McHale Performance

Holland Energy Park
Holland, Michigan

FACILITY – PTC 46
PERFORMANCE TEST REPORT

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APPROVED FOR ISSUE

Originator: By: Gabriel R. Ramos Date: May 13, 2017

Engineering Reviewer: By: John H. Bannen Date: May 13, 2017

Project Manager Approval: By: James L. Hollibaugh Date: May 13, 2017

EXECUTIVE SUMMARY

Facility Performance Testing at the Holland Energy Park in Holland, Michigan was conducted on May 6, 2017 by McHale & Associates, Inc. Testing was conducted in general accordance with PTC 46-1996 and the Facility Thermal Performance Test Procedure, Rev. 1, Dated February 2, 2017.

Performance Testing was conducted according to the Test Schedule in Section 1.1 with the goal of determining the following for information only. There are no contractual Facility performance goals.

- Facility Net Plant Electrical Output
- Facility Net Plant Heat Rate

Unit operational configuration was as follows for all Performance Tests:

- Gas Turbines operated at Base Load (T52L Control)
- Steam Turbine operated at Base Load
- Gas Turbines were fired on natural gas fuel with the properties shown in Appendix G
- Cooling tower was run in full plume abatement mode. All cooling tower fans were in-service, running in automatic control with the fan VFD in-service
- Evaporative Cooling was out of service
- Auxiliary Boiler was out of service
- CTG Anti-icing system was out of service
- Snowmelt system was out of service

Measured performance was corrected to the reference conditions stated in the Test Procedure. A summary of the corrected Test Results are presented in Table E-1:

Table E-1: Summary of Corrected Test Results[1]

Parameter	Units	Expected Performance	Corrected Performance
Facility Net Plant Electrical Output	MW	124.01[2]	123.12
Facility Net Plant Heat Rate	Btu/kWh (HHV)	7,426	6,842

1. Corrected result presented in Table E-1 was calculated using the average of two (2) one (1) hour Test Runs.
2. The expected Facility Net Plant Electrical Output value listed in Table E-1 was obtained from the guaranteed heat balance D001310-UDSM00005, Rev. 1, Dated August 29, 2016. A more recent version of the Zachry heat balance was released Oct. 26, 2016 with an expected Facility Net Output of 121.776 MW.

Further description of the plant disposition, testing methodology, and explanation of the Test Results are provided in this document. Detailed calculations, test data, and calibration records are also provided in the Appendix of this Test Report.

1 INTRODUCTION

1.1 GENERAL INFORMATION

Facility Performance Testing at Holland Energy Park was conducted on May 6, 2017 by McHale & Associates, Inc. Holland Energy Park is a combined cycle plant with two (2) Siemens SGT-800 gas turbines (CTG). Exhaust gases are routed through two (2) Vogt Heat Recovery Steam Generators (HRSG). Steam production is provided to a Siemens SST-400 steam turbine (SGT). Facility heat rejection is provided through an SPX steam surface condenser and an SPX Clearsky Plume Abated Cooling Tower.

Performance Testing was conducted according to the Test Schedule listed in Table 1-1.

Table 1-1: Test Schedule

Test Run	Date	Start Time	End Time
Stability	May 6, 2017	10:00	14:30
Test Run 1	May 6, 2017	15:45	16:15
Test Run 2	May 6, 2017	16:15	16:45
Test Run 3	May 6, 2017	16:45	17:15
Test Run 4	May 6, 2017	17:15	17:45

1. Note that the original start of the test was 14:30 according to the Test Sign-off Form provided in Appendix E. The start of the test was delayed due to the temporary CTG inlet temperature grid losing power shortly after the start of the test. Cycle isolation and plant stability was maintained during the loss of the power to the temporary instruments.

The Test Goals were evaluated per the Test Procedure provided in this Test Report as Appendix A. Corrected Test Results from each Test Run were arithmetically averaged and were calculated without uncertainty tolerances or degradation correction factors.

1.2 TEST GOAL

Performance Testing was conducted according to the Test Schedule in Section 1.1 with the goal of determining the following:

- Facility Net Plant Electrical Output
- Facility Net Plant Heat Rate

1.3 PARTIES TO THE TEST

The following are the Parties to the Test and their designated representatives:

Owner/Owner Representative:	Holland Board of Public Works (BPW)/HDR, Inc.
Representative:	Chris Zuelch (HDR)
Contractor:	Barton Malow
Representative:	Wayne Geyman

Testing Contractor:	McHale & Associates Inc.
Representative:	Gabriel Ramos

1.4 TEST ACTIVITIES

April 30, 2017

- One (1) of three (3) McHale performance testing employees
- Inventoried temporary test equipment and labeled equipment in preparation for installation
- OFE equipment walkdown to observe state of equipment and measurement locations
- Completed installation of the STG and CTG temporary Nexus 3-phase power meters downstream of the generator terminals

May 1, 2017

- All three (3) McHale performance testing employees arrive on site
- Attended daily Barton Malow meeting at 6:30 am
- OFE equipment walkdown to observe state of equipment and measurement locations
- Attended site safety orientation
- Obtained roof and confined space permits for CTG Inlets and Stack Exhaust Thermocouples
- Started temporary equipment installation
- Attended meeting between HDR, BPW, and Barton Malow.
- Spoke with the DCS engineer to confirm that the Deadband and/or Compression Algorithms were turned off for all primary test parameters. Confirmed that the deadband in the DCS was not turned off for every primary parameter. The deadband for every primary measurement in the DCS could not be turned off due to the time constraints and the time required to remove the deadband for every primary measurement. The deadband was either removed or significant figures were increased for only the primary measurements with a high sensitivity to the corrected results.

May 2, 2017

- Daily meeting at 6:30 am. Obtained roof/confined space permits
- Jacob continued Plume Abatement equipment setup with 2 site personnel. He will likely be finished by noon tomorrow.
- Completed installation of the CTG exhaust thermocouples, stack thermocouples, and exhaust dP measurements. All thermocouple measurements are recording on the MDAS
- Scaffolding built for the ST exhaust pressure measurements

May 3, 2017

- Daily 6:30 meeting
- Completed Facility/OFE temporary equipment setup with exception of Cooling Tower wet bulbs and MDAS for power meters
- Meeting with all parties to test (with exception of Siemens CTG team) at 11 am
- Completed noise survey on Aux Boiler
- Attempted to identify fuel sampling location with BM and Owner. Not too many options. Tomorrow we will attempt to explore more options for fuel samples.
- Attempted EDG noise survey. Didn't consider the load bank was going to be in service during the EDG emissions test. Spoke with Wayne and Nathan (BM electrician) for a possible solution. We decided to perform a load transfer of the emergency bus to the EDG whenever schedule allows.

May 4, 2017

- Completed Facility/OFE temporary equipment setup
- Meeting with HDR and Barton Malow

May 5, 2017

- Attended daily morning meeting
- Siemens elected to not water wash the CTGs
- Delayed start of the CTGs due to low temperatures and no inlet air heating
- Started both CTGs with steam on bypass until chemistry was within the Facility limits
- Admitted steam to steam turbine at a very slow rate due to the STG being offline for almost a month
- Observed Nexus STG power meter when STG breaker closed. Determined leads swapped since power was reading negative. Took STG offline and opened breaker to swap leads.
- Siemens performed a few functional tests on the STG before bringing the STG to full load
- Took steam turbine to base load at slow rate due to the STG being offline for almost a month
- Silica levels exceeded limits after admission of steam to the turbine. Blowdown was not isolated for the preliminary test due to high silica levels. Two hours of data collection a full load without cycle isolation

May 6, 2017

- Attended daily morning meeting
- Added two (2) temporary measurements for LP superheater outlet temperature upon Vogt's request after a discrepancy amongst station measurements was observed

- Facility at base load at 10 am. Initiated four (4) hour stability run.
- Observed cycle losses after initiating valve isolation during stability run. No issues noted.
- Delayed start of test from 14:00 to 14:30 due to discussions with HDR. Received signatures from all parties at 14:15.
- CTG inlet temperature grid lost power just after test started due to the GFCI trapping on the socket where the MDAS was receiving power. New test start time of 15:15.
- Finished almost all of noise testing. Cooling tower, snowmelt, and EDG remain for guaranteed testing. Workplace noise and Far Field (non guarantees) will be conducted sometime this week.
- Concluded test at 17:15. Data and cycle isolation was maintained until 18:00 to obtain additional test data.

1.5 TEST CLARIFICATIONS

The following are clarifications to the Test Procedure:

- It was observed that the deadband in the DCS was not turned off for every primary parameter. The deadband for every primary measurement in the DCS could not be turned off due to the time constraints and the time required to remove the deadband for every primary measurement. The deadband was either removed or significant figures were increased for only the primary measurements with a high sensitivity to the corrected results.

- The CTG and STG net revenue meter data could not be obtained for the Performance Test because of bad readings in the DCS. Net Electrical Power Output shall be calculated based on the Testing Specification as follows

$$P_{Meas} = P_{CTG10} + P_{CTG11} + P_{STG12} - \Sigma Aux_{BOP} - \Sigma L_{GSU}$$

Where:

P_{Meas}	= Calculated Net Electrical Power Output, kW
P_{CTG10}	= Measured Unit Gross Power Output for CTG 10, kW
P_{CTG11}	= Measured Unit Gross Power Output for CTG 11, kW
P_{STG12}	= Measured Unit Gross Power Output for STG 12, kW
ΣAux_{BOP}	= Sum of Auxiliary Power of the Entire Plant, kW
ΣL_{GSU}	= Sum of losses across Unit 10, 11, and 12 GSUs, as calculated below, kW

The losses across each generator step-up transformer shall be calculated according to the following equation:

$$P_{XFMR\_i} = P_{NLL} + P_{LL}\left[\frac{P_{Unit\_i}}{s_R \cos\varphi_{Meas}}\right]^2$$

Where:

P_{NLL}	=No-Load Transformer Losses (given by Manufacturer's Specification Sheet), kW
P_{LL}	= Apparent Load Proportional Transformer Losses (given by Manufacturer's Specification Sheet), kW
P_{unit_i}	= Component Power (CTG 10, CTG11, or STG12) on Low-Side of Step-Up Transformer, kW
$\cos_{\varphi Meas}$	= Power Factor (measured at unit generator terminals)
s_R	= Rated Apparent Power of Transformer (given by Manufacturer's Specification Sheet)

The total Transformer Losses, L_{GSU}, will be determined by summing the individual unit transformer losses.

$$L_{GSU} = P_{XFMR\_CTG11} + P_{XFMR\_CTG12} + P_{XFMR\_STG10} + P_{XFMR\_AUX}$$

2 CALCULATIONS AND RESULTS

2.1 RESULTS SUMMARY

The corrected test results summary are listed in Table 2-1. Detailed calculations are provided in Appendix C.

Table 2-1: Corrected Test Results Summary – Facility Net Plant Electrical Output

Test Run	Units	Test Measured	Corrected Result	Expected Performance[1]	% Margin
Test Run 1	MW	133.41	123.16	124.01	-0.69%
Test Run 2	MW	133.17	123.09	124.01	-0.74%
Average	MW	**133.29**	**123.12**	**124.01**	**-0.72%**

1. The expected Facility Net Plant Electrical Output value listed in Table E-1 was obtained from the guaranteed heat balance D001310-UDSM00005, Rev. 1, Dated August 29, 2016. A more recent version of the Zachry heat balance was released Oct. 26, 2016 with an expected Facility Net Output of 121.776 MW.

Table 2-2: Corrected Test Results Summary – Facility Net Plant Heat Rate

Test Run	Units	Test Measured	Corrected Result	Expected Performance[1]	% Margin[1]
Test Run 1	Btu/kWh (HHV)	7,168	6,836	7,426	-7.94%
Test Run 2	Btu/kWh (HHV)	7,169	6,847	7,426	-7.79%
Average	Btu/kWh (HHV)	**7,168**	**6,842**	**7,426**	**-7.87%**

1. A negative value indicates a result that is better than the Expected Performance for Net Plant Heat Rate

2.2 STABILITY

Prior to the commencement of the Performance Test the Facility operated in accordance with the operational configuration in the Execute Summary for four (4) hours. During this period, the CTGs, HRSGs, and STG operated at a stable load to ensure the equipment had reached equilibrium and did not undergo abnormal variations in operating parameters. The exception to this four (4) hour stability requirement was the Facility cycle isolation. Cycle isolation was completed one (1) hour prior to the Performance Test and was maintained throughout the duration of the Performance Test.

In addition to the stabilization period, the following operational parameters in Table 2-3 and Table 2-4 were maintained within the provided limitations:

Table 2-3: Maximum Variations in Operating Conditions – Unit 10[1]

Test Variable	Permissible Fluctuation During Any Test Run	Test Run 1 (First 30 Mins)	Test Run 1 (Last 30 Mins)	Test Run 2 (First 30 Mins)	Test Run 2 (Last 30 Mins)
Power Output[2]	±0.65%	0.16%	0.22%	0.15%	0.12%
Barometric Pressure[2]	±0.16%	0.01%	0.02%	0.02%	0.01%
Inlet Air Temperature[3]	±1.3	0.59	0.85	0.55	0.38
Fuel Flow[2]	±0.65%	0.34%	0.36%	0.42%	0.32%

1. Stability criteria is derived from ASME PTC 22-2014 Table 3-3.5-1 in accordance with Table 3-2 of ASME PTC 46-1996. Stability shall be assessed in 30 minute increments.
2. Relative deviation of the Standard Deviation of the Population
3. Absolute deviation of the Standard Deviation of the Population

Table 2-4: Maximum Variations in Operating Conditions – Unit 11[1]

Test Variable	Permissible Fluctuation During Any Test Run	Test Run 1 (First 30 Mins)	Test Run 1 (Last 30 Mins)	Test Run 2 (First 30 Mins)	Test Run 2 (Last 30 Mins)
Power Output[2]	±0.65%	0.27%	0.23%	0.15%	0.11%
Barometric Pressure[2]	±0.16%	0.01%	0.02%	0.02%	0.01%
Inlet Air Temperature[3]	±1.3	0.89	0.92	0.63	0.40
Fuel Flow[2]	±0.65%	0.37%	0.30%	0.32%	0.30%

1. Stability criteria is derived from ASME PTC 22-2014 Table 3-3.5-1 in accordance with Table 3-2 of ASME PTC 46-1996. Stability shall be assessed in 30 minute increments.
2. Relative deviation of the Standard Deviation of the Population
3. Absolute deviation of the Standard Deviation of the Population

2.3 POST-TEST UNCERTAINTY

The post-test uncertainty summary results are listed in Table 2-5. Detailed post-test uncertainty calculations are provided in Appendix D.

Table 2-5: Post-test Uncertainty Summary

Parameter	Units	Exhibit M Limit	PTC 46 Code Limit	Post-Test Uncertainty Results		
				Test Run 1	Test Run 2	Overall Uncertainty[1]
Facility Net Plant Electrical Output	%	0.5	1.0	0.82	0.83	0.83
Facility Net Plant Heat Rate	%	1.0	1.5	0.92	0.93	0.93

1. Overall Uncertainty is not a arithmetic average of the results, rather a statistical average based on ASME PTC 19.1.

It can be observed from Table 2-5 that the Facility Net Plant Electrical Output post-test uncertainty is above the Exhibit M uncertainty limits. In order to meet the Exhibit M uncertainty limits, the Facility would have to be equipped with one (1) plant net revenue meter. Instead there are three (3) net revenue meters, one (1) for each unit, that are summed together to determine net plant output. Using three (3) meters versus one (1) meter in the performance calculations increases the systematic uncertainty thereby increasing the overall post-test uncertainty.

2.4 PERFORMANCE CALCULATIONS

The test codes listed in Table 2-7 have been used as the basis for the performance calculations:

Table 1-4: Applicable Test Codes

Standard	Code	Date	Title
ANSI/ASME	PTC 1	2011	General Instructions
ANSI/ASME	PTC 19.1	2013	Test Uncertainty
ANSI/ASME	PTC 19.2	2010	Pressure Measurement Instruments and Apparatus Supplement
ANSI/ASME	PTC 19.5	2005	Flow Measurements
ANSI/ASME	PTC 22	2014	Performance Test Code on Gas Turbines
ANSI/ASME	PTC 46	1996	Performance Test Code on Overall Plant Performance
ASTM	D1945	2003	Standard Test Method for Analysis of Natural Gas by Gas Chromatography (Reaffirmed 2010
ASTM	3588	1998	Standard Practice for Calculating Heat Value, Compressibility Factor, and Relative Density of Gaseous Fuels (Reaffirmed 2011)
AGA	Report No 8	1994	American Gas Association's Compressibility Factor for Natural Gas and Related Hydrocarbon Gases, Transmission Measurement Committee Report no. 8
GPA	2145	2009	Table of Physical Constants for Hydrocarbons and Other Compounds of Interest to the Natural Gas Industry

3 INSTRUMENTATION

The data collection systems used for Performance Testing are listed below:

- DCS: The facility distributed control system (DCS)
- MDAS: McHale Data Acquisition System is a digital multiplexed HART data acquisition system constructed in accordance with ASME PTC 19.22

A list of the instruments used for Performance Testing is provided in Table 3-1. Instrument calibration records are provided in Appendix H.

Table 3-1: Test Instrumentation

Measurement	Temporary or Station	Data Collection Method	Elements Used in Test
CTG 10 Gross Power Output	Temporary	MDAS	Temporary Nexus Power Meter
CTG 10 Power Factor	Temporary	MDAS	Temporary Nexus Power Meter
CTG 11 Gross Power Output	Temporary	MDAS	Temporary Nexus Power Meter
CTG 11 Power Factor	Temporary	MDAS	Temporary Nexus Power Meter
STG Gross Power Output	Temporary	MDAS	Temporary Nexus Power Meter
STG Power Factor	Temporary	MDAS	Temporary Nexus Power Meter
Unit 10 UAT	Station	DCS	10ALA00GS010
Unit 11 UAT	Station	DCS	11ALA00GS011
Dry Bulb Temperature - Unit 10	Temporary	MDAS	TT010309, TT021902, TT021153, TT160020, TT020146, TT021576, TT021649, TT018422
Dry Bulb Temperature - Unit 11	Temporary	MDAS	TT021584, TT020255, TT024000, TT021692, TT023932, TT01084, TT021398, TT021677
Wet Bulb Temperature - Unit 10	Temporary	MDAS	TT010172, TT021695, TT021162, TT021175
Wet Bulb Temperature - Unit 11	Temporary	MDAS	TT016062, TT021186, TT021668, TT020014
Barometric Pressure	Temporary	MDAS	PTA20383, PTA20668
CT Wet Bulb Temperature	Temporary	MDAS	15055, 15082, 15060, 15059, 15070, 15056, 15052, 15068
Measured Fuel Flow - CTG 10	Station	DCS	10MBP10CF005
Measured Fuel Flow - CTG 11	Station	DCS	11MBP10CF005
Fuel Gas Composition	Temporary	Manual	Fuel samples collected during Test. Samples analyzed at McHale laboratories

4 CONCLUSION

The corrected Facility Net Plant Heat Rate results from the Facility Thermal Performance Test conducted on May 6, 2017 met the expected performance listed in Section 1.4 of the Test Procedure. The Facility Net Plant Electrical Output did not meet the Expected Performance listed in Section 1.4 of the Test Procedure. It should be noted that the Expected Performance value listed in Section 1.4 of the Test Procedure was obtained from the guaranteed heat balance D001310-UDSM00005, Rev. 1, Dated August 29, 2016. A more recent version of the Zachry heat balance was released Oct. 26, 2016 with an expected Facility Net Output of 121.776 MW. The corrected Facility Net Plant Electrical Output results from the Performance Test meet the Expected Performance from the latest Zachry heat balance.

Testing was conducted in general accordance with PTC 46-1996 and the Facility Thermal Performance Test Procedure, Rev. 1, Dated February 2, 2017 with Test Clarifications noted in Section 1.5 of this Test Report.