that it has only one rotor, the high pressure rotor.
The single spool gas generator consists of:

- An 16 stage axial compressor for the LM2500, and a 17 stage axial compressor for the LM2500+ and +G4
- An annular combustion chamber
- A 2-stage impuls type turbine, used only to drive the axial compressor

The power turbine is a 6-stage reaction type turbine and drives the load gear box and generator

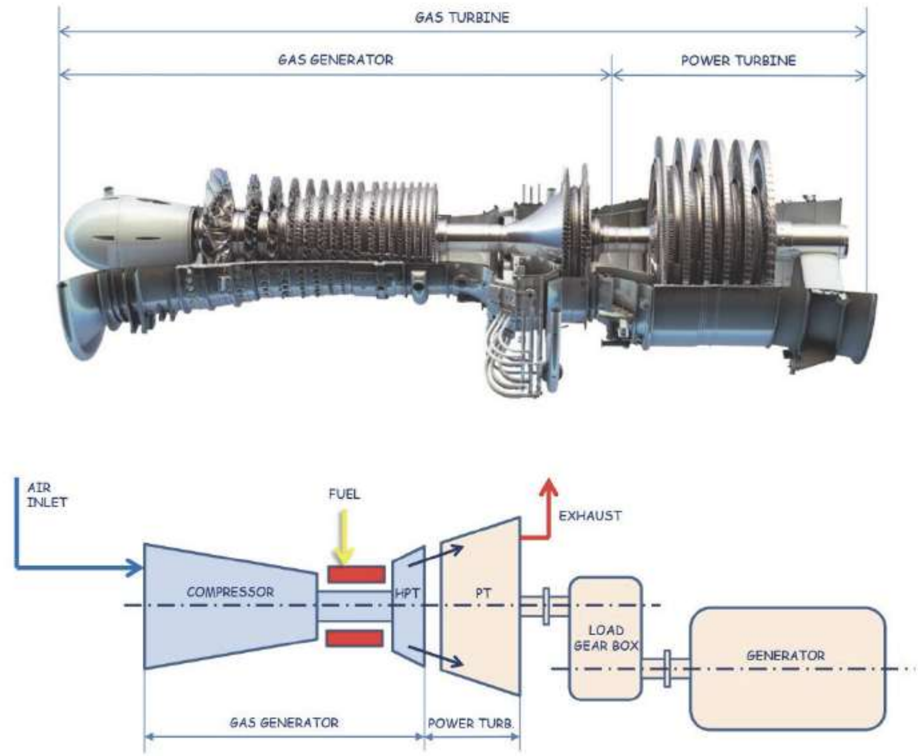


Figure 24: LM2500 gas generator / power turbine

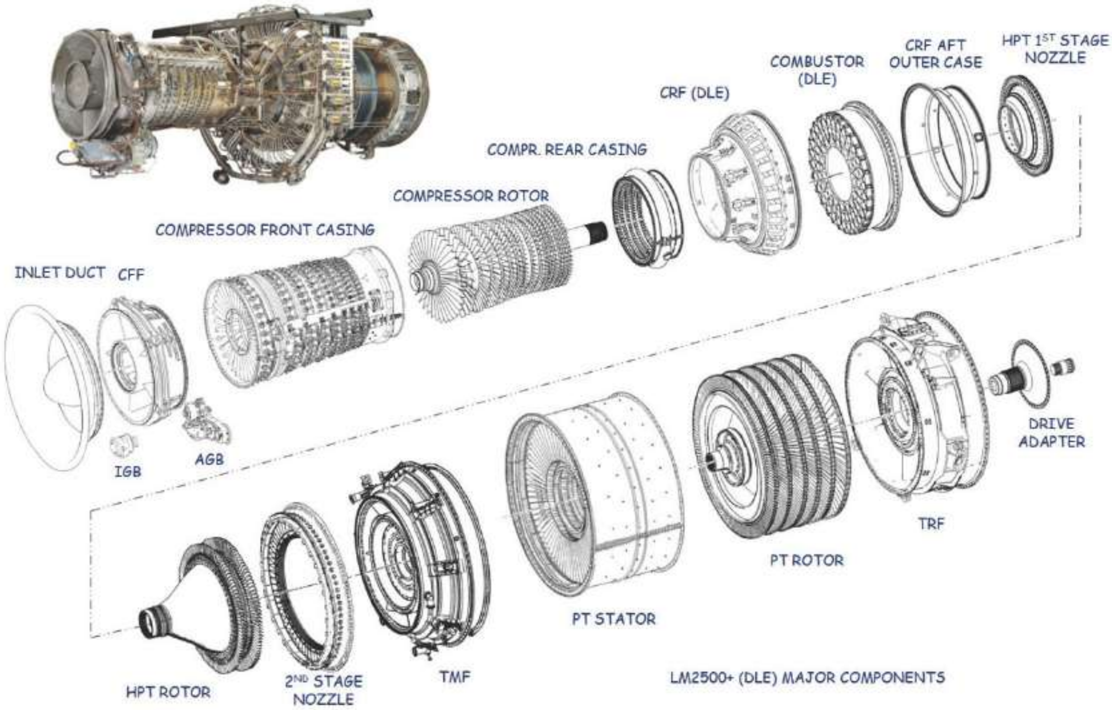


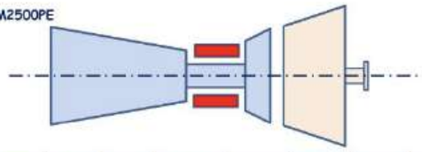
Figure 25: LM2500 major components

Performance data

MODEL	Comb. Sys. SAC / DLE Water Injection for NOx Reduction (WI)	Power Rating ISO Base Load MW	Heat Rate LHV kJ/kWh	Efficiency %	Pressure Ratio	Power Shaft Speed RPM	Exhaust Flow kg/s	Exhaust Temp. °C
LM1800e	DLE	16.6	10525	34.2	15.3	3000	61.6	486
LM2000PS	SAC / WI	18.4	10648	33.8	16.1	3000	66.3	463
LM2000PJ	DLE	17.9	10430	34.5	15.4	3000	63.7	496
TM2500	SAC / WI	23.1	10584	34.0	18.7	3000	71.6	517
LM2500PE	SAC	22.4	10146	35.5	18.2	3000	69.8	538
LM2500PE	SAC / WI	23.1	10577	34.0	18.7	3000	71.7	517
LM2500PJ	DLE	21.8	10173	35.4	17.9	3000	68.9	535
LM2500PH	SAC	26.5	9136	39.4	19.4	3000	76.2	497
TM2500+	SAC / WI	26.2	10239	35.2	21.3	3000	84.9	471
LM2500+PK	SAC / WI	29.3	10157	35.4	22.8	3000	89.5	488
LM2500+PR	DLE	30.0	9686	37.2	22.6	3000	88.7	528
LM2500+RC (G4)	SAC / WI	33.7	10255	35.1	24.2	3000	97.0	516
LM2500+RC (G4)	SAC / WI	36.0	9771	36.8	24.4	3600 GB	96.8	507
LM2500+RD (G4)	DLE	31.9	9753	36.9	23.0	3000	92.6	541
LM2500+RD (G4)	DLE	32.9	9335	38.6	23.1	3600 GB	91.4	525

Figure 26: Performance data LM2500 50Hz

Performance data LM2500PE

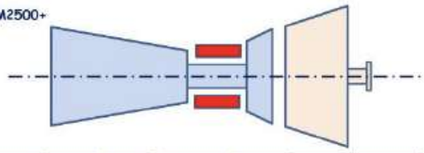


	In/out	HPC		Q_1 (CC)		HPT		PT	Q_2 (Exh.)
Power MW (hp x 1000)		27.6 (37)		64 (85.8)		27.6 (37)		22 (29.5)	38 (51)
Work kJ/kg (BTU/lb)		400 (172)		924 (397)		400 (172)		340 (146)	551 (237)
Pressure bara (psia)	1 (14.5)		18 (261)		17.1 (248)		4 (58)		1 (14.5)
Temp. °C (°F)	15 (59)		404 (759)		1144 (2091)		823 (1513)		530 (986)
Flow kg/s (lb/s)	69 (152)								69 (152)
Cp kJ/kg.K (BTU/lb°R)		1.03 (0.2460)		1.18 (0.2818)		1.23 (0.2938)		1.16 (0.2771)	1.07 (0.2556)
k (-)		1.38				1.31		1.33	

Work/kg air = $Cp \times \Delta T$
Power = $m \times Cp \times \Delta T$

Example HPC: Work = 1.03 x (404 - 15) = 400 kJ/kg
Example HPC: Power = 69 x 400 = 27600 kJ/s = 27.6 MW

Performance data LM2500+

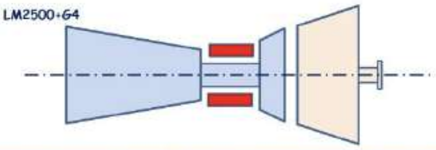


	In/out	HPC		Q_1 (CC)		HPT		PT	Q_2 (Exh.)
Power MW (hp x 1000)		38 (451)		75 (100.6)		38 (51)		33 (44.3)	42 (56.3)
Work kJ/kg (BTU/lb)		458 (197)		1087 (467)		458 (197)		398 (171)	506 (218)
Pressure bara (psia)	1 (14.5)		23 (334)		22 (319)		4.7 (68.2)		1 (14.5)
Temp. °C (°F)	15 (59)		465 (869)		1235 (2255)		850 (1562)		507 (945)
Flow kg/s (lb/s)	83 (183)	→		→		→		→	83 (183)
Cp kJ/kg.K (BTU/lb°R)		1.03 (0.2460)		1.18 (0.2818)		1.24 (0.2962)		1.16 (0.2771)	1.07 0.2556)
k (-)		1.38				1.29		1.33	

Work/kg air = $Cp \times \Delta T$
Power = $m \times Cp \times \Delta T$

Example HPC: Work = 1.03 x (465 - 15) = 463 kJ/kg
Example HPC: Power = 83 x 463 = 38400 kJ/s = 38 MW

Performance data LM2500+G4



	In/out	HPC		Q_1 (CC)		HPT		PT	Q_2 (Exh.)
Power MW (hp x 1000)		48.3 (64.8)		82.7 (110.9)		48.3 (64.8)		34 (45.6)	52.1 (69.9)
Work kJ/kg (BTU/lb)		519 (223)		891 (383)		519 (223)		367 (158)	562 (242)
Pressure bara (psia)	1 (14.5)		23.7 (343.7)		22.5 (326.3)		4.9 (71.1)		1 (14.5)
Temp. °C (°F)	15 (59)		515 (959)		1228 (2242)		855 (1571)		540 (1004)
Flow kg/s (lb/s)	93 (205)								93 (205)
Cp kJ/kg.K (BTU/lb°R)		1.039 (0.2482)		1.204 (0.2867)		1.239 (0.2959)		1.164 (0.2780)	1.07 (0.2556)
k (-)		1.38				1.31		1.33	

Work/kg air = $Cp \times \Delta T$
Power = $m \times Cp \times \Delta T$

Example HPC: Work = 1.039 x (515 - 15) = 519 kJ/kg
Example HPC: Power = 93 x 519 = 48267 kJ/s = 48.3 MW

Figure 27: Performance data LM2500PE, LM2500+, LM2500+G4

11.1. Scope for LM2500 DLE

SCOPE FOR MAXIMUM UNKNOWN EOH			
COMPONENT	**INCLUDED IN SCOPE**	**STATUS / COMMENTS**	**COST ESTIMATION**
ALTERNATIVE ENGINE			
LM2500 DLE Package	Yes	New package	€ 13.000.000,00
TOTAL			
TOTAL			€ 13.000.000,00
INCL. 25% BUDGET MARGIN			€ 16.250.000,00

11.2. Maintenance and operational costs

LM2500 Maintenance Activities

Borescope / Inspection: Every 6 mo./8000 hrs. Hot Section Inspections: Every 25,000 hrs. Major Overhauls: Every 50,000 hrs.

11.3. Risk assessment

Risks to consider:

- Delivery time (Estimated 3 years)
- Lead time engineering / installation / commissioning (4-6 months)
- High gas supply pressure needed (40 bar)
- Lower exhaust temperature means more additional boiler firing

11.4. Safety

From safety point of view it must be demonstrated that maintenance has been carried out in accordance with the manufactures instruction. The operating hours and origin of all installed turbine components must be available and within the permitted amount of equivalent operating hours c.q. equivalent operating cycles.

11.5. Steam production

The steam production derived from the engine is dependent on the exhaust heat towards the boiler. Less heat input means more additional firing on the boiler to achieve similar steam production.

Siemens SGT600 (Former GT10-B):

- Exhaust flow = 79.2 kg/s
- Exhaust temperature = 534 °C
- Exhaust heat = 44.7 MJ/s

General Electric LM2500 Base DLE

- Exhaust flow = 69 kg/s
- Exhaust temperature = 530 °C
- Exhaust heat = 38 MJ/s

General Electric LM2500+ DLE

- Exhaust flow = 83 kg/s
- Exhaust temperature = 507 °C
- Exhaust heat = 42 MJ/s

General Electric LM2500+ G4

- Exhaust flow = 93 kg/s
- Exhaust temperature = 540 °C
- Exhaust heat = 52.1 MJ/s

11.6. Efficiency

The overall efficiency of the LM2500 Base DLE is 35.4%. Since the SGT600 efficiency is 34.2% , the fuel consumption at same power output will drop with 1.2% for the LM2500 Base DLE model.

The overall efficiency of the LM2500+ DLE is 37.2%. Since the SGT600 efficiency is 34.2% , the fuel consumption at same power output will drop with 3.0% for the LM2500+ DLE model.

11.7. Emissions

The LM2500 DLE emission control, especially in part-load operation is a very strong feature of this engine. To understand the basics of this system please find below a global explanation of the LM DLE control system.

In modern society, the use of gas turbines for the production of mechanical shaft power or electrical power is essential. Although many ways to generate power exist, the gas turbine is utilized as an efficient instrument to convert chemical (fuel) energy into mechanical energy. As is the case in many methods of energy conversions, the gas turbine has its influence on the environment. The complex process of combustion results in unwanted emissions. In some installations, the harmful by-products in the gases are filtered. Washed out or chemical reduced. It is better to prevent the development of these harmful by-products during the combustion process itself. The DLE (Dry Low Emissions) system utilizes such technology.

Techniques for emission control

The NOx emission can be reduced by reducing the flame temperature peaks or hot spots within the flame using various options such as:

- Steam injection
- Water injection
- Lean combustion
- Staged combustion
- Premix lean combustion

Techniques for Emission Control	
NOx	• Water- or Steam Injection • Catalytic Combustion • Selective Catalytic Reduction (SCR) end of pipe • Dry Reduction Techniques
SOx	• Sulphur Content in Fuel
CO	• Design of Combustion Chamber (Combustion Efficiency)
CO_2	• Efficiency of a Process • Type of fuel
UHC / VOC	• Design of Combustion Chamber (Combustion Efficiency)
Dust	• Fuel and Air Composition
Smoke	• Design of Combustion Chamber • Fuel Composition

Figure 28: Techniques for emission control

Increasing the efficiency of a process can reduce the CO2 emissions and fuel costs. Nowadays gas turbines are very often utilized in a combined cycle process. If natural gas is used as a fuel (mainly consisting of Methane) the combustion product is CO2 (1/3) and water (2/3).

In theory, rich combustion could be a solution, but because of the resulting incomplete combustion and smoke development, this option is not feasible.

For several reasons , catalytic techniques are hardly ever used in gas turbines, but often more in boilers. It adds complexity and therefore expense and SCR systems are sensitive to fuels containing high amounts of Sulphur.

Water and steam injection adds expense, complexity and it cannot reach the single digit (ppm) levels that are nowadays increasingly required.

Removing Sulphur from the fuel, which is difficult and expensive, is the only way to reduce the development of Sulphuric Acid during combustion. For that reason fuels with a low content of Sulphur are preferred.

Occasionally natural gas contains H2S, a very poisonous and dangerous gas, which causes SOx during the combustion process. Coals and heavy-fuels contain substantial amounts of Sulphur and Sulphur compounds, sometimes more than 4%. In lighter liquid fuels the content of Sulphur will be approximately 0.5%.

The CO development is the least at stochiometric combustion, when the flame temperature is at the highest level. Unfortunately under these conditions the thermal NOx development is at its maximum. There is a contradiction, to reduce NOx we wish to reduce the flame temperature, but then CO emissions are increased.

The solution for NOx and CO emission control is premixing. The premix lean combustion is by far the best option. By using this method, the emissions are reduced at the source , without adding any other matter.

The graph in the figure below shows very clearly that at stoichiometric adiabatic combustion , producing the highest possible flame temperature, the combustion process develops a large amount of NOx.

NOx can be reduced considerably by applying a lean or rich combustion in the reaction zone in a combustion chamber. The figure shows that the flame temperature in this kind of combustion is the highest, and consequently the NOx emissions. Since the air to fuel ratio is very high in a gas turbine to achieve the correct turbine inlet temperature (firing temperature) the first designs to reduce NOx emissions were based in a lean combustion.

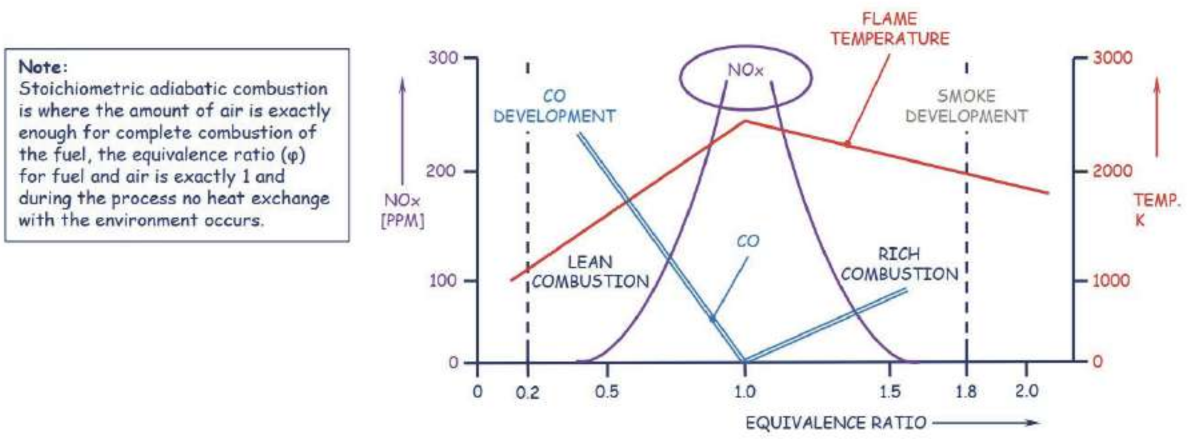


Figure 29: Simplified graph of the thermal emission production in a gas turbine

Since water or steam injection have some disadvantages, such as the use of expensive water and undesired pressure pulsations in the combustion system, a dry low emission system was developed. Before the attention was drawn to deceasing emissions, the combustion chambers were designed for almost stoichiometric combustion. Due to the large differences in air and fuel flows at different loads, it was difficult to achieve the desired low emissions. The fuel ratio from base-load to start-up is 40 to 1. The air ratio 30 to 1 and the fuel to air ratio varies 5 to 1. In addition, the flame in a combustion chamber is diffuse, because the air and fuel are injected into the reaction zone, with a strong recirculation in the reaction zone. The reduction in the first lean combustion design was approximately 20%. For those reasons the combustion system had to be made more complex with more combustion zones more fuel nozzles and premixed combustion. DLE stands for Dry Low Emission and describes a specific combustion technology which generates the lowest and dry NOx emissions, which means that there is no steam or water injection necessary.

The Dry Low Emission system utilizes three of the possible methods, which allow a significant reduction in NOx emissions from the gas turbine combustion system.

- Lean combustion (reduces flame temperature)
- Multiple fuel nozzles (reduces duration of the combustion)
- Premixed combustion

Premixed lean combustion reduces flame temperature (more equalized temperature profile, less hot spots) and CO emissions.

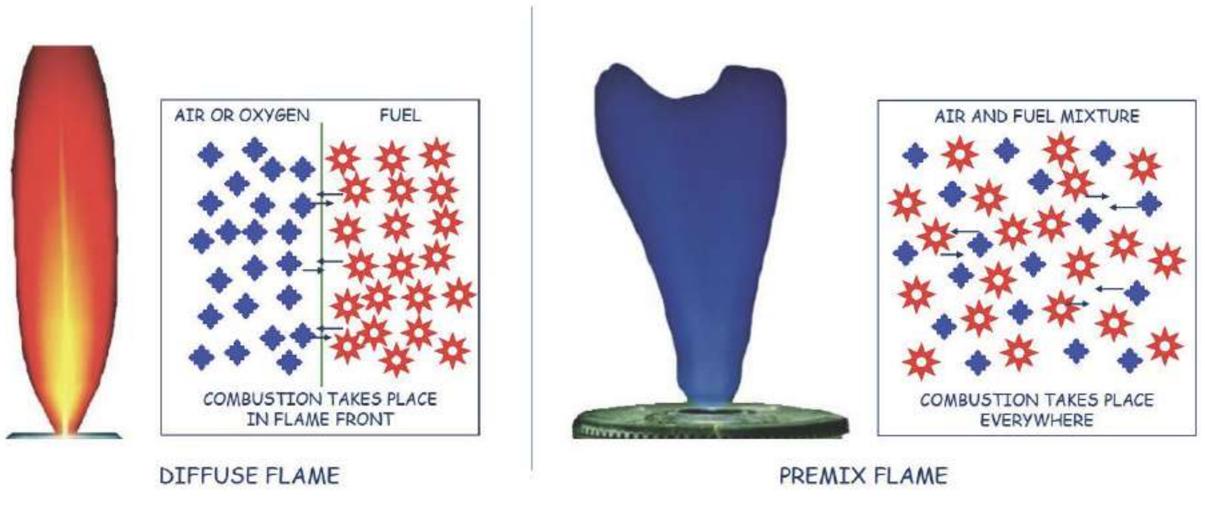


Figure 30: Diffuse versus Premix flame

Low NOx and CO is achieved by incorporating lean pre-mix combustion and by close control of the combustion flame temperature.

Flame temperature is controlled using two basic principles:

- Staged combustion, with sections of the combustor turned off at low power
- Maintaining proper fuel / air ratio using bleed air from the compressor.

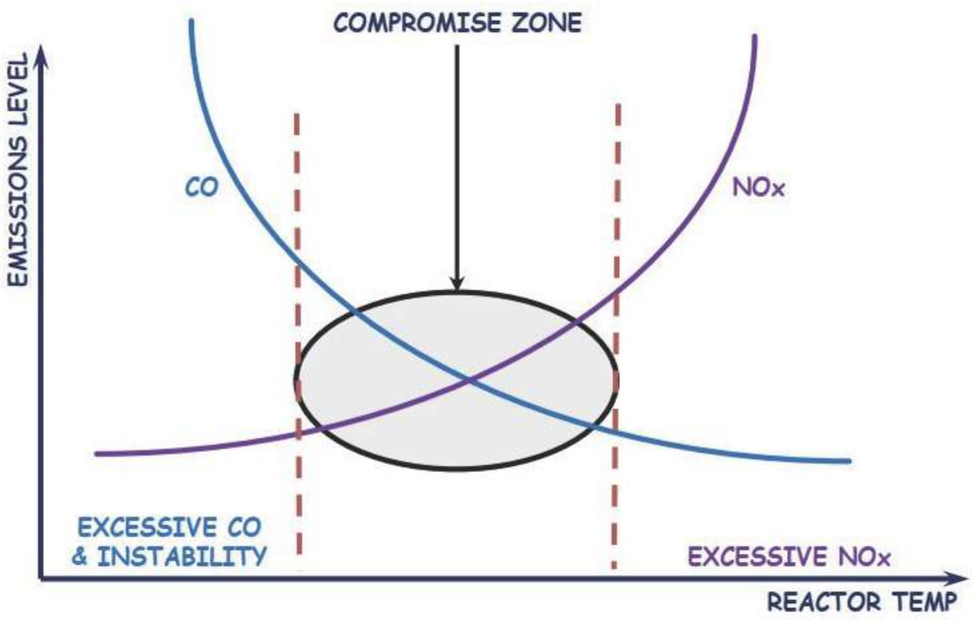


Figure 31: Emission control

The main problem with premix combustion. Especially when used to lower NOx emissions, is that it is unstable. This has always been a major technological stumbling block to lowering DLE combustor NOx emissions. Since stationary gas turbines emit NOx gasses that result in photochemical smog and acid rain, there are subject to strict regulations across the globe. An increasing number of local governments worldwide where public awareness about preserving air quality is high, are implementing even stricter NOx emissions standards that lower the acceptable emissions levels from 25 ppm to 15 ppm.

The LM2500 DLE models utilize a lean premix combustion system designed for operation on both natural gas and liquid fuel. The combustion chamber assembly is a triple annular design which enables the combustion chamber assembly to operate at a constant flame temperature across the entire power range, thus minimizing emissions.

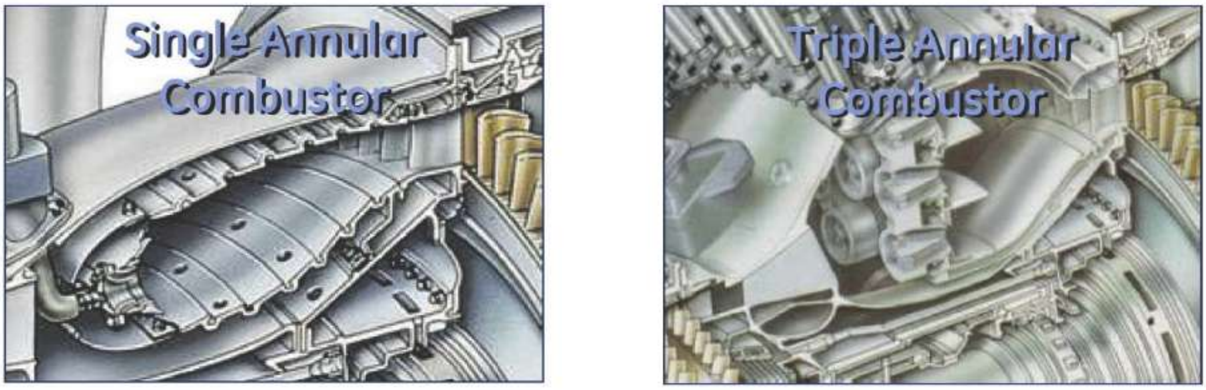


Figure 32: Single annular combustor vs Triple annular combustor

The DLE control system comprises the software in the gas turbine control panel and the hardware on the gas turbine. The system sees to it that the (peak) flame temperature in the combustion chamber will be at an acceptable (low) level, thus keeping the NOx and emissions low. At the same time the CO emissions are to stay low, so the flame temperature may not be too low. When operating at base load all 75 pre-mixers are in use and the flame temperature is at design level.

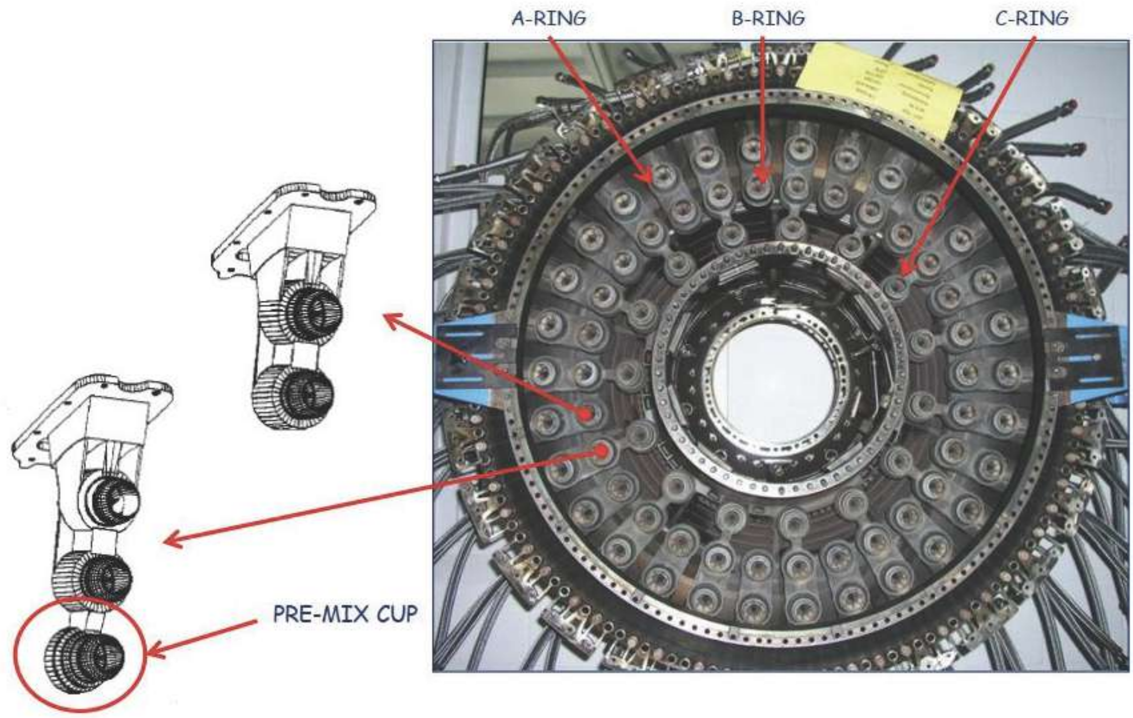


Figure 33: 75 pre-mix fuel nozzles

When running in part-load, the following systems control the airflow through the combustor and thus the flame temperature:

- The VGC control system(VSV)
- CDP compressor bleed

When loading from zero load the control system will select one of a number of operating modes ('the windows'), in each window controlling the flame temperature by selecting the number of pre-mixers in use and positioning the bleed valves.

The principle of such a window is shown in the figure below. The left and right border lines indicate the minimum and maximum air bleed. The lower and upper border lines indicate the minimum and maximum flame temperature. In the window, the control system's goals is to keep the operating point between minimum and maximum flame temperature.
In each window, when loading the gas turbine by burning more fuel and lowering the air bleed volume the upper right hand corner of a window will be reached. The system then select the next higher window, resetting the bleed valves to come on the target line again. When unlading the gas turbine by burning less fuel and increasing the air bleed volume the lower left hand corner of a window will be reached. The system will then select the next lower window, resetting the bleed valves to come on the control target line again.

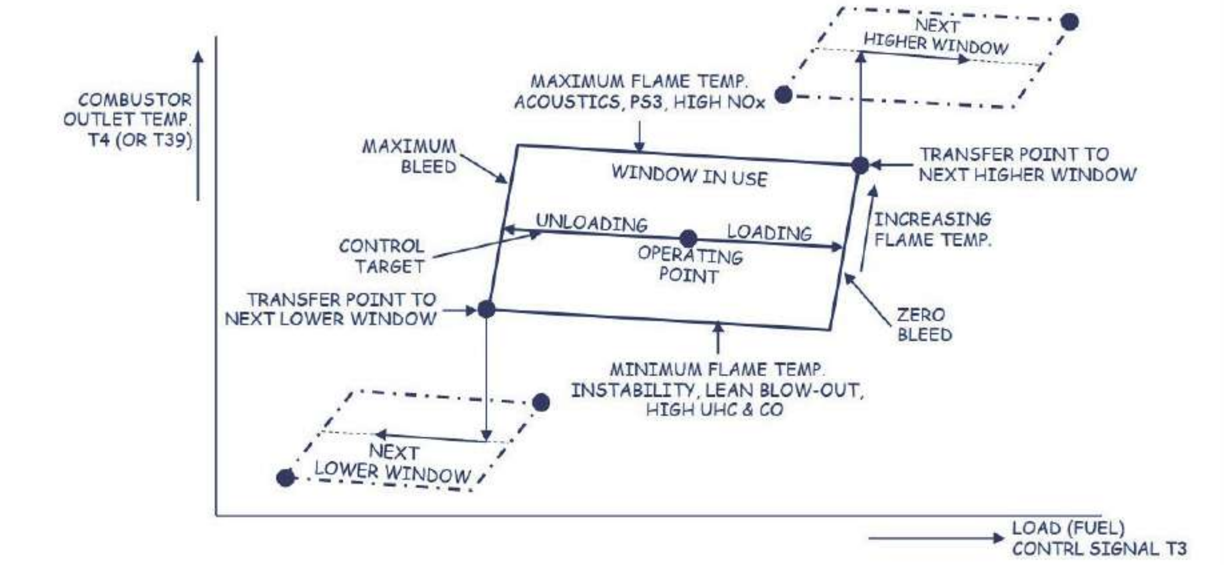


Figure 34: Window mapping

To be able to ignite the fuel during ignition some A pre-mixers will be in use, after ignition only the B pre-mixers will be iin use. As the load increases, the windows will use the following burner modes:

OPERATING CONDITION	BURNERS IN USE
IGNITION	A, THEN B
UP TO 5 % LOAD	B
UP TO 25 % LOAD	B + C/2 (B + 9C)
UP TO 35 % LOAD	B + C
UP TO 50 % LOAD	B + C + 2A (B + C + 12A)
UP TO 75 % LOAD	B + A
UP TO FULL LOAD	B + A + C

BRNREQ	BRNDMD	A-STAGING VALVES	C-STAGING VALVES	BURNER MODE	NUMBER OF BURNERS	Load (appr.)
0	0	0	0	B	30	Up to 5%
	1	0	1		30 + 3 = 33	
	2	0	2		30 + (2x3) = 36	
(3)	3	0	3	B+C/2	30 + (3x3) = 39	
	4	0	4		30 + (4x3) = 42	
5	5	0	5	B+C	30 + (5x3) = 45	Up to 25%
	6	1	5		30 + (5x3) + (1x6) = 51	
7	7	2	5	B+C+2A	30 + (5x3) + (2x6) = 57	Up to 35%
	8	3	4		30 + (4x3) + (3x6)= 60	
	9	4	2		30 + (2x3) + (4x6) = 60	
10	10	5	0	B+A	30 + (5x6) = 60	Up to 50%
	11	5	1		30 + (5x6) + (1x3) = 63	
	12	5	2		30 + (5x6) + (2x3) = 66	
	13	5	3		30 + (5x6) + (3x3) = 69	
	14	5	4		30 + (5x6) + (4x3) = 72	
15	15	5	5	B+A+C	30 + (5x6) + (5x3) = 75	Up to 100%

Figure 35: Burner control schedule

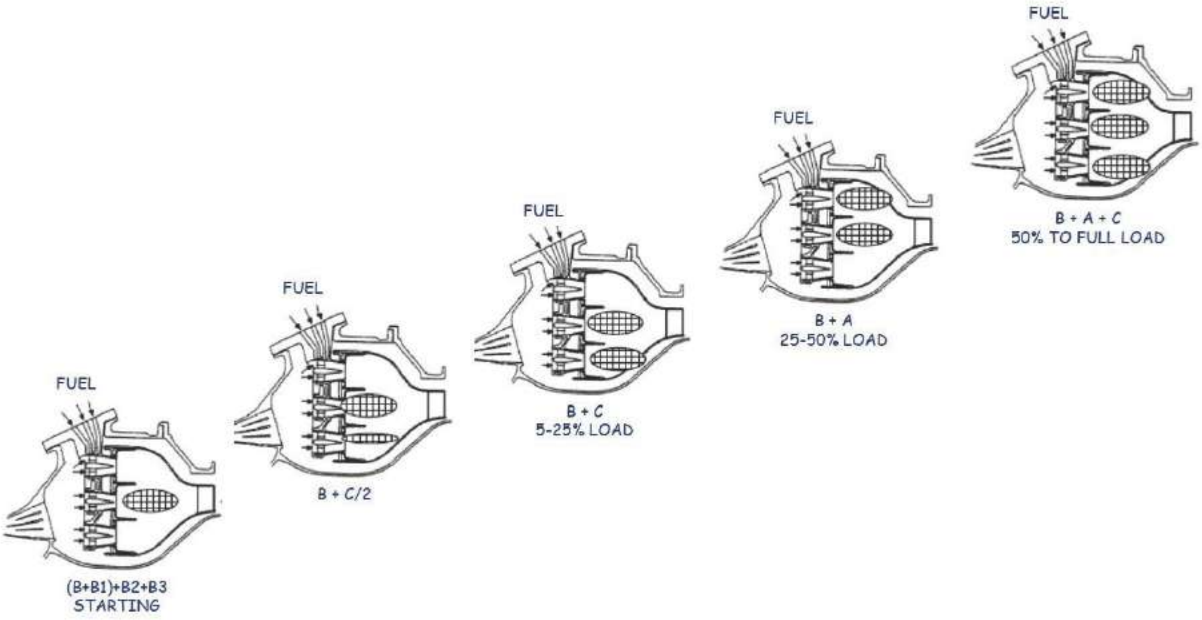


Figure 36: Burner demand

Mapping schedule

In each window, when loading the gas turbine by burning more fuel and lowering the air bleed volume the upper right hand corner of a window will be reached. The system will then select the next higher window, resetting the bleed valves to come on the control target line again.

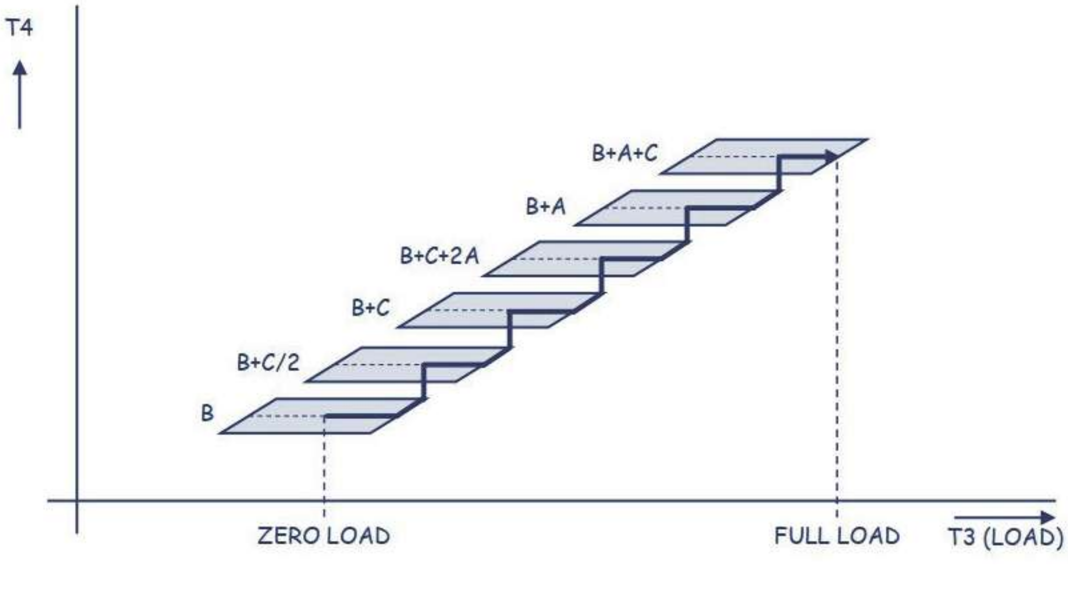


Figure 37: DLE control when loading the gas turbine

When unloading the gas turbine by burning less fuel and increasing the air bleed volume the lower left hand corner of a window will be reached. The system will then select the next lower window, resetting the bleed valves to come in the control target line again. From this figures it shows that the transfer points are based on temperature T4 (= combustor exhaust temperature). As the T4 temperature is not directly measured , a control algorithm will calculate T4

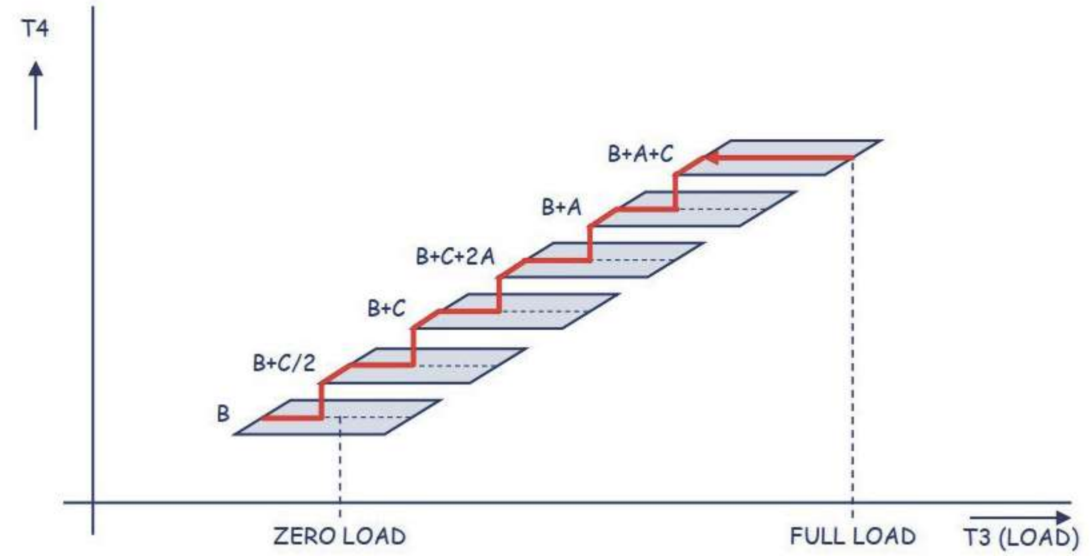


Figure 38: DLE control when unloading the gas turbine

11.8. Availability

Emergency power is supplied by parties that can significantly reduce their electricity consumption in a short period of time, or can quickly increase the production of electricity. This is called up-or down regulation. Emergency power can also be provided by reducing production or increasing offtake. The compensation fee for emergency power up/down-regulation is multiple times the normal electricity rate. The LM2500 has the ability to run in deep part load while maintaining good emission values by burner staging technology. This wide operation range is a very interesting feature to be flexible and profitable in the power imbalance market while running in cogeneration mode.