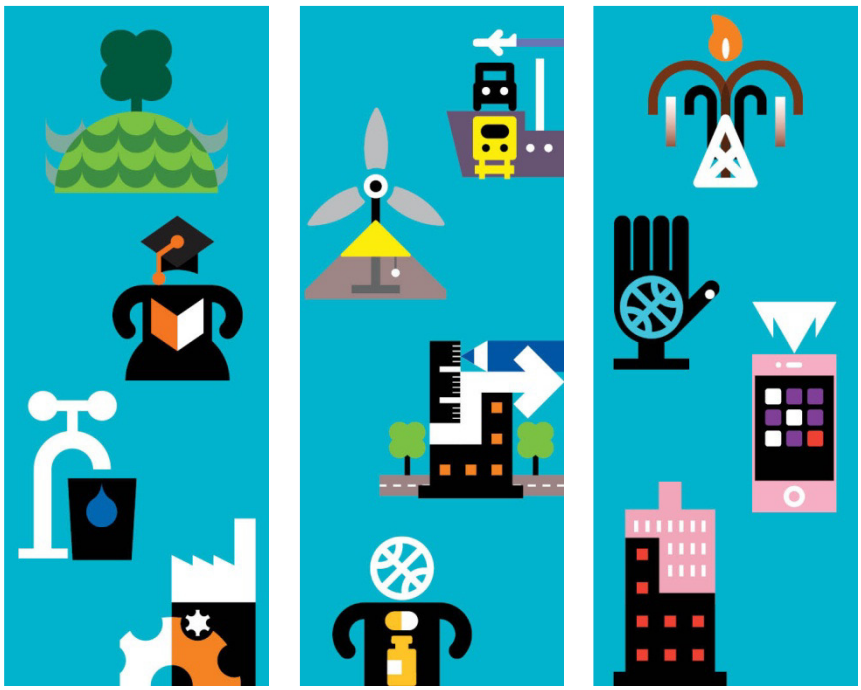

IE Report
Malta Delimara 3 PS
Fuel Conversion

Performance Acceptance Tests - Phase I
(GasOil)

September 2016

D3 Power Generation Ltd.

Mott MacDonald

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Issue and revision record

Revision	Date	Originator	Checker	Approver	Description
0	30 Sept 2016	A Nelson	n/a	n/a	Draft issue (unchecked)
A	11 Oct 2016	A Nelson	S David	S David	Reissue after receipt of SEP-Minghua performance test report
B	12 Oct 2016	A Nelson	S David	S David	Revised after Client's comments

Information class: Standard

Contents

Tables

Executive Summary

Further to the redelivery tests for Malta Delimara 3 which were undertaken in May 2016, Mott MacDonald witnessed the acceptance tests post conversion of the Wärtsilä diesel engines whilst firing Gasoil (LFO). This is to confirm performance after partial conversion, as Gas is not available at this time.

The objective of these acceptance tests is to measure and compare the heat rate, power and noise of the units, and compare the results to the pre-conversion redelivery test results.

The test schedule was as follows:

- Witness Performance Acceptance Tests on LFO 29th September 2016, with Engines #'s 45,46,47,48 in service at loads:
  - 16.6 MWe each in exhaust heat recovery mode, 100% load;
  - 14.9 MWe each in exhaust heat recovery mode, 90% load;
  - 13.3 MWe each in exhaust heat recovery mode, 80% load.
    [heat recovery mode = STG combined cycle operation]

Shanghai Minghua Electric Power Technology Engineering Co., Ltd (SEP-Minghua) conducted the tests, which were witnessed by Andrew Nelson from Mott MacDonald.

Mott MacDonald note that during the 100% load test, the steam turbine generator (STGen) power output oscillated significantly. Looking back at the DCS traces for the May redelivery tests it is evident that a similar condition was present. Operations staff believe this is due to settings on the ST governor and that it can be rectified by revising settings.

Mott MacDonald recommend that prior to the next performance testing on both LFO and Gas, when gas is available, the following actions should be undertaken:

- The ST output variation at 100% load is resolved such that variation of power output is regulated within a reasonable amount;
- DCS data downloads are available (for relevant parameters at an appropriate frequency) such that performance data for the performance tests can be extracted into Excel spreadsheets for ease of use;
- The required calibration gases are made available on site to confirm the emissions to air.

The formal test report from SEP-Minghua was received for review on Saturday 8 October 2016, complete with laboratory LFO analysis and PM emissions analysis.

Although stable test conditions were not achieved during the stabilisation period or for the pre-test, attributed to the STGen output fluctuations, it was agreed by all parties to proceed with the acceptance tests. The fluctuation of STGen output, which although was relatively high in magnitude (when just considering the ST MWe output alone), was uniform and had a very regular frequency oscillation and therefore not expected to be significant for the results of the overall plant in combined cycle mode (when compared to the combined output of the four diesel engines and ST).

1 Testing

1.1 Introduction

D3 Power Generation Ltd., (D3PG) is a subsidiary of Shanghai Electric Power Malta Holding Ltd. (SEPM). SEPM owns 90% of the shares of D3PG and Enemalta plc. owns 10%. The off-taker power purchase agreement (PPA) is with Enemalta and the EPC Contractor is SEPEM. Black & Veatch is the Owner's Engineer and Mott MacDonald is the Independent Engineer. SEP-Minghua is undertaking the performance testing.

The D3 power plant, located in Delimara Bay Malta, commenced operation in 2012. It comprises eight diesel engines, eight heat recovery boilers and one steam turbine (13 MWe), which together have a maximum generating output of 149.8 MWe.

There is a phased upgrading of the power plant equipment being undertaken with the aim of both improving emissions and improving overall plant efficiency. As part of this work the 18V46 Wärtsilä diesel engines are being converted from HFO firing to LFO and/or gas firing, as per the following table:

Table 1.1: D3 Equipment Upgrading

Equipment	Pre-Conversion		Post Conversion		OEM
	No.Off	Type	No.Off	Type	
Diesel Generating Sets	8	18V46	4	18V50DF	Wärtsilä
			4	18V50SG	Wärtsilä
Heat Recovery Steam Generators	8	-	8	-	AALBORG
Steam Turbine Generator	1	Frame 30 (13MWe)	1	-	Dresser-Rand
Auxiliary Boiler	0	-	1	-	

Source: D3 Power Generation Ltd.

The type 18V50DF diesel engines are dual-fuel, firing LFO and/or gas and the type 18V50SG diesel engines will fire gas only.

The predicted performance of the units following conversion is as follows:

Table 1.2: Predicted Performance Post Conversion

Parameter	Pre-Conversion	Post Conversion	
Diesel Engine	8 x 18V46	4 x 18V50DF	4 x 18V50SG
Fuel	HFO	GAS/LFO	GAS
Unit Output (MWe)	17.025	16.638	18.321
Plant Output (MWe)	149.8	152.8	
Overall Plant Efficiency	47%	50%	
Emissions:	HFO	Gas / LFO	Gas
NOx (mg/Nm^3)	<160	<75 / 160	<75
CO (mg/Nm^3)	<240	<100 / 100	<100
PM (mg/Nm^3)	<10	<10 / 10[1]-30[2]	<10
SO_2 (mg/Nm^3)	<120	<15 / 70	<15
Noise		To be no worse than pre-conversion	

Source: D3 Power Generation Ltd.
Note: 1. With FG-BF and 2. No FGD-BF

The conversion is phased such that 4 units are converted to operate on dual fuel initially and proven in operation on LFO first and then gas (when available), then the subsequent 4 units will be converted to gas firing. Being optimised on gas only, the subsequent 4 units will have a slightly higher generating output (as is shown in the table above).

Together with an improvement in overall efficiency, the emissions to air from the units post conversion will be significantly reduced, as indicated in the predicted performance data quoted above.

1.2 General

The objective of these tests is to measure the heat rate, power, noise and emissions of the units; and compare this to the benchmark data recorded prior to the conversion of the units.

Delimara 3 power plant formally went into production in December 2012. Currently, the power plant is equipped with eight 18V46 type generators from Wärtsilä. Each generator has a power output of about 17.1 MWe. Each diesel engine is of the four-stroke medium-speed, direct injected, turbo-charged, and two-stage inter-cooled design. The fuel oil system is designed for operation on heavy fuel oil (HFO) as the main fuel, and diesel oil (DO) as back-up fuel. The fuel system consists of three sub-systems: the transfer and supply system, the common treatment system, and direct diesel engine related injection system. There is a preheater to ensure correct fuel viscosity during all engine loads. Seawater is circulated for extracting the heat generated by the engine. The entire engine cooling water system consists of two separate systems: a high temperature (HT) system and a low temperature (LT) system.

Each internal combustion unit is configured with one heat recovery boiler operating at two pressures. The high pressure steam is supplied to the common small steam turbine, with a capacity of approximately 13 MWe. The turbine is equipped with a sea water cooled condenser.

Table 1.3: D3 Technical Parameters

Designation	Delimara 3 Power Plant
Diesel engine manufacturer	Wärtsilä
Diesel engine type	18V46
Diesel engine speed	500rpm
Number of engines	8 pcs
ISO shaft rating (100% MCR)	17.550 MW
Generation voltage and frequency	15kV 50Hz
Cooling type	Seawater via central coolers
Combustion air intake concept	Ducted from outside
Engine configuration	With attached LO and 2pcs CW pumps
Process configuration	With Waste Heat Recovery steam boilers and one common seawater cooled steam turbine generator unit
Fuel type	HFO,1%S
Plant environmental configuration	SCR deNOx and Particulate reduction/deSOx facility

Source: The scheme of redelivery test of the Malta Delimara 3 Power Generation Ltd

Table 1.4: Reference Environmental Parameters

Designation	Numerical value
Ambient reference air temperature	24℃
Ambient barometric pressure	1013mbar
Ambient air humidity	65%
Seawater intake temperature	21℃
Fuel ref. LCV: Gas / LFO	40.71 / 42.7 MJ/kg
Power factor at generator terminals	0.8

Source: The scheme of redelivery test of the Malta Delimara 3 Power Generation Ltd

For the redelivery tests, the 18V46 type engines were tested to benchmark pre-conversion performance in order that comparison can be made following the conversion to gas operation. The phase 1 converted engines #45, 46, 47 & 48 are now type 18V50DF (diesel ignited) engines and are rated at 16.6 MWe. The subsequent phase 2 conversion will be to engines #41, 42, 43 & 44 and these will be 18V50SG (spark ignited), rated at 18.32 MWe. These engines have different bore and stroke than the 18V46.

1.3 Acceptance Test Procedure

The procedure for the acceptance tests is as detailed in the SEP-Minghua document “The scheme of acceptance test for Phase I on LFO after conversion of the Malta Delimara 3 power plant”, dated August 2016.

The test schedule was as follows:

- Witness Performance Acceptance Tests on gas oil 29th September 2016, with Engines #’s 45,46,47,48 in service at loads:
  - 16.6 MWe each in exhaust heat recovery mode, 100% load;
  - 14.9 MWe each in exhaust heat recovery mode, 90% load;
  - 13.3 MWe each in exhaust heat recovery mode, 80% load.
    [heat recovery mode = STG combined cycle operation]

It is noted that Wärtsilä has already had acceptance and contractual sign-off from SEP on LFO operation, based on performance testing on each engine (#45-48). These tests are to confirm the combined cycle performance of the plant with engines #45-48.

Phase 2 testing will be undertaken once gas is available.

1.4 Witness of Acceptance Testing, Engines #45, 46, 47 & 48

1.4.1 Pre-testing familiarisation at site (28 Sept 2016)

Mott MacDonald attended site on 28th September to have a pre-meeting with the test team for the acceptance tests on units # 45, 46, 47, & 48. SEPM staff gave a tour of the site together with brief discussions regarding the test procedure, measurements and proposed schedule.

Observations to note:

- There is no actual measurement of the pilot fuel quantity; this is assumed to be 1%. The LFO fuel flow is read from local meters hourly throughout the tests;
- No calibration gases are available at site for emissions tests to set zero and span and check drift during test period; Note 1
- FGD and bag-filter have been removed and so some question regarding whether target SO_2 and PM levels will be met during testing; Note 2
- The DCS had not been prepared such that raw data files could be downloaded for the main parameters during the tests. SEP advises that software may be in place in time for the next testing to enable this to be done. This would enable the use in Excel spreadsheet for more easily processing and interrogating data. Manual data readings are noted at set intervals;
- Reliability Run was in progress (3 days, but split between 2+2 unit operation) – acceptance tests commence when this is completed successfully – due to be around 10:00am 29th September 2016.
- SCR ammonia consumption is not a guaranteed value.
- As two engines feed into each stack with two stacks for engines 45-48 and as there was only one set of emissions measuring equipment, it was agreed that emissions testing would be carried out for half the time on one stack and then switched to the other stack for the remaining time.

Note 1: Recommend that when final tests are undertaken including gas that the emissions are rechecked and calibration gases are made available on site.

Note 2: D3PG post-test note - Emissions for SO_2 and PM with diesel operation were still met under the available and current IPPC permit conditions. The authorities are still to communicate the permissible emission levels when operating with gas and the emissions levels when the engines are operated with diesel (i.e. if there will be any changes to the current permit levels for diesel operation).

1.4.2 Acceptance Tests (29th September 2016)

Mott MacDonald attended site on 29th September at 08:30 and the reliability run was still in progress for two units. SEPEM advised that this was successfully competed at 10:30 and that all four engines for testing (45, 46, 47, & 48) were now in service and being brought up to full load. Engines 41, 42, 43 & 44 were not in service.

However, due to grid requirements it was not possible to commence the full load combined cycle test as planned. This was postponed and it was agreed that the 80% and 90% non-guarantee tests would be

undertaken first and the 100% guarantee test be conducted when a suitable period of stable generation at full load became possible.

The actual test schedule was as follows:

Table 1.5: Actual Test Schedule, 29 September 2016

Test condition and Load		Time
90% load:	13.3 MWe each in exhaust heat recovery mode [not guarantee]	10:45 – 13:00
80% load:	14.9 MWe each in exhaust heat recovery mode [not guarantee]	13:00 – 15:00
100% load:	16.6 MWe each in exhaust heat recovery mode – Pre-Test (1.5hr)	15:30 – 17:00
100% load:	16.6 MWe each in exhaust heat recovery mode – Formal Guarantee Acceptance Test (2hr)	17:00 – 19:00

Note: Tests undertaken in heat recovery mode, i.e. STG combined cycle operation

The testing was under taken by staff from Shanghai Minghua Electric Power Technology Engineering Co. Ltd., (SEP-Minghua) including Sheng Liao (Leo); D3PG (Owner) staff, including Zhenjun Zhang (Matthew) and witnessed by Howard Jenner from Black & Veatch (Owner's Engineer) and Andrew Nelson from Mott MacDonald (Independent Engineer). Melchior Pace (D3PG) was coordinating engine loading with Enemalta dispatch section from the CCR throughout the whole test.

The 90% and 80% load tests were undertaken to provide information for the thermal operations model and are not guarantee conditions. For the 100% formal guarantee acceptance test, separate preliminary and formal tests were performed one after the other, without stopping.

For the formal guarantee acceptance test:

- Fuel oil samples were taken for each engine (three sample bottles per engine);
- Gross electrical readings were taken from the MWhr meters located in the local control panels, whilst simultaneously (by personnel using synchronised watches) total fuel oil flow readings were taken using the local instrumentation for each unit under test;
- Ambient conditions (temperature, pressure and relative humidity) were recorded using temporary test instrumentation installed adjacent to the permanent temperature instrumentation for unit #45;
- Emissions measurements were taken at the stack (1 hour for each stack for the 2+2 units);
- Noise measurements were taken at pre-determined noise locations inside and outside of the noise enclosures and outside the engine hall.

SEP-Minghua took photographic evidence of the MWhr and fuel flow meters of the units on test, together with screen shots from the DCS to confirm that the readings presented in the report are a true reflection of the test values. Mott MacDonald also took spot readings and photos from the DCS in order that verification of test readings can be made.

It was advised that for the guarantee test the units were set up as per normal operation: the blowdown of the boilers were not isolated and demineralised water make-up was to the deaerator as per normal operation for this plant.

1.4.3 Post Acceptance Test Meeting, 30 September 2016

Following the acceptance testing a meeting was held between staff from D3PG (Owner), SEPEM (EPC Contractor), SEP-Minghua (sub-contractor to SEPEM for the testing), Black & Veatch (Owner's Engineer) and Mott MacDonald (Independent Engineer) to discuss the preliminary results.

Key staff present included:

- David Griscti — D3PG
- Melchior Pace — D3PG
- Matthew Zhang — D3PG
- Tan Qing — SEPEM (Project Manager)
- Zhang Liang — SEPEM
- Sheng Liao (Leo) — SEP-Minghua
- Minghua Xue — SEP-Minghua
- Howard Jenner — Black & Veatch (Owner's Engineer)
- Andrew Nelson — Mott MacDonald (Independent Engineer)

1.4.3.1 SEP-Minghua's Presentation of the Preliminary Acceptance Test Results

SEP-Minghua presented the preliminary calculations on the test results, based on the LFO analysis from a sample taken recently. The actual test fuel samples are waiting analysis.

SEP-Minghua advised that both the gross output and the heat rate achieved during the combined cycle test at 100% load was better than the guaranteed value, with emissions to air all within the permissible limits (subject to later confirmation by analysis for particulate matter). Noise levels were confirmed to be no higher than pre-conversion.

In conclusion, all performance is within the guaranteed requirements.

SEP-Minghua will prepare its test report and submit to Mott MacDonald together with the calculations for later verification. In addition, copies of data sheets, DCS trends, photographs (DCS screen shots and of equipment, readings), and calibration certificates will be provided.

1.4.3.2 Mott MacDonald's Comments on the Acceptance Testing

Mott MacDonald confirmed that it had witnessed the performance acceptance test and noted that the preliminary results presented by SEP-Minghua would indicate that the performance guarantees have been satisfied. However it should be noted that there are some issues that need to be recorded regarding the undertaking of the tests:

1. High level of STGen output fluctuation (>±20%) – outside typical code validity requirements, although this was equivalent to only about ±2% of the total combined cycle plant output for the test;
2. Frequency of data recording and parameters recorded – would benefit from DCS data download, which could be supplemented by simultaneous manual data recording;
3. Lack of calibration gases for emissions measuring equipment on site (SEP-Minghua calibrated the equipment in China due to the difficulty they faced getting the gases imported into Malta).

It should also be noted that the pilot fuel consumption is not measured, but is taken as an assumed 1%, in-line with Wärtsilä's recommendations.

Mott MacDonald would note that the level of STGen output fluctuation is above that considered acceptable under strict interpretation of typical performance test codes, however it would appear that no specific test code and/or test procedure for the combined cycle plant performance is stated in the EPC Contract.

Mott MacDonald recommended that the issues be resolved if possible before the Phase 2 testing is undertaken on LFO/gas on units 45-48 and on gas for units 41-44.

2 Review of Results

2.1 General

SEP-Minghua submitted its formal report to Mott MacDonald for review by email on Saturday 8th October 2016 at 17:58. This report has been updated with the as-tested fuel analysis and the laboratory analysis results of the particulate matter samples from the tests.

The calculation methodology was previously confirmed by Mott MacDonald for the May 2016 testing. We would note that the formula for correction of steam turbine output power (page18, 6.5) has not been amended as per agreements in correspondence subsequent to the May 2016 tests, however the corrected value is appropriately derived and so this is not an issue.

Mott MacDonald generated its own spreadsheet for comparison of the results, which correlates well with Minghua's presented results. It should be noted that the time period taken for the formal guarantee tests was agreed to be 16:30 to 18:30. This includes part of the pre-test period, but it was necessary as grid requirements meant that plant output had to be reduced towards the end of the guarantee test period.

A summary of the results from the tests is presented below:

Table 2.1: DE45-DE48 Engines plus STG Combined Cycle Test at 100% load (29th September 2016 16:30-18:30)

Parameter	Units	Reference	Actual Test
Ambient air temperature	℃	24	26.33
Ambient barometric pressure	mbar	1013	1024.46
Ambient air humidity	%	65	Not used
Seawater intake temperature	℃	21	23
Light Fuel Oil (LFO) LCV	MJ/kg	42.7	42.91
Power factor at generator terminals	-	0.8	Note 1
Main Performance Parameters			
Steam Turbine Power Output (Gross) Corrected to reference conditions	kWe	~5800	5867.17
Combined cycle gross Power Output DE45-DE48 engines plus STG. Corrected to reference conditions	kWe	66,552	72,380.67
Combined cycle gross heat rate of DE45-DE48 plus STG Corrected to reference conditions, plus 1% pilot fuel	kJ/kWh	≤7,624	7,547.98
Exhaust gas emissions to Air, after Abatement			
Nitrogen Oxides (corrected to 15% Vol.O_2, dry) [NOx]	mg/Nm^3	≤160	95.8 / 49.2 [3]
Sulphur Dioxides (corrected to 15% Vol.O_2, dry) [NOx]	mg/Nm^3	≤70	21.2 / 19.1 [3]
Carbon Monoxide (corrected to 15% Vol.O_2, dry) [CO]	mg/Nm^3	≤100	58.6 / 58.9 [3]
Particulate Matter (corrected to 15% Vol.O_2, dry) [PM]	mg/Nm^3	≤30 [2]	5.1 / 6.8 [3]
Diesel Engine Noise (45, 46, 47, 48)			
DE45 Average P1-P9 measuring points [Inside enclosure]	dB	105.37	104.84

Parameter	Units	Reference	Actual Test
DE46 Average P1-P9 measuring points [Inside enclosure]	dB	105.46	105.40
DE47 Average P1-P9 measuring points [Inside enclosure]	dB	105.59	105.40
DE48 Average P1-P9 measuring points [Inside enclosure]	dB	105.24	**105.53**
DE45 Average P10 & P11 measuring points [Outside enclosure]	dB	77.45	76.85
DE46 Average P10 & P11 measuring points [Outside enclosure]	dB	78.45	77.85
DE47 Average P10 & P11 measuring points [Outside enclosure]	dB	81.15	78.40
DE48 Average P10 & P11 measuring points [Outside enclosure]	dB	79.65	79.15
Average P12 & P13 measuring points [External at plant boundary]	dB	70.65	66.35

Source: SEP-Minghua Formal Test Report
Notes: 1. Assumed to be as reference
2. No FGD-BF in operation
3. Stack3 (DE45 and 46) / Stack 4 (DE47 and 48) [NOx level of Stack 4 is lower due to the larger amount of ammonia injection for DE47 and DE48]

As can be seen from the table above, the performance requirements have been met for the main performance parameters, including the emissions to air and noise (with the exception of the inside enclosure measurement of DE48, which is marginally higher but not considered to be significantly so).

2.2 Conclusion

DE45-DE48 Engines plus STG in combined cycle operation have satisfied the test requirements at 100% load when firing LFO.

Although stable test conditions were not achieved during the stabilisation period or for the pre-test, attributed to the STGen output fluctuations, it was agreed by all parties to proceed with the acceptance tests. The fluctuation of STGen output, which although was relatively high in magnitude (when just considering the ST MWe output alone), was uniform and had a very regular frequency oscillation and therefore not expected to be significant for the results of the overall plant in combined cycle mode (when compared to the combined output of the four diesel engines and ST).

If desired for the purposes of more accurate benchmarking of performance, it is suggested that the opportunity of repeat testing on LFO on DE 45, 46, 47 & 48 is taken when further performance testing is undertaken on the units when gas is available.

In addition, for future tests it is recommended that the following points are taken into consideration:

- Pre-test protocol is issued with criteria for starting test, for each party to sign;
- Copies of calibration certificates for all test equipment are provided prior to commencing the tests;
- Post-test protocol is issued with criteria for completion of test, for each party to sign, confirming tests have been carried out in accordance with the test procedure;

- Copies of the test data sheets are handed over on the day of testing (initialled by parties if required);
- The ST output variation at 100% load is resolved such that variation of power output is regulated within a reasonable amount;
- DCS data downloads are available (for relevant parameters at an appropriate frequency) such that performance data for the performance tests can be extracted into Excel spreadsheets for ease of use;
- The required calibration gases are made available on site to confirm the emissions to air.

Appendices

Appendix A. SEP-Minghua Test Report

The performance acceptance test report for Phase I on LFO after conversion of Malta Delimara 3 plant - formal report (Shanghai Minghua Power Technology Engineering Co., Ltd) – as received 8th October 2016. [Total 60 pages].