




Development of Performance Acceptance Test Guidelines for Large Commercial Parabolic Trough Solar Fields

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DEVELOPMENT OF PERFORMANCE ACCEPTANCE TEST GUIDELINES FOR LARGE COMMERCIAL PARABOLIC TROUGH SOLAR FIELDS

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Abstract

Prior to commercial operation, large solar systems in utility-size power plants need to pass a performance acceptance test conducted by the EPC contractor or owners. In lieu of the present absence of standards developed for this purpose, NREL has undertaken the development of interim guidelines to provide recommendations for test procedures that can yield results of a high level of accuracy consistent with good engineering knowledge and practice. The fundamental differences between acceptance of a solar power plant and a conventional fossil-fired plant are the transient nature of the energy source and the necessity to utilize an analytical performance model in the acceptance process. These factors bring into play the need to establish methods to measure steady state performance, potential impacts of transient processes, comparison to performance model results, and the possible requirement to test, or model, multi-day performance within the scope of the acceptance test procedure. The power block and BOP are not within the boundaries of this guideline. The current guideline is restricted to the solar thermal performance of parabolic trough systems, and has been critiqued by a broad range of stakeholders in CSP development and technology.

Keywords: solar thermal electric, parabolic trough, performance, acceptance tests, uncertainty analysis

1. Introduction

Parabolic trough power plants consist of large fields of mirrored parabolic trough collectors, a heat transfer fluid/steam generation system, a power system such as a steam turbine/generator cycle, and optional thermal storage and/or fossil-fired backup systems.

The solar field is made up of large modular arrays of single-axis-tracking parabolic trough solar collectors (see Fig. 1) that are arranged in parallel rows, usually aligned on a north-south horizontal axis. Each solar collector has a linear parabolic-shaped reflector that focuses the direct beam solar radiation on a linear receiver located at the focal line of the parabola. The collectors track the sun from east-to west during the day, with the incident radiation continuously focused onto the linear receiver where a heat transfer fluid (HTF) is heated to nearly 400ºC. Because a concentrating collector must focus the sun's rays on the receiver, the solar resource relevant to performance is the beam radiation from the sun, measured as the Direct Normal Insolation (DNI) on a plane perpendicular to the rays. In a linear-axis tracking trough collector, the effective beam radiation is the DNI component perpendicular to the plane of the aperture of the parabolic-shaped mirrors, referred to in this paper as the Aperture Normal Insolation, or ANI.

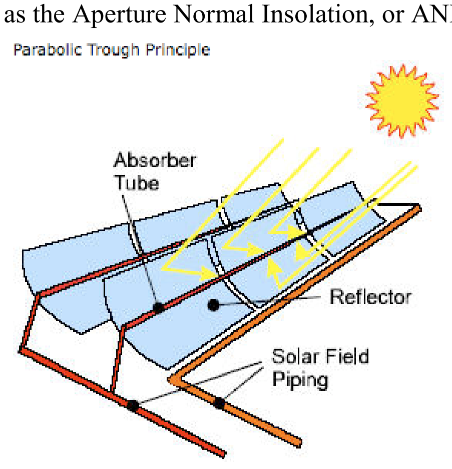

Figure 1. Schematic of Parabolic Trough Collector (Courtesy of Flagsol GmbH)

Solar thermal trough power plants are being proposed in large turbine capacities of up to 280 MWe gross and, if significant thermal storage is included in the system, can require solar fields up to about 2.6 million m^2 of reflector aperture even in areas of high solar resource. The land requirement for a trough plant with thermal storage is about 7.5 acres (~3 hectares) per MWe. Heretofore, developers, debt providers, owners and EPC contractors have had no standardized test procedures for reference or use associated with the performance acceptance of these large solar fields. As deployment of parabolic trough plants increase in Spain, the US and elsewhere, this need will intensify.

Commercial agreements in a utility-scale solar power project invariably require performance acceptance tests as part of the turnover of major equipment to the engineering, procurement, and construction (EPC) contractor or project owner. While the parabolic trough power projects that are currently in operation have gone through project-specific acceptance procedures of the solar system, no general approach exists in the industry for this purpose. In the summer of 2009, NREL initiated an effort to address this need by undertaking the development of a set of performance acceptance test guidelines [1], starting with parabolic trough solar systems (defined to include both the solar field and HTF system), and including many stakeholders throughout the international CSP community in the critique of the resulting document (such as developers, technology providers, EPC firms, independent engineering firms, utilities and equity/debt providers, and the SolarPACES Task 1 membership). A selected advisory committee of particular acumen provided guidance throughout the development process of the final guidelines. Final publication is planned for late 2010. This paper describes the results of that activity. The American Society of Mechanical Engineers (ASME) has initiated a parallel process to develop Performance Test Code PTC 52 covering all CSP technologies, an undertaking that will take several years to come to fruition. The NREL guidelines are intended to provide preliminary guidelines to interested stakeholders, as well as early input to the ASME activity, particularly for trough systems.

2. Objective and Scope

The underlying purpose of a performance test guideline is to provide recommendations for test procedures that can yield results of a high level of accuracy consistent with good engineering knowledge and practice. The fundamental differences between acceptance of a solar power plant and a conventional fossil-fired plant are the transient nature of the energy source and the necessity to utilize an analytical performance model in the acceptance process. These factors bring into play the need to establish methods to measure steady state performance, potential impacts of transient processes, comparison to performance model results, and the possible requirement to test, or model, multi-day performance within the scope of the acceptance test procedure. The power block and BOP are not within the boundaries of this protocol. Figure 2 illustrates the system boundaries and also notes the nature of a solar system test whereby the measured test result for a particular set of ambient and operating conditions is compared to the prediction of a performance model.

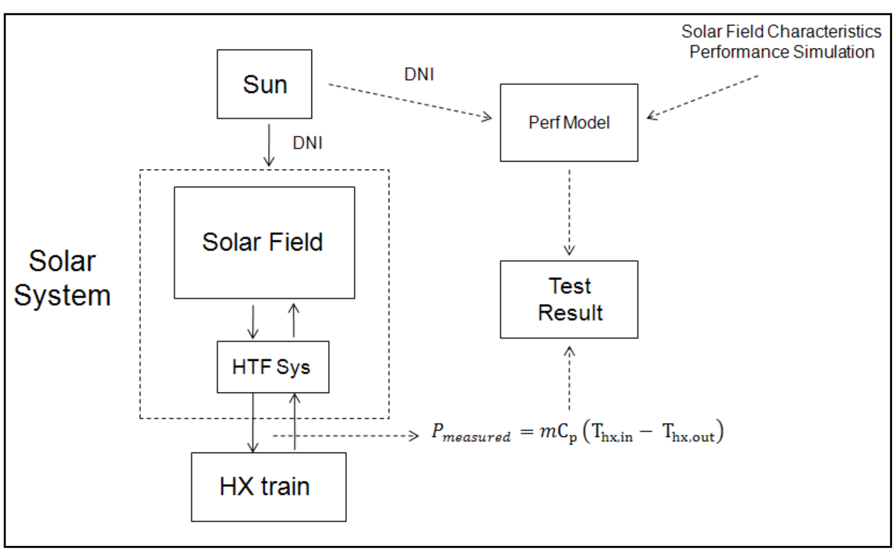

Figure 2. Simple schematic of the solar system boundary and performance comparison

Possible test scenarios vary from a single short-duration steady-state test, similar to that conducted on a boiler or steam turbine, to a longer multi-day test, or a set of seasonal tests. But each of these options presents obstacles not encountered in a test of fossil-fired equipment where the rate of input energy can be maintained constant. The scope of the guidelines is to recommend procedures, instrumentation, equipment operating requirements, calculation methods, and methods of uncertainty analyses. Like ASME Performance Test Codes, these guidelines do not specify means to compare test results to contractual guarantees. Therefore, it is expected that the parties to a commercial test will address and agree on these matters before starting the test and signing the contract. It is beyond the scope of the NREL guidelines to determine or interpret how such comparisons shall be made.

Performance acceptance test guidelines or codes form the basis for a detailed Test Plan to be written on behalf of the project owners, typically by the EPC contractor, to conform to the specific requirements of a project. A number of details need to be agreed upon by the solar system technology provider, the EPC contractor and the Owner's Engineer in the writing of the Test Plan, ranging from location of instrumentation to the method and timing of the performance tests.

3. Test Definitions

Performance acceptance tests proposed in the NREL guidelines include measurement of the thermal power output and thermal efficiency of the solar system under clear sky conditions over a short period during which thermal steady state conditions exist, as well measurement of the total solar field energy production over a longer period with varying levels of DNI and cloud cover during which transient effects on thermal output are observed.. These tests are defined to be the Short Duration Steady-State Thermal Power Test and the Multiday Continuous Energy Test, and are described in more detail in the following sections.

3.1. Short Duration Steady-State Thermal Power Test

Test Conditions for Short Duration Test: The steady state thermal power tests can be run on clear days during any time of year. Even with a high direct normal insolation (DNI), which can be experienced on a clear winter day, the important solar resource term that dictates the thermal energy input into the solar field is the ANI. Suitably high ANI conditions are preferable to minimize the uncertainty associated with solar field power and efficiency tests, and for conducting rated design point thermal power tests.

Calculations and Measurements: The thermal power output of the solar system should be calculated based on temperature measurements at the solar heat exchangers in order to include thermal losses associated with solar system header piping. For each train, the delivered power is computed from:

$$P_{measured} = m\mathrm{C_p}\left(\mathrm{T_{hx,in}} - \mathrm{T_{hx,out}}\right)$$

where $P_{measured}$ is the calculated solar thermal power, m is the HTF mass flow rate, $\mathrm{C_p}$ is the temperature weighted specific heat of HTF, $\mathrm{T_{hx,in}}$ is the HTF average bulk inlet temperature to solar heat exchanger train, and $\mathrm{T_{hx,out}}$ is the HTF average bulk outlet temperature at the exit of the solar heat exchanger train.

For a large solar power plant the solar field design will likely be configured in solar system sub-fields that, together, make up the full solar field. In some cases the HTF from an individual set of sub-fields will be collected to go to an associated set of solar steam generator trains. In such instances, the total measured power will consist of the summation of the power from the individual sub-fields configurations.

The solar thermal efficiency can be based on either DNI or ANI in the denominator, though the latter is preferred from a physical standpoint. The thermal efficiency based on ANI is calculated from

$$\eta_{measured} = \frac{P_{measured}}{DNI \cdot \cos\theta \cdot A_{aperture}}$$

where $\eta_{measured}$ is thermal efficiency, ANI is the vector of direct normal insolation, $A_{aperture}$ is the solar field aperture area in tracking mode during the test period, and θ is the solar incidence angle associated with data collected during a test run.

3.2. Multiday Continuous Energy Test

Test Conditions for Multiday Test: The objective of this test is to gather continuous 24 hours per day thermal output energy production (integrated power output), and to compare the energy results to projections from a performance model. Both clear sky and partly cloudy conditions are acceptable. Conditions in which cloud cover unevenly affects portions of a large solar field will need to be treated on a case-by-case basis, and agreed upon by both parties. In the event of multi-day fully cloudy or rainy weather, and perhaps in the event of non-uniform cloud coverage as mentioned just above, the test should be stopped and then restarted when appropriate. Additionally, the functionality of the solar system should be observed with regard to such items as daily start-up, normal operation and shut-down.

4. Evaluation of Transient Conditions

4.1 Test conditions for steady-state testing

A crucial premise of this Guideline is that during an individual short test run the combination of small variations in the ANI along with the HTF outlet temperature flow control can satisfy the requirements for a steady state condition adequate for testing. With clear skies there will be no cloud transients, and with HTF flow control the solar field outlet temperature will be held within close bounds and the controlled small changes in mass flow will be near-instantaneous throughout the HTF system because the oil is, for all practical purposes, incompressible. By these means, there will be negligible heat exchange between the header pipe walls and the HTF fluid, and therefore no thermal inertia effects. The HTF mass flow rate change will follow the variation in the ANI; that is, as the ANI changes the HTF mass flow rate will be automatically adjusted accordingly.

The change in ANI was evaluated analytically to examine the stability of the heat input to a trough collector for short periods in different seasons. Using 1-minute accurately-measured DNI data from the NREL Solar Radiation Research Laboratory in Golden, Colorado, example patterns in ANI for clear days during June, March and December are shown in Fig. 3 for the entire day (left) and for the daytime period between 8am and 4pm (center). Also shown (right) are the percent changes in the ANI over the previous 30-minutes during the daytime period for these three months. These results show that the variations in ANI over short time periods, e.g. 30 minutes, are relatively small during certain periods, often within a few percent. We believe these results support the basic premise that with a slowly changing heat input (ANI) and no transient heat exchange in the headers between fluid and pipe will allow valid measurements of power and efficiency at any time of year, averaged over short test runs of about 30 minutes in duration. However, if a test of design solar system thermal power capacity is required, tests for that condition will likely need to be run in higher ANI periods. Furthermore, with continuous data acquisition and reduction on small time steps (e.g., 1-minute) the performance of the solar system can be accurately tracked and observations made on the steadiness of the results.

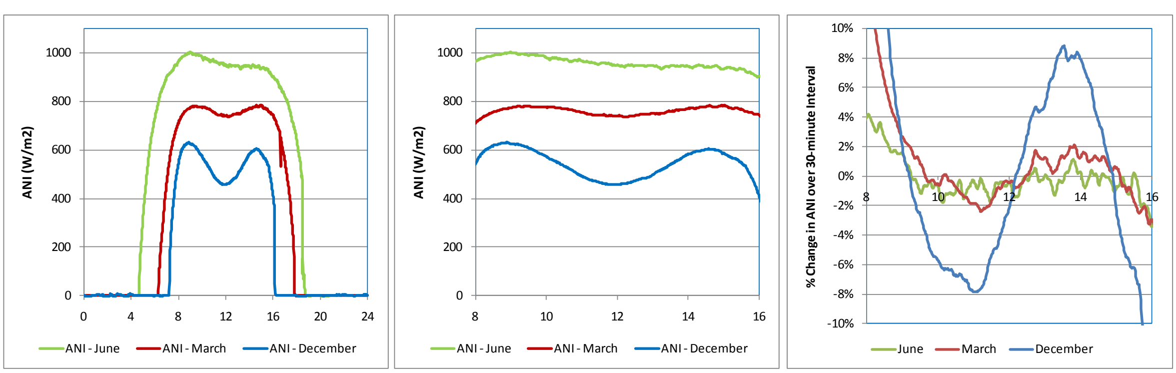

Figure 3. Patterns from ANI analysis.

4.2 Transients in long header piping

The solar system is required to deliver a specified solar thermal power level, at an expected efficiency, to the heat exchanger trains at the power block. The solar field and heat exchanger trains will be separated by long distances in a large system, and the transit time of the HTF can be as high as 30-40 minutes from the solar collector sub-fields furthest from the power block. Thermal inertia effects will affect the results if the HTF exit temperature from the solar field has a rapid perturbation, followed by a period of heat exchange between the HTF and the header piping to come back to thermal equilibrium. Calculations show that it will typically take slightly longer than the transient time before such thermal equilibrium is reached. However, under steady ANI conditions, or with a slowly varying ANI but with the HTF flow rate controlled by variable-speed-controlled pumps (as discussed above), the HTF solar field outlet temperature will be held constant, or nearly so, and the no thermal inertia effects will introduce errors into the delivered solar system power calculations.

5. Instrumentation and Test Uncertainty

5.1. Data Requirements

The data requirements for the solar system acceptance tests are straightforward. Based on definitions for solar field power and efficiency, the tests require the measurement of or accurate data on the HTF volumetric flow rate, the physical properties of the HTF including the specific heat and density (for the case of volumetric flow meters), the HTF temperature, the DNI, ambient weather conditions including wind velocity/direction and dry bulb temperature, and the latitude and longitude of the DNI instrument (for subsequent ANI calculations).

5.2 Instrumentation

Temperature Measurement: RTDs (Resistance Temperature Detectors) or TCs (thermocouples) are judged to be the most appropriate instruments to measure fluid temperature in the HTF stream. Although both are suitable but the higher accuracy of the RTD suggests it is better suited for acceptance testing. RTDs have a narrower operating range and a slower response time than thermocouples, but are potentially more accurate. For short term performance testing purposes, accuracy is more important than durability, favoring RTDs as the likely choice. Some RTDs can have significant drift during break-in that must be considered. Their relatively slower response than thermocouples is likely not an issue for performance testing. The lesser durability of an RTD should be a significant consideration if the device will be permanently installed.

Flow Measurement: Accurately measuring the volumetric flow rate of the HTF is a significant engineering problem, particularly in the large pipes that characterize large parabolic trough projects. ASME PTC 19.5 is an excellent reference for flow measurements [2]. ASME PTC 6 and ISO 5167 provide further information on flow measurement techniques [3,4]. These sources include design, construction, location, and installation of flow meters, connecting piping, and computations of flow rates. For the conditions of a solar system performance acceptance test, a number of flow measurement devices are suitable, and have been evaluated on the basis of the most important criteria for this measurement. Candidate flow measurement devices include differential pressure, ultrasonic flow, vortex, and turbine type flow meters. When selecting a flow measurement device, proper consideration to accuracy, pressure drop, turn-down ratio, temperature range, and piping requirements for the instrument.

Solar Resource Measurement: Two conventional devices, the rotating shadow-band radiometer and the 2-axis tracking pyrheliometer, are available to measure DNI. High accuracy of this measurement is required to keep the uncertainty in the calculated solar field efficiency as low as possible. For this reason, despite the higher cost the pyrheliometer option is highly preferred for acceptance test purposes. The total expanded uncertainty for well-characterized tracking pyrheliometers are on the order of ±2.5% [5].

For large solar fields (e.g. a 250-MWe trough plant may have 1.0-2.5 million square meters of solar collector aperture area and occupy a land area about 3 times larger), multiple DNI instruments are advised, though this is primarily a matter of judgment and agreement between the test parties. Under clear skies, the DNI should be uniform over areas of this size. Regarding solar field instrument placement, multiple instruments might be placed in each discrete subsections of the solar field.

HTF Physical Properties*:* The HTF density and specific heat are required to calculate the energy transferred out of the solar system into the heat exchanger train. The uncertainty in the specific heat measurement can be on the order of ±1-3%, a significant factor in the uncertainty analysis. The measurement of fluid density is typically much more straightforward and has a lower uncertainty, with values less than ±1%.

While the HTF should presumably have a relatively consistent composition, its properties may vary because of outside factors, such as a multiple source of HTF, different lots, a lengthy period of time between delivery of the HTF and performance of the acceptance test, or an extended performance test period. If this is the case a more rigorous sampling program may be required to ensure representative samples. For these reasons, the parties to the test should agree whether to accept the manufacturer's property table for a newly purchased fluid, or to have random samples tested. Samples can be sent to authorized laboratories for tests.

Mirror Reflectivity: While not directly used in the calculation of solar field power and efficiency, measurement of the average reflectivity of the solar field is important for comparison against performance model projections, as mirror reflectivity is an important input value to the solar system performance model. The primary instrument used at NREL and at operating plants is the D&S Portable Specular Reflectometer Model 15R-USB. The Model 15R has been extensively used at (all) the SEGS (solar electric generation system) parabolic trough plants to measure mirror soiling for determining when mirror washing is required. The numbers and locations of reflectivity data sampling requires further evaluation for better understanding of the best procedures.

5.3. Test Uncertainty

Test uncertainty is an important element within any performance test code. ASME in particular has placed critical importance on test uncertainty analyses of all measurements and calculations associated with performance test codes, and therefore significant attention has been paid to this aspect of the guidelines. Because of the resource variability and imperfections in control systems, variation in all of the measured parameters is inevitable. The frequency and period of data collection directly impacts the test uncertainty and it is highly recommended that a pre-test uncertainty analysis be carried out prior to selection and subsequent installation of any instrumentation. An acceptance test will typically consist of more than one test run (data collected during a period of time in which the measured parameters are relatively steady). Conducting more than one test is recommended in that it will verify the repeatability of the test results as well as the validity of the pre-test uncertainty analysis.

Due to various influences no test results are completely accurate. The uncertainty interval is a possible value of the error, and describes our lack of knowledge about the true value of a measured quantity. The uncertainty of an interval about a measured value is usually expressed with a probability or level of confidence. Uncertainties are typically categorized as bias (or systematic) errors and random (or precision) errors.

The systematic error associated with a measurement of a single parameter can come from many sources including the calibration process, instrument systematic errors, transducer errors, and fixed errors of method. The test engineer should be diligent in identifying all of these sources of error although it is often the case that one or several will dominate within a particular measurement parameter.

Random errors can similarly be based on manufacturer's specification. However, the random uncertainty for a given measurement can be reduced based on repeated measurements over the interval in which the system is considered to be at steady state (defined by a minimal change in the Aperture Normal Insolation plus HTF flow control over the test period such that the effects of thermal exchange between the HTF and solar field piping are negligible). For repeated measurements, the random standard uncertainty can be defined by

$$s_{\bar{X}} = S_X/\sqrt{N}$$

where S_X is standard deviation of a series of sampled data and N is the number of data points collected over the test interval (e.g. 30 data points for a 30-minute test with data collected at 1-minute intervals).

Both a pre-test and a post-test uncertainty analysis is very important to ensure good testing methods and valid test results. ASME PTC 19.1 is devoted to this topic and is an excellent resource [6]. An example calculation using the PTC 19.1 principles and notation is described in detail below. The purpose is to describe how the uncertainties in each of the measured variables X associated with an acceptance test propagate into the value of a calculated resulting quantity R.

Calculated results, such as the delivered power and the solar thermal efficiency not measured directly but rather are based on parameters measured during the course of one or multiple acceptance tests. For this case the calculated result, R, is a function of individual or average values of these independent parameters as described by

$$R = f(\overline{X_1}, \overline{X_2}, \dots, \overline{X_\iota})$$

where the subscript *i* describes the number of parameters used in the calculation of the result and $\overline{X}$ is either the value of a single measurement of the parameter or the average value of the parameter based on a number of repeated measurements.

The expression for the standard measurement uncertainty of a calculated result based on multiple error sources can in many cases be calculated from the root-sum-square of the total uncertainty of the individual systematic and random error sources

$$u_R = [(b_R)^2 + (S_R)^2]^{1/2}$$

where b_R is the systematic standard uncertainty of a result and S_R is the standard random uncertainty of a result as calculated by

$$b_R = \left[\sum_{i=1}^{I}\left(\frac{\partial R}{\partial \bar{X}_i} b_{\overline{X_i}}\right)^2\right]^{1/2} \text{ and } S_R = \left[\sum_{i=1}^{I}\left(\frac{\partial R}{\partial \bar{X}_i} s_{\overline{X_i}}\right)^2\right]^{1/2}$$

For the equations above, $b_{\bar{X}}$ is defined as the systematic standard uncertainty of a component and $s_{\bar{X}}$ is the random standard uncertainty of the mean of N measurements. Definitions for the standard systematic and random uncertainty, as well as the methodology for calculating these values, are described in detail in ASME PTC 19.1 as well as in an excellent text on the subject authored by Dieck [7]. It is important to note that the "standard" uncertainties described above imply that the calculated result will capture the true result within a 68% confidence level (one standard deviation). Typically a confidence level of 95% (two standard deviations) is desired by the performance test engineer. For this case, the expanded uncertainty in the result is given by

$$U_{R,95} = 2u_R$$

Applying the methodology described above to the equation for the calculated solar field power, the standard systematic uncertainty of the result is calculated by

$$b_R{}^2 = \left(C_p(T_{hxin} - T_{hxout})\right)^2 b_m{}^2 + \left(m(T_{hxin} - T_{hxout})\right)^2 b_{C_p}{}^2 + \left(mC_p\right)^2 b_{T_{hxin}}{}^2 + \left(mC_p\right)^2 b_{T_{hxout}}{}^2$$

Similarly the absolute standard random uncertainty of the result is calculated by

$$S_R{}^2 = \left(C_p(T_{hxin} - T_{hxout})\right)^2 S_m{}^2 + \left(m(T_{hxin} - T_{hxout})\right)^2 S_{C_p}{}^2 + \left(mC_p\right)^2 S_{T_{hxin}}{}^2 + \left(mC_p\right)^2 S_{T_{hxout}}{}^2$$

The above methodology can be applied identically to the equations for solar field efficiency to arrive at estimated uncertainties. The resulting equation for the standard systematic uncertainty associated with the solar field efficiency is

$$\begin{aligned} b_R{}^2 = & \left(\frac{C_p}{DNI \cdot \cos\theta \cdot A_{aperture}}(T_{hxin} - T_{hxout})\right)^2 b_m{}^2 \\ & + \left(\frac{m}{DNI \cdot \cos\theta \cdot A_{aperture}}(T_{hxin} - T_{hxout})\right)^2 b_{C_p}{}^2 \\ & + \left(\frac{mC_p}{DNI \cdot \cos\theta \cdot A_{aperture}}\right)^2 b_{T_{hxin}}{}^2 + \left(\frac{mC_p}{DNI \cdot \cos\theta \cdot A_{aperture}}\right)^2 b_{T_{hxout}}{}^2 \\ & + \left(\frac{mC_p(T_{hxin} - T_{hxout})}{DNI^2 \cdot \cos\theta \cdot A_{aperture}}\right)^2 b_{DNI}{}^2 + \left(\frac{mC_p(T_{hxin} - T_{hxout})}{DNI \cdot \cos\theta \cdot A_{aperture}{}^2}\right)^2 b_{A_{Aperture}}{}^2 \end{aligned}$$

A similar equation can be derived as above for the random uncertainty.

Tables 1 and 2 below provide a summary of uncertainty data and results derived from the methodology described above as applied to the solar field power and efficiency calculations, and can be considered as an example of a pre-test uncertainty analysis. While any such analysis must be undertaken with the specific system and instrumentation in mind, the systematic and random uncertainties of measurement parameters given below are representative of what may occur in a typical field installation.

Symbol	Description	Units	Calculated Value, R	Absolute Systematic Standard Uncertainty, b_R	Absolute Random Standard Uncertainty, S_R	Combined Standard Uncertainty, u_R	Expanded Uncertainty of the Result, $U_{R,95}$	Expanded Uncertainty of the Result, $U_{R,95}$ (%)
P	Solar Field Power	kJ/s	306528	5894	400	5908	**11816**	**3.9%**

Table 1. Summary of Data – Solar Field Power

Symbol	Description	Units	Calculated Value, R	Absolute Systematic Standard Uncertainty, b_R	Absolute Random Standard Uncertainty, S_R	Combined Standard Uncertainty, u_R	Expanded Uncertainty of the Result, $U_{R,95}$	Expanded Uncertainty of the Result, $U_{R,95}$ (%)
η	Solar Field Efficiency	--	0.754	0.018	0.001	0.014	**0.035**	**4.7%**

Table 2. Summary of Data – Solar Field Efficiency

6. Conclusions and Future Work

Significant progress has been on the development of performance acceptance guidelines for parabolic trough solar fields. This development has involved and benefited from input from a wide variety of stakeholders throughout the international CSP community. In the near term, we plan to validate these guidelines by applying them to one or more operating parabolic trough plants in order to verify that the measurements will meet the requirements of all parties involved in the tests. Such validation will require the formulation of a test plan, preferably involving an EPC knowledgeable in preparing for and conducting such tests for conventional generating plants. Any measurements taken will be compared to model projections, both for clear-sky steady-state tests and for multi-day transient energy tests. Such comparisons will require a clear understanding of inputs to the model that may vary during the course of an acceptance test, e.g. ambient weather conditions, average solar field reflectance, and other solar field parameters. Lastly, lessons learned from current and future development these guidelines will be applied and extended where applicable to other CSP technologies (e.g. power towers, dish-engines, and linear Fresnel systems).

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13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
Prior to commercial operation, large solar systems in utility-size power plants need to pass a performance acceptance test conducted by the EPC contractor or owners. In lieu of the present absence of engineering code developed for this purpose, NREL has undertaken the development of interim guidelines to provide recommendations for test procedures that can yield results of a high level of accuracy consistent with good engineering knowledge and practice. The fundamental differences between acceptance of a solar power plant and a conventional fossil-fired plant are the transient nature of the energy source and the necessity to utilize an analytical performance model in the acceptance process. These factors bring into play the need to establish methods to measure steady state performance, potential impacts of transient processes, comparison to performance model results, and the possible requirement to test, or model, multi-day performance within the scope of the acceptance test procedure. The power block and BOP are not within the boundaries of this guideline.

15. SUBJECT TERMS
solar thermal electric; parabolic trough; performance; acceptance tests; uncertainty analysis

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
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