Dry Low NOx Systems Retrofit for Gas Turbines

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Abstract: The purpose of this paper is provide an overview to an audience of senior officials in the energy industry on some of the key elements in the planning process and successful execution of the Dry Low NOx (DLN) conversion of gas turbines, including; challenges, experiences, and share d lessons learned.

In line with the Qatar National Vision 2030 RasGas is fully committed to respecting the environment and as such RasGas made NOx reduction one of its priorities.

The DLN Combustion System Technology has been adopted by RasGas to reduce the current emission levels of the gas turbines and to comply with the latest regulations set by Qatar's Ministry of Environment (MoE) for the NOx emission that target 125 milligrams per normal cubic meter (mg/Nm ^{3}) as a maximum level, down from 240 (mg/Nm^3) for running Gas Turbines. Based on the above, RasGas has successfully complet ed phase one by converting six G as Turbines in the power generation application , followed by phase two for converting two Gas Turbines in the process trains and one unit in th e power generation plant , thus making RasGas a pioneer in the DLN conversion for Gas Turbines in the State of Qatar.

Keywords: Gas Turbines, NOx emissions.

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Contents:

A) Background

Ras Gas LNG Company ("RasGas") was established in year 1997 by Emiri decree at RasLaffan Industrial City, North of Qatar with LNG as a main product and bi - product s of Condensate, Helium & sweet natural gas.

The main shareholders of R asGas are Qatar Petroleum & Exxon Mobil. With current LNG capacity of 37 MTPA, existing two gas processing trains and future expansion for additional two gas processing trains under the Barzan project, RasGas is one of the largest natural gas processing facilities.

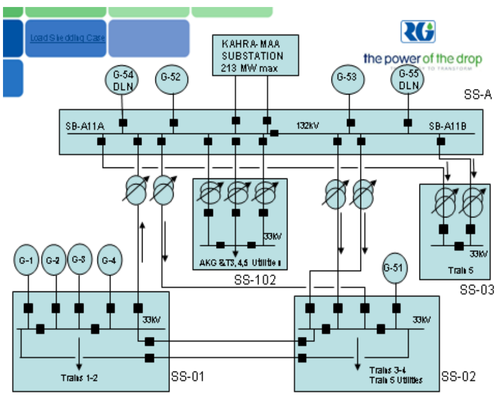
LNG plants are energy intensive installations with a large number of Gas Turbines for power generation & mechanical drive applications .

DLN combustion system technology has been adopted by RasGas to reduce the current emission levels of the gas turbines and to comply with the latest regulations set by Qata r's Ministry of Environment (MoE) .

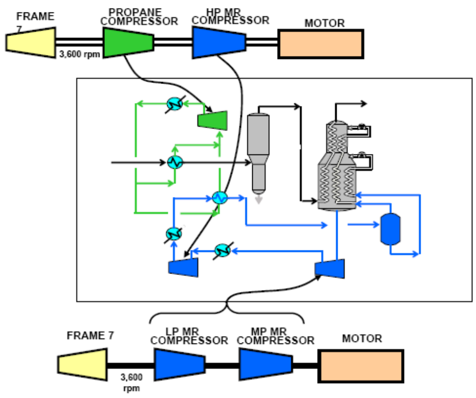
DLN retrofits for Gas Turbines start ed in Ras Gas since 2008 and all gas turbine units were retrofitted with the same DLN -1 technology for NOx emissions control.

RasGas has successfully completed Phase 1 & 2 for DLN retrofits covering six gas turbines in the power generation application and t wo Gas Turbines for mechanical drive application, in order to meet the NOx compliance norms.

Phase 1



Phase 2



Phase 3 will be for two mechanical drive turbines in LNG train during year 2012, followed by phase 4 for three unit s in year 2013 and phase 5 for two units in year 2014.

B) Aims / Project Objectives

To comply with the latest regulations set by Qatar's Ministry of Environment (MoE) for the NOx emission that target 125 milligrams per normal cubic meter (mg/Nm ^{3}), down from 240 mg/ Nm ^{3} for installed machines with output power above 15 MW .

Ras Gas plans to retrof it all the installed gas turbine units of more than 15 MW output power to meet the NOx emissions of less than 25ppm. Typically such retrofits are aligned with scheduled major inspections of the turbines to optimize the outage window.

C) Methodology

1. Technology s election:

Dry Low NOx (DLN) technology was evaluated against the Wet Low NOx (WLN) technology, Steam Injection Technology and Catalytic converter for NOx reduc tion in the Gas Turbine emissions.

DLN Technology was selected based on techno-economic criteria covering various considerations such as scheduled outage requirements, available exiting facilities, operation & maintenance costs, site experience for DLN m achines and environmental norms for chemical disposal.

2. Description of DLN Technology:

The Dry Low NOx -1 combustion system reduces NOx emission, through lean-premixed burning in multi-zone combustion liners and by new fuel control equipment which directs f uel to the different liner zones depending upon the mode of operation.

There are two sources of NOx emissions in the exhaust of the gas turbine. Thermal NOx is generated by atmospheric nitrogen fixation in the flame. The conversion of fuel bound nitrogen (FBN) also generates NOx.

The methods described here control thermal NOx emissions and are not effective in controlling the conversion of FBN. FBN is usually found in lower quality distillates and coal gasses . The GE DLN-1 combustor is a two -stage premixed combustor designed for use with natural gas fuel and is capable of operation on liquid fuel as well. RasGas Gas Turbines are using Natural Gas fuel supply source only.

The combustion system includes four major components: fuel injection system, liner, venturi and cap/centre-body assembly. These components are arranged to form two stages in the combustor. In the premixed mode, the first stage serves to thoroughly mix the fuel and air and deliver a uniform, lean, unburned fuel -air mixture to the second st age. Total fuel flow is controlled by conventional methods; either by speed ratio/gas control valves on gas fuel systems or by the fuel oil bypass valve for liquid systems.

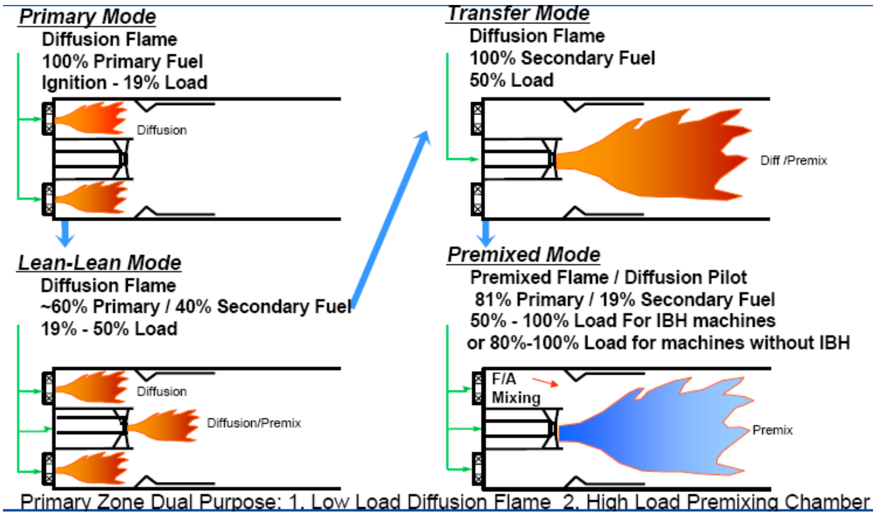
Modes of operation for DLN system

The combustion system operates in four distinct modes of operation.

- *Primary* – Fuel to the primary nozzles only. Flame is in the primary stage only. This mode of operation is used to ignite, accelerate and operate the machine over low- to mid-loads, up to a pre-selected combustion reference temperature.
- *Lean-Lean* – Fuel to both the primary and secondary nozzles. Flame is in both the primary and secondary zones. This mode of operation is used for intermediate loads between two pre-selected combustion reference temperatures.
- *Secondary* – Fuel to the secondary nozzle only. Flame is in the secondary zone only. This mode is a transition state between lean-lean and premix modes. This mode is necessary to extinguish the flame in the primary zone, before fuel is reintroduced into what becomes the primary premixing zone.
- Premix – Fuel to both primary and secondary nozzles. Flame is in the secondary stage only. This mode of operation is achieved at and near the combustion reference temperature design point. Optimum emissions are generated in premix mode.

The load range associated with these modes varies with the degree of inlet guide vane modulation and, to a smaller extent, with the ambient temperature. At ISO ambient, the premix operating range is 50% to 100% load with IGV modulation down to 42°, and 75% to 100% load with IGV modulation down to 57°. The 42° IGV minimum requires an inlet bleed heat system.

If required, both the primary and secondary fuel nozzles can be dual-fuel nozzles, thus allowing automatic transfer from gas to liquid fuel throughout the load range. When burning either natural gas or distillate oil, the system can operate to full load in the lean-lean mode. This allows wet abatement of NOx on oil fuel and power augmentation with water on gas.



3. Scope for DLN retrofits :

Two main parts of the scope for DLN retrofit are covered in this paper. One is the modifications done inside the Gas turbine and the other is the modifications done outside the turbine in the associated systems.

a. Gas Turbine internal modifications for DLN retrofit:

These modifications include new combustion casings, combustion liners, combustion covers and primary and secondary fuel nozzles. In addition, several valves and piping arrangements need to be modified or replaced.

- Combustion System
    - Primary fuel nozzle assembly – gas fuel
    - Secondary fuel nozzle assembly – gas fuel
    - Combustion chamber arrangement
    - Combustion case arrangement
    - Transition piece hardware kit
    - Combustion cap & liner assembly
- Fuel Gas Sub-System
    - DLN fuel gas valve module
    - Instrumentations
- On-Base Fuel and Associated Systems
    - Hydraulic manifolds
    - Fuel gas piping modifications

- Cooling water piping modifications
- Control oil piping modifications
- Cooling and sealing air piping modifications
- DLN flame detector system
- DLN ignition system
- DLN spark p lug igniter assembly

- General Items
  - Liner re-tune
  - Three piece control curve
  - Interconnecting primary & secondary piping (GT to DLN module)
  - Interconnecting hydraulic oil & drain piping (GT to DLN module)

b. **Gas Turbine associated system modifications for DLN retrofit:**

The associated system modifications are necessary to meet DLN combustion system requirements for a reliable operation. The requirements are as follows :

- Controlled change of fuel gas quality (Wobbe Index): Fuel Gas Mixing Drum Upgrade
- Steady fuel gas supply pressure : Fuel Gas Pressure ramp up logic modification
- Turbine operation on part load: Inlet Bleed Heat (IBH)
- Liquid free gas fuel: Fuel Gas filtration system upgrade

DLN units are more sensitive than standard combustion units for pressure fluctuations , nitrogen content fluctuation in the fuel gas as well as sudden changes in fuel gas composition. Such changes can lead the unit operation to shift from Premix steady state to extended lean-lean operating mode , which is re-ignition in the primary zone at high loads above 80% for units which don't have IBH. Turbine operation on extended lean -lean mode is not recommended as the maintenance factor is 10x, due to exposure of combustion hardware to high temperatures. The life of combustion hardware is de-rated by a factor of 10 (1 hour operation in extended lean -lean mode is equivalent to 10 hour operation in premix steady state mode), severely impacting the machine inspection interval.

- Fuel Gas Mixing Drum Upgrade

Modified Wobbe Index (MWI) measures the fuel quality in terms of GHV, Specific gravity & temperature. Changes in fuel gas pressure, temperature and molecular weight are captured by the MWI. A stable operation in DLN mode requires rate of change of MWI to be less than 0.3% per sec. During start-up of LNG train or in event of upsets such as fuel gas compressor trip, the fuel gas composition changes significantly from very lean 'End Flash Gas' to rich gas from feed. To achieve controlled changes in the fuel gas quality during such scenarios, fuel gas mixing drum has been resized & new mixing drum was installed to guarantee MWI rate of change < 0.3%/sec from existing design of 0.5%/sec.

- Fuel Gas Pressure ramp up logic modification

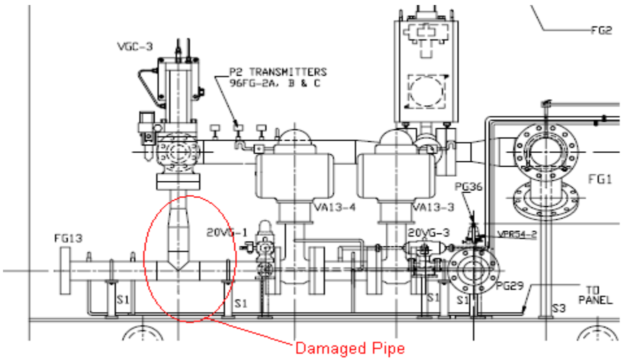
Fuel gas pressure fluctuations during fuel gas compressor upsets or trips has been overcome by invention of a proactive logic to ensuring fast make of alternative fuel supply from feed gas (FFF). The Logic is based on the flow & discharge pressure signals from the fuel gas compressor.

- [Inlet Bleed Heat (IBH)]

Lower operating loads on gas turbines can result in turbine operation moving out of 'Premix Steady State' mode, resulting in emissions beyond norms. This is particularly applicable to gas turbine generators, which typically operate on part loads due to var ious considerations. Provision of 'Inlet Bleed heating System' ensure that the turbine combustion reference temperatures always stays above reference points to continue operation in 'Premix Steady state' even under part load conditions.

- [Fuel Gas filtration system upgrade]

The fuel gas supplied to gas turbines is 'End Flash gas' which is used for Dryer regeneration & treated for sour gas removal using Selexol. Lessons learned with existing DLN1 units indicated that accumulation of Selexol mist upstream the Gas Transfer valve can lead to combustion troubles and cause damage to piping in the valve skid due to exposure to hot purge air. (Refer pictures below).

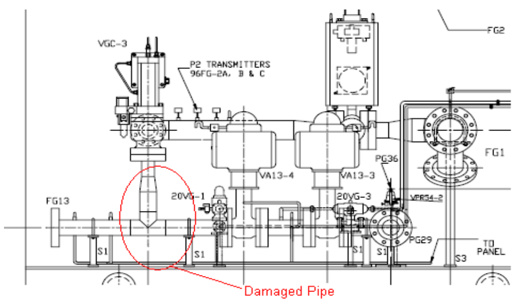


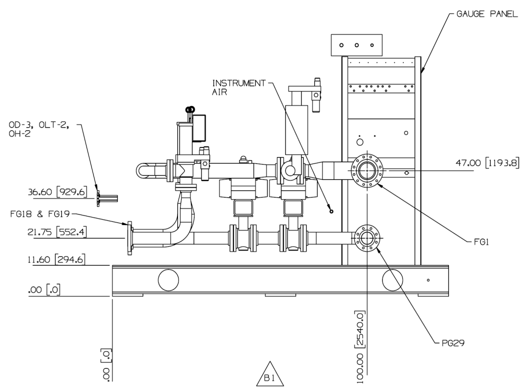
Mitigations for presence of Selexol as well as other heavy hydrocarbons in the fuel gas supply to DLN Gas turbines should be considered. These include:

- Installations of demister tray in the Mix drum
- Installations of high efficiency Coalescer filter elements, with removal efficiency of 99.99% for particulates down to 0.3 micron
- Avoid dead pockets which can have liquid accumulations and sudden carry over to the turbine valve skid.
- Redesign the fuel gas valve skid to avoid accumulation of Selexol and heavy hydrocarbons (see below modifications)

Original Design for existing DLN units

Improved design with new DLN retrofits





4. Lessons learnt & key challenges for DLN retrofit project :

For successful DLN conversion of Gas Turbines in brown field environment poses special challenges. These are briefly summarized below:

- ✓ Design basis:
  The retrofit design should achieve robust combustion flame stability as well specified NOx emissions. The design basis should include the actual operating conditions f or the fuel system, fuel gas compositions and upset scenarios , ambient conditions , operating loads and also the gas t urbine current operating parameters . These have an immense effect to guarantee correct ly design ed hardware and associated control parameter s. Optimum design can avoid potential delays due to prolong ed system tuning during start-ups. Worst case scenarios may require liners' retune or even re-sizing the fuel nozzles, which would have long lead time & prolong the turbine outage significantly.

- ✓ Fuel gas system design changes:
  Fuel gas specifications for DLN system are not the same as standard combustor designs. Significant changes may be required to be carried out to meet the specs & ensure long term reliability of the turbine post DLN retrofit. Redesign of fuel gas mixing drum & filtration systems are already discussed above. Additionally higher pressure requirements for DLN system may require hydraulic calculations review & actual DP losses survey across orifices and control valves to identify fuel gas system capability. Mere use of PFD values may lead to costly options such as fuel gas compressor upgrade, resulting in significant cost over runs .

- ✓ Control system challenges:

  Additional control requirements for DLN system arise due to additional fl ame scanners, new fuel gas transfer valve & controls; add on systems such as Combustion Dynamic Monitoring system, etc. Thorough review of the control system during the design phase for additional I/O requirement & assessment of existing system for the available I/O is a must to plan for additional cards & upgrade of the existing control panel.

Special control schemes may require to be developed to address issues of transient or upset conditions. Such control schemes require consideration of electrical gri d stability (ELICS system) Vis a Vis turbine protection. Controlled load reduction is required to avoid sudden changes in flame which can lead to flame instability and blow out.

- ✓ Operator training & instructions:

  Training of operators on new controls, ope rating philosophy & potential areas of concern can go along way into assuring success of the DLN retrofit. Operating challenges are more unique for LNG trains though power generators have their own challenges as well. Turbine load during LNG train start -up can vary significantly leading to potential swings in & out of pre -mix operating mode. Fuel gas system upsets & potential loss of loads / system upsets are other areas which call for specific response & operator trainings.

- ✓ Project Management challenges :
  DLN retrofit of gas turbines in brown field set -up has many challenges. OEM, Vendor, EPCM & operations interfaces & coordination, scheduled shutdown execution timelines, HSE & work conflicts due to congested areas, etc are some of the key challenges.

D) Results

Frame 6B gas turbines have achieved NOx emissions reduction from average of 80 to 120 mg/NM3 to 14 to 17 mg/NM3.

Frame 7EA gas turbines have achieved NOx emissions reduction from average of 180 to 220 mg/NM3 to 12 mg/NM3.

These emission levels are si gnificantly below the MoE norms & exceed the project success criteria as well .

Please refer to below table for frame 6B and frame 7EA emissions' pre and post DLN conversion.

Source		FRAME	3rd Quarter 2007 (before DLN conversion)				SCE Limits (mg/Nm3)	4th Quarter 2011 (After DLN conversion)				SCE Limits (mg/Nm3)
Tag No.	Description			Nox	SO2	O2			Nox	SO2	O2	
Utilities			Status	mg/Nm^3	mg/Nm^3	%	Nox / SO2	Status	mg/Nm^3	mg/Nm^3	%	Nox / SO2
1	Gas Turbine Generator No.1	6	Normal	102.0	32.0	17.5	240 / 1000	Normal	17	0	14.8	125 / 1000
2	Gas Turbine Generator No.2	6	Normal	111.0	35.0	17.3	240 / 1000	Normal	14	0	14.8	125 / 1000
3	Gas Turbine Generator No.3	6	Normal	166.0	43.0	16.2	240 / 1000	Normal	14	3.0	14.9	125 / 1000
4	Gas Turbine Generator No.4	6	Normal	87.0	21.0	18.5	240 / 1000	Normal	16	0	14.9	125 / 1000
5	Gas Turbine Generator No. 5	6	Normal	81.0	23.0	18.5	240 / 1000	Shutdown	-	-	-	125 / 1000
6	Gas Turbine Generator No. 6	6	Normal	126.0	83.0	16.5	240 / 1000	Normal	6	2	14.9	125 / 1000
LNG Train												
1	C3 Compressor Turbine	7	Normal	187.0	80.0	15.3	240 / 1000	Normal	12	2	14.9	125 / 1000
2	MR Compressor Turbine	7	Normal	221.0	70.0	16.3	240 / 1000	Normal	12	2	15.2	125 / 1000

E) Summary/Conclusions

DLN conversion for Gas Turbines has been successfully implemented in both power generation application units as well as mechanical drive units in LNG process trains by Ras Gas Company .

DLN conversion for Gas Turbines is a successful approach to reduce the NOx emissions significantly & has great potential towards contribution for a cleaner climate .

RasGas Company Limited is one of pioneers in the LNG industry for DLN conversion of Gas Turbines in the LNG process trains.

Effective project management team is the key to success of such brown field project.

Lessons learned during DLN conversion of Gas Turbines are of great benefit to maximize unit reliability post DLN conversion.

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