

73.09.02.010_FR_EPC – EPC FINAL PERFORMANCE TEST REPORT

Grand River Energy Center Unit 3

KED PROJECT NO. 2014-071

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EPC – FINAL PERFORMANCE TEST REPORT

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REFERENCES

Engineer, Procure and Construct Contract (EPC Contract)

ASME PTC Test Codes: 1-2011, 4.4-2008, 6.2-2011, 19.1-2005, 19.2-2010, 19.3-2004,
19.5-2004, 22-2005, 46-1996

ASTM Standards: D1945-1996, D3588-1998

AGA Report 8

ASME Steam Tables – 1997

ASHRAE Psychrometric Properties – 2009

GPA 2145-2009

SECTION 1

EXECUTIVE SUMMARY

1.1 Overview

The Engineer, Procure and Construct (EPC) testing at the Grand River Energy Center Unit 3 (GREC U3) project was conducted from 23:00 to 24:00 on July 6th, 2017 and from 3:15 to 5:15 on July 7th 2017 to verify the facilities capabilities to satisfy Kiewit's EPC contractual guarantees with the Grand River Dam Authority (GRDA). The facility includes one MHI M501J Combustion Turbine Generators (CTG), one Heat Recovery Steam Generators (HRSG) with supplemental firing capability, one axial exhaust Steam Turbine Generator (STG) and associated balance of plant (BOP) equipment. The CTGs are natural gas fired only. Performance testing was conducted with the CTG at base load, with the plant operating as outlined in the test procedure over three (3) separate one (1) hour test periods to determine the following:

- Facility-Wide Unfired Net Electrical Output and Heat Rate

The performance test data collected during the test periods indicates failing results. Details about the calculations performed for this performance test are included in Section 4 of this report. A summary of the performance test results are included below:

Parameter	Units	Guarantee	Measured Test Results	Corrected Test Results	Margin	Pass / Fail
Unfired Net Electrical Output	kW	449,960	444,232	450,521	561	Pass
Unfired Net Heat Rate	Btu/kWh LHV	5,723	5,800.1	5,714.4	8.6	Pass

Any major deviations from the test requirements and/or procedures are documented in Section 4. These deviations were agreed to by all parties to the test. The major deviations along with brief discussions of the reason for deviations are included below:

- Section 2.3 and Appendix C of the procedure state that the auxiliary power will be measured using a temporary instrument at five-minute time intervals. All parties to the test agreed to use the station instruments (which have been validated using temporary instruments) for the HRSG Aux Power measurement and to use the STG Aux Power measurements taken using a temporary instrument one time after the performance test.
- All parties to the test agreed two closed cooling water heat exchangers will be in service during testing as one heat exchanger was insufficient to support plant operation.

- All parties to the test agreed the fuel gas heater 3 way gas bypass valve will not be closed during the testing. This is inconsistent with the thermal design of the plant, but required by MHPSA to support CTG operation.
- All parties to the test agreed that an IGV inspection shall not be performed within 24 fired hours of the start of testing.
- All parties to the test agreed that a separate pretest need not be performed.
- All parties to the test agreed that in order to accurately measure the cooling steam going to the gas turbine, the HP backup steam warming line and the associated DSH (03-V035635 and 03-TV-035636) were to be closed for the duration of the testing.
- All parties to the test agreed that there shall be no load change between test runs 2 and 3 due to the length of time required to get the CTG back in “high power” mode after a load change.

The following deviations from the test requirements and/or procedures occurred during the performance test. The deviations along with brief discussions of the reason for deviation are included below:

- None

END OF SECTION

SECTION 2

TEST DESCRIPTION

2.1 Test Overview

The objective of the EPC Performance Test was to determine the capability of the facility to satisfy the guarantees set forth in the contractual agreement to GRDA. All performance testing was conducted with the CTGs at base load with the chiller off and the HRSG unfired.

The Performance Test for the GREC U3 EPC was conducted from 23:00 to 24:00 on July 6th, 2017 and from 3:15 to 5:15 on July 7th 2017. The performance test was conducted over three (3) one (1) hour test periods to determine the following:

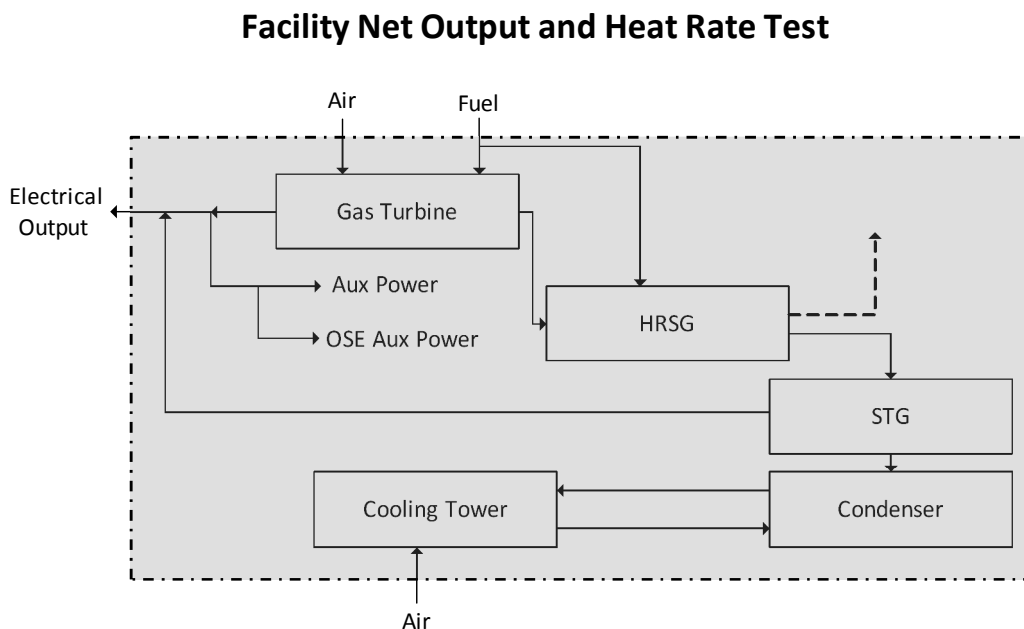
- Facility-Wide Unfired Net Electrical Output and Heat Rate

2.2 Test Facility Information

The Grand River Energy Center Unit 3 is a new power production facility located on the property of the existing Grand River Energy Center near Chouteau, Oklahoma. The facility consists of one MHI M501J Combustion Turbine Generator (CTG), one three-pressure Heat Recovery Steam Generator (HRSG) with supplemental firing capability, one axial exhaust Steam Turbine Generator (STG) and associated Balance of Plant (BOP) equipment.

2.3 Test Boundary

A schematic of the scope for the performance tests is shown below:



2.4 Key Party Representatives

The following parties and their designated representatives were present for the Grand River Energy Center Unit 3

Performance Tests.

Kiewit: Adam Decker, Parag Pathak, Chris Stelzer, Russ
McLandsborough
GRDA: Jammie Burrow
B&V: Travis Brockmeyer, Erik Keltner

END OF SECTION

SECTION 3

TEST EQUIPMENT

3.1 Equipment Overview

To the greatest extent possible the test data was monitored and recorded by the permanent plant instrumentation using the Facility's Distributed Control System (DCS). Temporary test instrumentation and metering equipment was used where there was not permanent plant instrumentation and/or where performance test instrument accuracy was required. Data from the DCS was recorded electronically at 10-second time intervals and temporary test instruments was recorded electronically at 30-second time intervals.

3.2 Equipment Information

The general information for the temporary and permanent plant instrumentation used during the performance test is included in Appendix D and includes the following:

- Measured Parameter
- Instrument Location
- Instrument Tag Number

3.3 DAS Description

Performance test data were recorded from permanent plant instruments via the DCS, temporary test instrumentation, and manual data taken by personnel. Temporary instrument measurements were compiled to centralized computers provided by McHale Performance. Following the completion of the performance test, this data was distributed to all key witnessing parties. Data was gathered every 10 or 30 seconds.

3.4 Calibration Summary

Instruments used for data collection were classified as Primary or Secondary before commencement of the performance test. A Primary instrument is any instrument used in the performance test calculations. All other instruments recording data during testing are considered secondary instruments.

All Primary instruments were calibrated by a third party within 6 months prior to the start of testing with the exception of flow meters. Primary instruments were calibrated to a NIST traceable standard. Secondary instruments having factory calibrations were acceptable. Secondary instruments were required for loop calibration before commencement of testing.

Copies of the calibration certificates were provided to interested parties upon request. The calibration certificates are included in Appendix E.

END OF SECTION

SECTION 4

TEST DEVIATIONS AND DISCUSSION

4.1 Major Test Deviations

The following deviations from the test requirements and/or procedures are documented along with brief discussions of the reason for deviation below:

4.1.1 Test Deviations Discussed Prior to Testing

The following major deviations from the test requirements and/or procedures were discussed and agreed to by all parties to the test prior to testing. The major deviations along with brief discussions of the reason for deviation are included below:

- Section 2.3 and Appendix C of the procedure state that the auxiliary power will be measured using a temporary instrument at five-minute time intervals. All parties to the test agreed to use the station instruments (which have been validated using temporary instruments) for the HRSG Aux Power measurement and to use the STG Aux Power measurements taken using a temporary instrument one time after the performance test.
- All parties to the test agreed two closed cooling water heat exchangers will be in service during testing as one heat exchanger was insufficient to support plant operation.
- All parties to the test agreed the fuel gas heater 3 way gas bypass valve will not be closed during the testing. This is inconsistent with the thermal design of the plant, but required by MHPSA to support CTG operation.
- All parties to the test agreed that an IGV inspection shall not be performed within 24 fired hours of the start of testing.
- All parties to the test agreed that a separate pretest need not be performed.
- All parties to the test agreed that in order to accurately measure the cooling steam going to the gas turbine, the HP backup steam warming line and the associated DSH (03-V035635 and 03-TV-035636) were to be closed for the duration of the testing.
- All parties to the test agreed that there shall be no load change between test runs 2 and 3 due to the length of time required to get the CTG back in “high power” mode after a load change.

4.1.2 Test Deviations Found During Testing

The following major deviations from the test requirements and/or procedures occurred during the performance test. The major deviations along with brief discussions of the reason for deviation are included below:

- None

4.2 Test Discussion

The following are not test deviations, but are items of note:

- At this time, testing was only conducted for the unfired conditions.
- The vacuum pump heat exchangers were be run on service water in between test runs, and switched to circulating water for the test runs to minimize fouling of the strainers and heat exchangers.

4.2.1 Other Test Deviations

The following are not deviations to the CTG test, but are deviations to the other tests performed simultaneously. They are included to give a more complete picture of the testing.

STG Test

- Section 3.5.2.7 of the procedure states the unfired f_{Design} is 0.0693. All parties to the test agreed the correct value is 0.0369.
- Section 2.3 and Appendix C of the procedure state that the auxiliary power will be measured using a temporary instrument at five-minute time intervals. All parties to the test agreed to use the STG Aux Power measurements taken using a temporary instrument one time after the performance test.
- One of the steam turbine LP balance pipe sensing lines on DP2 was plugged and could not be cleared. All parties to the test agreed to use the design value for the flows through the LP balance piping.
- All parties to the test agreed that there shall be no load change between test runs 2 and 3 due to the length of time required to get the CTG back in “high power” mode after a load change.
- The data collected during the N2 packing test did not evaluate into a result that made sense. The data predicts approximately 36% N2 packing leakage. MHPS believes the location of the HP to LP balance piping is influencing the measurements taken during the N2 packing test. For results purposes, the N2 packing leakage was calculated as follows:

$$Q_{N_2} = Q_{HP_FW} + Q_{HP_TCA} + Q_{HP_DSH} - Q_{HP_FGH} - Q_{HP_CS} - Q_{HP_Gland} - Q_{HP_to_LP} - Q_{CRH} - U_{N_2}$$

Where U_{N_2} is the uncertainty of the calculated N2 flow and $Q_{CRH_Measured}$ is the CRH flow measured using the CRH flow element.

- The stability of the LP steam flow was outside the procedure limits during test run 2. In order to meet the procedure stability criteria, the analysis period for test run 2 was changed from 3:15-4:15 to 3:45-4:15.
- The leakage out of the cycle was greater than the test code requirement of 0.25% of the condensate flow. This leakage has been subtracted from calculated flows on a flow weighted basis.

HRSG Test

- Appendix C of the procedure states the auxiliary power will be measured using a temporary instrument. All parties to the test agreed to use the station instruments (which have been validated using temporary instruments) for this measurement.
- All parties to the test agreed that there shall be no load change between test runs 2 and 3 due to the length of time required to get the CTG back in “high power” mode after a load change.
- The HP feedwater flow did not meet the stability criteria for variation during a test run listed in the test procedure for any of the test runs.
- The TCA flow did not meet the stability criteria for variation from the reference conditions listed in the test procedure for any of the test runs.
- The TCA duty did not meet the stability criteria for variation from the reference conditions listed in the test procedure for any of the test runs
- The measured HRH temperature at the STG was used to calculate the HRSG performance as the HRH temperature measured at the HRSG was suspect as it was lower than the temperature at the STG.
- The Ammonia Vaporizer power was not measured during the performance test. The vaporizer supplier provided a curve of power consumption vs ammonia flow which was used to add to the measured HRSG aux power.

CTG Test

- All parties to the test agreed the fuel gas heater 3 way gas bypass valve will not be closed during the testing. This is inconsistent with the thermal design of the plant, but required by MHPSA to support CTG operation.
- All parties to the test agreed that an IGV inspection shall not be performed within 24 fired hours of the start of testing.
- All parties to the test agreed that a separate pretest need not be performed.

- All parties to the test agreed that in order to accurately measure the cooling steam going to the gas turbine, the HP backup steam warming line and the associated DSH (03-V035635 and 03-TV-035636) shall be closed for the duration of the testing.
- All parties to the test agreed that there shall be no load change between test runs 2 and 3 due to the length of time required to get the CTG back in “high power” mode after a load change.
- All parties to the test agreed that the CTG is not required to operate only in exhaust temperature control mode, but rather operation on either blade path temperature control or exhaust temperature control is acceptable.

END OF SECTION

SECTION 5

DATA COLLECTION AND CALCULATIONS

5.1 Data Collection

Performance test data were recorded on the DCS, temporary test instrumentation, and manual data were taken by personnel. Data from the DCS and temporary test instruments were recorded electronically. Manual data were recorded on data sheets and was scanned for storage and distribution.

All the data and information gathered were used to correct the measured test results to the base reference conditions listed in Appendix A of the Test Procedures. Data used to calculate the corrected performance results for the Performance Tests were provided to the key witnessing parties.

5.2 Data Reduction

Performance test data collected were arithmetically averaged for each test period. The averaged data were used to correct the initial test results of each test period. After all corrections were completed, the corrected results were arithmetically averaged for comparison to the contractual guarantee values.

Data collected were analyzed for bad data and outliers. The methods contained in ASME PTC 19.1 were used to conduct the outlier analysis. No data was excluded as a result of this analysis.

5.3 Definition of Terms

The following is a summary of the terms used in the computation of test results

FGH – Fuel gas heater

DSH – Desuperheater

TCA – Turbine cooling air cooler

Design – Subscript indicates design value

5.3.1 Power Measurements

P_{CTG} = CTG Generator Gross Power Output, kW

P_{STG} = STG Generator Gross Power Output, kW

P_{UAT} = Aux Transformer Low Side Power, kW

P_{RAT} = Reserve Aux Transformer Low Side Power, kW

PF_{CTG} = CTG Generator Power Factor

PF_{STG} = STG Generator Power Factor

PF_{CTG_GSU} = CTG GSU Power Factor

PF_{STG_GSU} = STG GSU Power Factor

PF_{UAT} = Aux Transformer Power Factor

PF_{RAT} = Reserve Aux Transformer Power Factor

HZ_{CTG} = CTG generator frequency, Hz

$P_{\text{Non_Design}}$ = Non-Design Aux Loads in Operation, kW

5.3.2 Boundary Measurements

$T_{\text{DB_CTG}}$ = Ambient dry bulb temperature at CTG, Deg F
 $T_{\text{WB_CTG}}$ = Ambient wet bulb temperature at CTG, Deg F
 P_{Baro} = Barometric pressure, psia
 $T_{\text{DB_CT}}$ = Cooling tower dry bulb inlet temperature, Deg F
 $T_{\text{WB_CT}}$ = Cooling tower wet bulb temperature, Deg F
 T_{FG} = Fuel gas temperature at metering station outlet, Deg F
 P_{FG} = Fuel gas pressure upstream compressor suction, psig
 $N_{\text{Fuel_x}}$ = Fuel gas composition, mole % (x=components)

5.3.3 Flow Measurements

$Q_{\text{FG_ACF}}$ = Plant fuel gas flow, ACF/h
 P_{FG} = Plant fuel gas pressure, psia
 T_{FG} = Plant fuel gas temperature, Deg F
 P_{DB} = Duct burner fuel gas pressure, psia
 T_{DB} = Duct burner fuel gas temperature, Deg F
 DP_{DB} = Duct burner fuel gas DP, inH2O

5.3.4 Corrected CTG Test Data

$P_{\text{Corr_CTG}}$ = Corrected CTG Net Output, kW
 $HR_{\text{Corr_CTG}}$ = Corrected CTG Net Heat Rate, Btu/kWh
 $T_{\text{Corr_CTG}}$ = Corrected CTG Exhaust Temp, Deg F
 $EF_{\text{Corr_CTG}}$ = Corrected CTG Exhaust Flow, kW
 $E_{\text{Corr_CC}}$ = Corrected CTG Combustor Cooler Energy, mmBtu/h
 $E_{\text{Corr_TAC}}$ = Corrected CTG TAC Energy, mmBtu/h

These values were obtained from concurrent CTG testing

5.3.5 Corrected HRSG Test Data

$Q_{\text{Corr_HP}}$ = Corrected HP Steam Flow, lb/h
 $Q_{\text{Corr_IP}}$ = Corrected IP Steam Flow, lb/h
 $Q_{\text{Corr_LP}}$ = Corrected LP Steam Flow, lb/h
 $T_{\text{Corr_HP}}$ = Corrected HP Steam Temp, Deg F
 $T_{\text{Corr_HRH}}$ = Corrected HRH Steam Temp, Deg F
 $T_{\text{Corr_IP}}$ = Corrected IP Steam Temp, Deg F
 $T_{\text{Corr_LP}}$ = Corrected LP Steam Temp, Deg F
 $DP_{\text{Corr_HRSG}}$ = Corrected HRSG Backpressure, inH2O
 $DP_{\text{Corr_RHTR}}$ = Corrected Reheater Pressure Drop, psi
 $P_{\text{HRSG_Aux}}$ = Corrected HRSG Aux Power, kW

These values were obtained from concurrent HRSG testing

5.3.6 Corrected STG Test Data

$P_{\text{Corr_STG}}$ = Corrected STG Net Output, kW
This values was obtained from concurrent STG testing

5.3.7 Calculated Values

$P_{\text{CTG_GSU_Loss}}$ = CTG GSU Transformer losses, kW
 $P_{\text{STG_GSU_Loss}}$ = STG GSU Transformer losses, kw
 $P_{\text{UAT_Loss}}$ = Aux Transformer losses, kW
 $P_{\text{RAT_Loss}}$ = Reserve Aux Transformer losses, kW
 $A_{\text{CTG_Excite}}$ = CTG Excitation Current from V curve, A
 $A_{\text{STG_Excite}}$ = STG Excitation Current from V curve, A
 $P_{\text{CTG_Excite}}$ = CTG excitation power, kW
 $P_{\text{STG_Excite}}$ = STG excitation power, kW
 P_{PN} = Net Plant Output, kW
 HR_{PN} = Net Plant Heat Rate, Btu/kWh
 Q_{FG} = Plant fuel gas flow, lb/h
 Q_{DB} = Duct burner fuel gas flow, lb/h
 HV_{FG} = Fuel gas heating value, Btu/lb LHV
 HI_{PN} = Net Plant Heat Input, Btu/h
 HI_{DB} = Duct burner heat input, Btu/h
 $P_{\text{Corr_PN}}$ = Corrected Net Plant Output, kW
 $HR_{\text{Corr_PN}}$ = Corrected Net Plant Heat Rate, Btu/kWh

5.4 Correction Factors

Corrections were made to the performance of plant equipment using additive and multiplicative correction factors.

5.4.1 Additive Corrections

The following corrections were made to the performance of plant using additive correction factors.

Corrections for OFE performance

Corrections were based on the corrected performance of each parameter as determined using the appropriate equipment test procedure with the exception that any degradation correction (if present) was not applied.

ΔP_{CTG} = Correction for power output of CTG during test, kW
 ωP_{CTG} = Correction for power output of CTG during test, Btu/h
 ΔP_{STG} = Correction for power output of STG during test, kW
 ΔP_{HRSG} = Correction for auxiliary power of HRSG during test, kW
 ΔHR_{CTG} = Correction for heat rate of CTG during test, kW
 ωHR_{CTG} = Correction for heat rate of CTG during test, Btu/h

ΔET_{CTG}	=	Correction for exhaust temp of CTG during test, kW
ΔEF_{CTG}	=	Correction for exhaust flow of CTG during test, kW
ΔTCA_{CTG}	=	Correction for TCA cooler energy during test, kW
ΔSCE_{CTG}	=	Correction for steam cooling energy during test, kW
$\Delta RHDP_{HRSG}$	=	Correction for HRSG RHTR pressure drop during test, kW
ΔDP_{HRSG}	=	Correction for HRSG backpressure during test, kW
ωDP_{HRSG}	=	Correction for HRSG backpressure during test, Btu/h
ΔQ_{HP}	=	Correction for HRSG HP steam flow during test, kW
ΔT_{HP}	=	Correction for HRSG HP steam temp during test, kW
ΔQT_{RHTR}	=	Correction for HRSG IP added flow and reheater temperature during test, kW
ΔQT_{LP}	=	Correction for HRSG LP flow and temp during test, kW

Corrections for plant performance

$\Delta 2_{GSU}$	=	Correction for GSU Losses, kW
$\Delta 2_{Gen}$	=	Correction for generator power factor, kW
$\Delta 5_A$	=	Correction for ambient conditions at cooling tower, kW
$\Delta 6_{OD}$	=	Correction for off design auxiliary loads in operation, kW
$\Delta 6_{FGC}$	=	Correction for fuel gas pressure, kW
$\Delta 7$	=	Correction for duct burner duty different than design, kW
$\omega 7$	=	Correction for duct burner duty different than design, Btu/h

5.4.2 Multiplicative Corrections to Power

The following corrections were made to the performance of plant using multiplicative correction factors.

$\alpha 1\&3$	=	Correction for ambient temperature and RH at CTG
$\alpha 2$	=	Correction for barometric pressure
$\alpha 4$	=	Correction for fuel supply temperature
$\alpha 5$	=	Correction for fuel composition
$\alpha 6$	=	Correction for speed/frequency

5.4.3 Multiplicative Corrections to Heat Input

$\beta 1\&3$	=	Correction for ambient temperature and RH at CTG
$\beta 2$	=	Correction for barometric pressure
$\beta 5$	=	Correction for fuel composition
$\beta 6$	=	Correction for speed/frequency

5.4.4 Corrections for Degradation

No corrections for degradation were applied. Specifically, the OFE equipment corrected results for use in calculating the Corrected Facility Net Results were calculated without application of any degradation corrections.

5.5 Calculations

The Corrected Net Output and Heat Rate were calculated as follows:

5.5.1 Miscellaneous Calculations

$$P_{CTG_Excite} = 12.5 + 6.4 + 20.8 * \frac{A_{CTG_Excite} * \frac{\sqrt{2}}{\sqrt{3}}}{2890} + \frac{A_{CTG_Excite}^2 * 0.1113 + 2 * A_{CTG_Excite}}{1000}$$

$$P_{STG_Excite} = 11.2 + 5.69 + 10.67 * \frac{A_{STG_Excite} * \frac{\sqrt{2}}{\sqrt{3}}}{2870} + \frac{A_{STG_Excite}^2 * 0.0966 + 2 * A_{STG_Excite}}{1000}$$

5.5.2 Corrected Facility Net Electrical Output

$$P_{PN} = P_{CTG} + P_{STG} - P_{UAT} - P_{RAT} - P_{CTG_Excite} - P_{STG_Excite} - P_{CTG_GSU_Loss} - P_{STG_GSU_Loss} - P_{UAT_Loss} - P_{RAT_Loss}$$

$$P_{Corr_PN} = (P_{PN} + P_{Non_Design} + \Delta 2_{GSU} + \Delta 2_{Gen} + \Delta 5_A + \Delta 6_{OD} + \Delta 6_{FGC} + \Delta 7) * \alpha 1 \& 3 * \alpha 2 * \alpha 4 * \alpha 5 * \alpha 6 + \Delta P_{STG} + \Delta P_{CTG} + \Delta P_{HRSG} + \Delta HR_{CTG} + \Delta ET_{CTG} + \Delta EF_{CTG} + \Delta TC_{CTG} + \Delta SCE_{CTG} + \Delta RHDP_{HRSG} + \Delta DP_{HRSG} + \Delta Q_{HP} + \Delta T_{HP} + \Delta QT_{RHTR} + \Delta QT_{LP}$$

5.5.3 Corrected Facility Net Heat Rate

$$HI_{PN} = HV_{FG} * Q_{FG}$$

$$HR_{PN} = \frac{HI_{PN}}{P_{PN}}$$

$$HR_{Corr_PN} = \frac{(HI_{PN} + \omega 7) * \beta 1 \& 3 * \beta 2 * \beta 5 * \beta 6 + \omega HR_{CTG} + \omega P_{CTG} + \omega DP_{HRSG}}{P_{Corr_PN}}$$

Additional detail regarding the calculation can be found in Appendix A.

END OF SECTION

SECTION 6

TEST RESULTS AND CONCLUSIONS

6.1 Test Results

The calculated test results for the STG Tests are listed in the tables below:

Parameter	Units	Guarantee	Measured Test Results	Corrected Test Results	Margin	Pass / Fail
Unfired Net Electrical Output	kW	449,960	444,232	450,521	561	Pass
Unfired Net Heat Rate	Btu/kWh LHV	5,723	5,800.1	5,714.4	8.6	Pass

6.2 Test Conclusions

The Corrected Unfired Net Electrical Output greater than the Guarantee value and the Corrected Unfired Net Heat Rate less than the Guarantee value has indicated the facility's ability to satisfy the Kiewit contractual guarantees to GRDA.

END OF SECTION