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14. ABSTRACT
This TOP provides guidance for the test and analysis of tactical hybrid power sources (THPS). The described procedures should only be followed when the procurement agency determines the procedures from MIL-STD-705D, Test Method Standard for Mobile Electric Power Systems, are not applicable for the system under test.

15. SUBJECT TERMS

Hybrid	Power Systems	Power Quality
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Voltage	Frequency	rms

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 09-2-290 22 August 2018
DTIC AD No.:

POWER QUALITY AND EFFICIENCY TESTING OF TACTICAL HYBRID POWER SOURCES (THPS)

1. SCOPE.

a. This Test Operations Procedure (TOP) provides guidance for the test and analysis of tactical hybrid power sources (THPS). The described procedures should only be followed when the procurement agency determines the procedures provided in Military Standard (MIL-STD)-705D[1**] are not applicable for the system under test. Two specific procedures for the testing of THPS are outlined in this TOP: Power Quality Characterization and Energy Efficiency (Fuel and Solar). These procedures are to be used as a framework for setup, testing, and analysis to minimize variability in results despite inherent variability in system design and operation.

b. Power Quality. The Power Quality portion of this TOP provides test procedures to properly evaluate the electrical power characteristics of THPS. This section contains power quality metrics derived from MIL-STD-1332B[2]. The metrics are provided to show how they were derived and the differences between the power quality metrics outlined in MIL-STD-1332B and those parameters measured to determine quality power of THPS. The procurement agency shall provide the applicable metrics with which any tactical hybrid power source is to be compared for power quality, or provide confirmation that the metrics in this TOP are appropriate.

c. Energy Efficiency (Fuel and Solar). The energy efficiency procedures outlined in this TOP are intended to be used as guidelines for the test and analysis of THPS with the intent of consistently generating averaged hourly performance metrics and instantaneous performance metrics during steady-state load conditions with and without a solar resource.

d. Due to the dynamic nature and design tradeoffs of the technologies tested under this TOP, a basic understanding of hybrid power system operation, functionality, and design trade space is required to accurately and safely conduct the testing described in this document. This TOP will define the necessary measurements for generic system configurations and explain test design parameters and methods of data computation and interpretation.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

No facility requirements exist. See Paragraph 3 for environmental conditions.

2.2 Instrumentation.

2.2.1 Power Quality Characterization.

A triggering mechanism must be established first, to define proper power quality instrumentation for a specific test, in compliance with International Electrotechnical Commission (IEC) 61000-4-30 Ed3[3]. Measurement methods and appropriate performance requirements for each measured parameter should correspond to Class A of IEC 61000-4-30 Ed3 (for normative measurement requirements).

** Superscript numbers correspond to Appendix C, References.

a. Data Collection Parameters. Test-specific data requirements should be referenced before choosing a data acquisition and analysis method, as one or more of the following parameters may need to be recorded:

(1) Root Mean Square (RMS). RMS data are defined as the square root of the arithmetic mean of the squares of a set of data for a defined time interval. All RMS values shall be measured and collected over the course of one cycle and should be refreshed and recorded at an interval of one cycle or less.

(2) Waveform. Waveforms are obtained by collecting instantaneous data for a voltage or current measurement. Waveform data should be collected at a rate no less than 128 samples per cycle. Waveform data may be of use in troubleshooting any observed power quality issues.

(3) Frequency. Instantaneous frequency should be calculated and recorded at a rate of one sample per cycle.

b. Computation Methods and Time Stamps. Algorithms used to monitor and analyze power quality parameters must be able to operate in sinusoidal and non-sinusoidal conditions. Signal processing computation includes:

(1) Digital filtering technique applied for frequency measurement under sinusoidal and non-sinusoidal conditions.

(2) Kalman filter technique applied for on line tracking of power system harmonics.

(3) Fast Fourier Transform and statistical method applied for real time detection.

(4) Multi-resolution signal decomposition techniques based on wavelet transform for on line detection, localization, and classification of disturbances.

c. All instruments should use a unified time stamp for data recording and allow data to be synchronized if collected on more than one instrument.

d. Triggered Recordings. Triggered data recordings should capture a minimum of 0.166 seconds (s) of data prior to an event and 4 s of data after the start of an event. This would equate to roughly 10 and 240 cycles, respectively, for a 60-Hertz (Hz) power source.

2.2.2 Energy Efficiency (Fuel and Solar).

Devices for Measuring	Minimum Sampling Rate
Alternating current (AC) power, direct current (DC) power, fuel tank weight, and fuel flow rate	0.25 samples/s

a. AC parameters may be obtained and reported via an AC power analyzer. DC parameters should be calculated via voltage and current measurements of the component under analysis. Fuel tank weight should be measured using a calibrated balance or platform scale. Flow rates for fuel should be measured using calibrated flow meters. Permissible measurement accuracy for all measuring instruments used during this test must be defined in the procurement document or agreed upon by the sponsor and test engineer. All instrumentation used during testing must be calibrated to standards traceable to the National Institute of Standards and Technology (NIST).

b. All other THPS parameters should be measured as outlined in Paragraph 2.2.1.

c. Solar Simulator.

(1) Variability of real solar resources does not align with the intent of testing performed in accordance with this document. Photovoltaic (PV) solar power generation depends on several factors that are hard to monitor and control when characterizing a hybrid system. Thus, solar simulators shall be used when characterizing hybrid systems since they provide a compact and repeatable source of simulated solar power. Solar simulators must use a solar array simulation (SAS) standard model to define solar array behavior based on solar panel characteristic parameters and ambient condition parameters. The parameters required to describe the solar panel characteristics are the reference irradiance, reference temperature, solar power output, output voltage, Beta temperature correction factor, and fill factor. These terms are defined in Appendix B.

(2) The ambient conditions replicated during testing, such as solar irradiance and temperature, should be defined by the system procurement agency.

3. REQUIRED TEST CONDITIONS.

Unless otherwise specified by the procurement agency, all testing shall be performed at standard ambient test conditions as described in MIL-STD-810G (w/Change 1)[4].

4. TEST PROCEDURES.

4.1 Power Quality Characterization.

The procedures in this section are applicable for THPS. Due to the dynamic nature of hybrid power systems and the potential for drastic load variance in an operational environment, the power output of a hybrid power source must maintain sufficient voltage and frequency characteristics to safely power critical loads. Because of the unique operational scenarios for THPS, unique terminology is used which may differ from that called out in MIL-STD-1332B. This terminology is defined in Appendix B. The tests described in this document are designed to validate power quality characteristics over the full operational range of a hybrid power system.

4.1.1 Regulation and Stability and Transient Response Test.

Hybrid power generation's transient response is affected by those parameters associated with the governing power source at the time of a transient load condition, and by the parameters associated with the supplementary power sources, such as photovoltaics. This test evaluates the voltage and frequency characteristics of the primary power sources of a THPS, as produced autonomously by the system, the fuel consuming generator, and the inverter during transient load conditions.

a. Method. Testing will be performed on the output power of the system in accordance with MIL-STD-705D, Test Method 608.1c, Short Term Frequency and Voltage Regulation, Stability, and Transient Response Test, with the following modifications to the test procedures:

(1) This test will be performed on each electrical output of the THPS at rated current. The output power of the system will be operated and allowed to stabilize at rated voltage, rated frequency, and rated power (0.8 power factor (pf)).

(2) Before each regulation and stability and transient response test, the power generation system will be operated and allowed to cycle through a complete discharge and charge cycle while operating at 50 percent of the system's rated load (RL). Once the energy storage is fully charged and the generator has shut down, the load will be removed, and the system's stabilized operating voltage and frequency will be verified.

(3) After the system setup procedures are performed and a steady-state operating voltage and frequency is validated, the load conditions will be switched in accordance with Table 1, and each load step will be operated for a minimum of 60 s. The load steps were derived from load conditions described in MIL-STD-705D, paragraph 608.1.3.2b.

Note: If a THPS is provided with a nominal output power rating and a peak power rating, the procurement agency shall devise a modified load condition, than that provided in Table 1, to account for load steps conducted at the peak power rating.

TABLE 1. LOAD CONDITIONS FOR REGULATION AND STABILITY AND TRANSIENT RESPONSE TEST

STEP NO.	LOAD CONDITION	STEP NO.	LOAD CONDITION	STEP NO.	LOAD CONDITION
1	RL to No Load (NL)	11	75% to NL	21	25% to NL
2	NL to RL	12	NL to 75%	22	NL to 25%
3	RL to NL	13[a]	50% to NL	23	25% to NL
4	NL to RL	14	NL to 50%	24	NL to 25%
5	RL to NL	15	50% to NL	25[a]	RL to NL
6	NL to RL	16	NL to 50%	26	NL to RL
7[a]	75% to NL	17	50% to NL	27	RL to NL
8	NL to 75%	18	NL to 50%	28	NL to RL
9	75% to NL	19[a]	25% to NL	29	RL to NL
10	NL to 75%	20	NL to 25%	30	NL to RL

[a] At each of these steps the load will be adjusted as described and then the adjusted load will be maintained for a minimum of 60 s prior to dropping to no load for the first time. This gives the system enough time to stabilize prior to the first transient event.

(4) Once all load steps have been performed, the system will be loaded at 50 percent of its rated load. When the generator turns on autonomously, the load will be removed.

Note: If the generator turns on during the load step portion of this testing, the test will just be continued as described and the time the generator started should be documented in the report. However, if a generator start occurs during the load steps, a complete charge and then discharge with the system operating at 50 percent of its rated load should be conducted prior to proceeding to Step 5.

(5) The steps outlined in paragraph 4.1.1.a(3) shall then be repeated with the generator on ,supporting the AC bus (or on in any manner to recharge the batteries). Once all load steps have been performed, the system will be loaded at 50 percent of its rated load. When the generator turns on autonomously, the load will be removed and the test concluded.

Note: If the generator turns off during this test, the testing will be continued as described.

b. Data Collection and Analysis.

(1) Derived THPS Performance Metrics. The applicable short-term frequency and voltage regulation, stability, and transient response power parameters from MIL-STD-1332B are outlined in Table 2. Because of possible source switching throughout normal THPS operations, the requirements for steady-state operations have been modified to avoid false failures in power quality. The individual limits for voltage regulation and stability percentage have been merged into a single "regulation and stability" bandwidth percentage. As a result, the parameters by

which recovery time and transient percentage are calculated have also changed; however, the limits for those remain the same as outlined in MIL-STD-1332B. The same respective changes were made for the frequency parameters. These changes are presented in Table 3.

TABLE 2. MIL-STD-1332B, PARAMETERS FOR TEST METHOD 608.1

CHARACTERISTIC PARAMETER	PRECISE CLASS 1	UTILITY		
		CLASS 2A	CLASS 2B	CLASS 2C
a. Voltage Characteristics				
1. Regulation (%)	1	2	3	4
2. Steady-State-Stability (Variation) (Bandwidth %)				
(a) Short-term (30 s)	1	1	2	2
(b) Long-term (4 hour)	2	2	4	4
3. Transient Performance				
(a) Application of Rated Load				
(1) Dip	15	20	20	30
(2) Recovery (s)	0.5	3	3	3
(b) Rejection of Rated Load				
(1) Dip	15	30	30	30
(2) Recovery (s)	0.5	3	3	3
b. Frequency Characteristics				
1. Regulation (%)	0.3	0.5	3	3
2. Steady-State-Stability (Variation) (Bandwidth %)				
(a) Short-term (30 s)	0.5	0.5	2	4
(b) Long-term (4 hour)	1	1	3	4
3. Transient Performance				
(a) Application of Rated Load				
(1) Dip	4	4	4	4
(2) Recovery (s)	2	4	4	4
(b) Rejection of Rated Load				
(1) Dip	4	4	4	5
(2) Recovery (s)	2	4	4	6

TABLE 3. DERIVED PARAMETERS FOR TACTICAL HYBRID POWER SOURCES FROM MIL-STD-1332B

CHARACTERISTIC PARAMETER	HYBRID PRECISE CLASS 1-H	HYBRID UTILITY		
		CLASS 2A-H	CLASS 2B-H	CLASS 2C-H
a. Voltage Characteristics				
1. Regulation and stability (bandwidth % from nominal)	2	2	4	4
2. Transient Performance				
(a) Application of Rated Load				
(1) Dip	15	20	20	30
(2) Recovery (s)	0.5	3	3	3
(b) Rejection of Rated Load				
(1) Dip	15	30	30	30
(2) Recovery (s)	0.5	3	3	3
b. Frequency Characteristics				
1. Regulation and stability (bandwidth %)	1	1	3	4
2. Transient Performance				
(a) Application of Rated Load				
(1) Dip	4	4	4	4
(2) Recovery (s)	2	4	4	4
(b) Rejection of Rated Load				
(1) Dip	4	4	4	5
(2) Recovery (s)	2	4	4	6

(2) Allowable Voltage and Frequency Envelopes. THPS output voltages and frequency shall be monitored and compared with the derived parameters for voltage and frequency presented in Table 3 or similar parameters provided by the procurement agency. These parameters are represented by the voltage steady-state, dip, and rise envelope shown in Figure 1 and the frequency steady-state, undershoot, and overshoot envelope shown in Figure 2 for Class 2B hybrid utility power. For any system load application or rejection, the system voltage and frequency will be compared with these envelopes to ensure the system remains within the voltage and frequency limits.

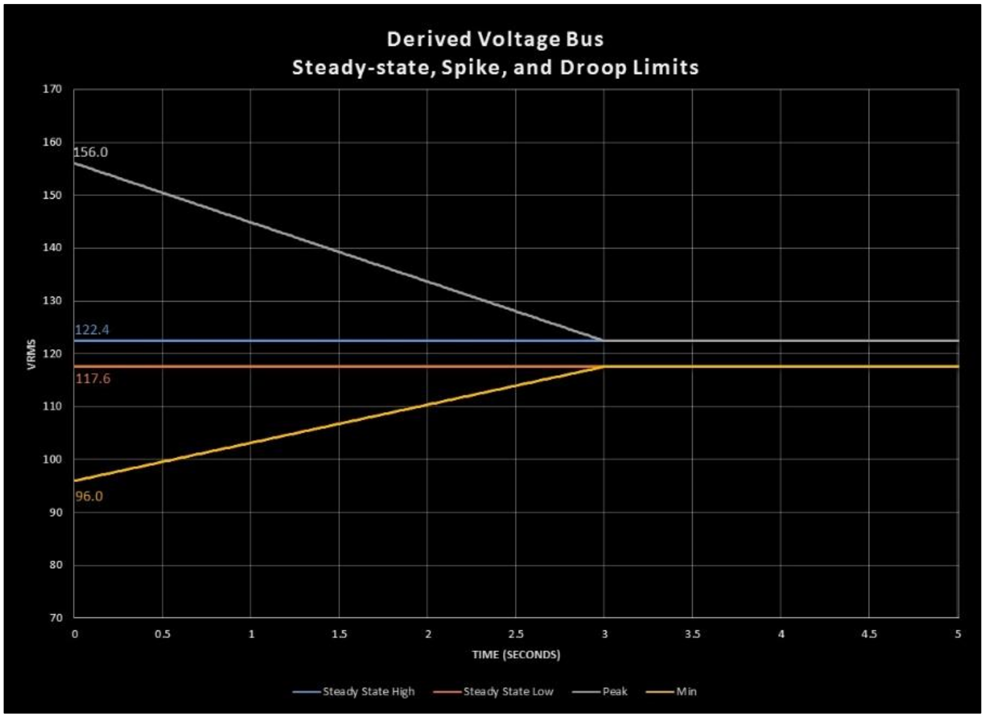

Figure 1. Voltage steady-state, dip, and rise envelope.

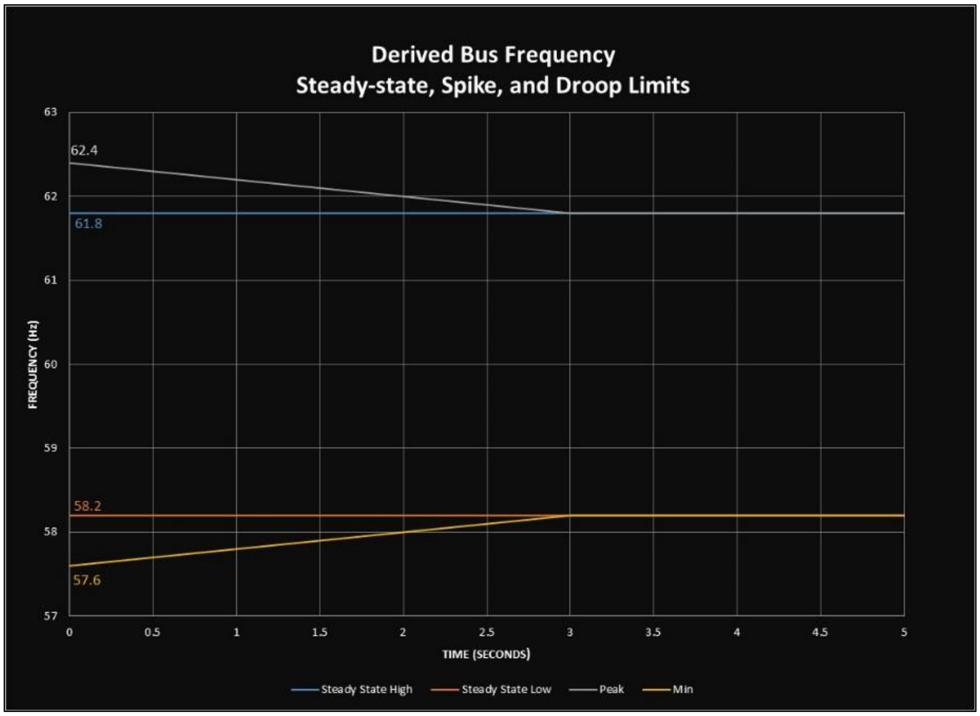

Figure 2. Frequency steady-state, undershoot, and overshoot envelope.

(3) The following data analysis procedures shall be used, and each event should be aligned with the appropriate voltage or frequency recovery window as follows:

(a) Event start time, or t_0, is equivalent to the data point just prior to any phase exceeding the regulation and stability threshold.

(b) Recovery end time, or t_1, is determined as the data point of the last phase to return and stay within the regulation and stability bandwidth thresholds.

(c) Recovery time is equal to (t_1- t_0); if recovery time is greater than the criteria specified in the performance document, the event shall be assessed as failing.

(4) An example of a transient event is shown in Figure 3 to illustrate the data necessary to align the event with a recovery window and the maximum deviation. It should be noted that this method of analysis looks at all data points for each phase of a single- or three-phase system in aggregate. Once properly aligned, the transient data recording should resemble the voltage dip scenario shown in Figure 4.

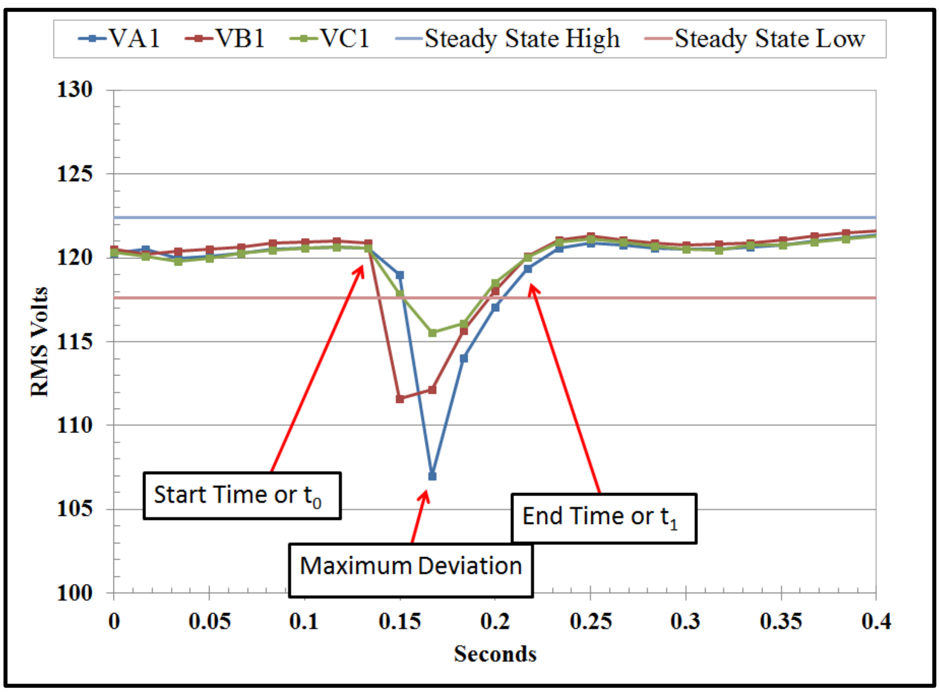

Figure 3. Illustration of transient start, stop and maximum deviation.

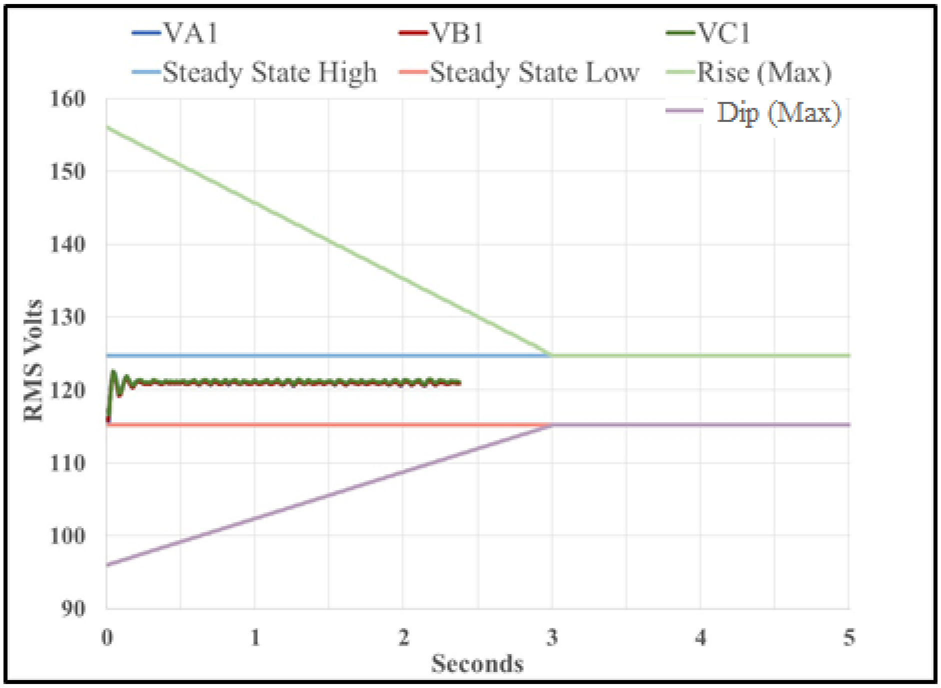

Figure 4. Properly aligned transient recording for voltage dip.

4.1.2 Long-term Stability and Source Switching Test.

Hybrid power systems may have multiple power generation, conversion, and storage devices which are capable of supporting the system's load requirements. Power source switching typically occurs during the on/off cycling of an AC generator, where the generator would dictate the AC power characteristics while running, and an inverter would dictate the power characteristics while the generator is off. Power source switching would exclude supplementary power generation devices which may be directly connected to the AC bus but are not used as voltage and frequency references, such as renewable resources.

a. Method. This test shall be performed in conjunction with all other ongoing THPS testing, such as energy efficiency (Paragraph 4.2), or similar long-duration testing like system reliability. Instrumentation shall be installed to monitor the system output power in accordance with Paragraph 2.2.1.

b. Data Collection and Analysis. During power source switching, a system must meet the same voltage and frequency characteristics specified for steady-state performance (Table 3). All collected THPS power data shall be analyzed to correlate recorded events with THPS primary power source switching events. A voltage or frequency event outside of the allowable prescribed "regulation stability bandwidth percentage" metrics outlined in Section 4.1.1, or similar parameters provided by the procurement agency, will be analyzed. Any event that exceeds the allowable regulation stability thresholds, and is not classified as being induced by load switching, should be assessed as not meeting the performance criteria for regulation stability bandwidth. Each event that exceeds the regulation stability bandwidth shall be analyzed as outlined in Paragraphs 4.1.1.c(3) and 4.1.1.c(4), and presented in a tabulated form that outlines the operational conditions that induced the event (i.e., source switching, steady-state load, etc.) as presented in Table 4.

TABLE 4. EXAMPLE OF DISTURBANCE RECORDINGS

DATE/TIME	LOAD (% OF RATED)	EVENT TYPE	TRIGGER TYPE	VOLTAGE SPIKE, OVER/ UNDERSHOOT (V)	FREQUENCY SPIKE, OVER/ UNDERSHOOT (HZ)	DEVIATION DURATION (S)
Date and time of each event, time shall be presented as Year, Month, Day, HH:MM:SS. XXX	25	Stability	Volts	126.4	60.10	0.25
	25	Gen to Inverter	Frequency	120.2	62.50	1.50
	25	Gen to Inverter	Volts	128.7	60.25	1.15
	50	Gen to Inverter	Volts	130.2	60.12	1.50
	50	Inverter to Gen	Volts	115.2	60.20	1.52

4.2 Energy Efficiency (Fuel and Solar).

4.2.1 Method.

a. The test methods described in this TOP should be performed at multiple steady-state load levels throughout a system's operational range to properly characterize system performance. The specific test levels should be specified by the procurement agency, but at a minimum, testing should be performed at the following load percentages of system rated power:

(1) No load.

(2) 25 percent of rated load.

(3) 50 percent of rated load.

(4) 75 percent of rated load.

(5) 100 percent of rated load.

b. General Test Setup. This setup applies to tests with and without solar. For consistent and accurate generation of metrics and for maximum accountability of energy, there should be a thorough understanding of system and component use strategies. Before data are collected for use in the fuel consumption analysis, a minimum of one full charge and discharge cycle shall be performed to calibrate system state of charge (SOC) for autonomous system operation. Any maintenance, bulk, or calibration cycles required by the manufacturer or designed into the system's startup procedures should not be included in the analyzed data. For cycle testing with a solar resource, no solar input from the solar simulator should be applied to the system during this time. Automated recalibration or maintenance cycles experienced during normal cyclic operation should be included in the analyzed data if they occur within the analyzed portion of data as defined below, but should be caveated as such. If the period of occurrence is a fixed system design parameter, additional cycles may be added during any given load step to generate more consistent data sets, which include maintenance cycles. Typically, increasing the test duration will increase the accuracy of the data; however, all start and end conditions should still be met. The decision to caveat data, versus adjusting the test duration, should be made by the test engineer and approved by the program manager. Whenever possible, accuracy should be the priority.

c. Cyclic Testing without Solar. This test replicates the cyclic behavior of a hybrid power system without a renewable power source, such as PV arrays, wind turbines, or similar auxiliary inputs. This test will generate data to inform performance requirements such as fuel consumption and SOC accuracy. This test may also be used to characterize and validate system operational parameters which may be initially unknown or assumed. Such parameters may be used as baseline operational parameters for use in the analysis sections.

(1) Cycle Definition. During testing under a steady-state load, as defined in the performance document, a system cycle without renewable or auxiliary inputs shall be defined as follows:

(a) A cycle shall start at the “Low SOC” threshold or “Generator On” threshold as defined by the system’s automation set points.

(b) The system shall complete one full charge sequence, at which point it reaches the “High SOC” or “Generator Off” threshold, as defined by the system’s automation set points.

(c) The system shall complete one full discharge sequence, at which point it reaches the “Low SOC” threshold or “Generator On” threshold, as defined by the system’s automation set points.

(2) Minimum Test Duration and Period of Analysis. Each steady-state load level, as defined by the procurement agency, shall consist of a minimum of three consecutive cycles. The Period of Analysis for tests without solar is equal to three cycles.

d. Cycle Testing with Solar. This test characterizes performance metrics of a hybrid power system with the aid of renewable resources as defined by any governing requirements documents. The program manager should be consulted regarding the amount and type of renewable resources used during this test to properly align with the intended application of the system. Before performing this test, reference any relevant TOPs and conduct any additional data acquisition or instrumentation procedures in accordance with relevant TOPs.

(1) Renewable Resource.

(a) During testing in accordance with this TOP, all renewable resources will be simulated using the solar simulation devices specified in Paragraph 2.2.2.c or an equivalent device. The procurement agency will provide a 24-hour diurnal solar resource profile that corresponds with the system's intended deployment configuration and location.

(b) The solar simulation devices will be configured in accordance with the solar technology intended to be used with the system, and will match the manufacturer's specified array configuration. The procurement agency should provide a renewable resource definition, such as the one presented in Table 5 and Figure 5, for use during this test. If no such profile is provided by the procurement agency, the irradiance profile outlined in MIL-STD-810G (w/Change 1), Figure 505.5C-6, shall be used.

Note: The procurement agency should also provide the total rating of the solar panels used for the system under test, panel technology and efficient, to the test agency to ensure the proper solar simulation is used.

TABLE 5. SOLAR IRRADIANCE,
AFGHANISTAN (JUNE-JULY)

HOURS	kW/m^2	HOURS	kW/m^2
0.0	0.00000	12.5	0.84967
0.5	0.00000	13.0	0.81822
1.0	0.00000	13.5	0.78676
1.5	0.00000	14.0	0.72690
2.0	0.00000	14.5	0.66703
2.5	0.00000	15.0	0.58409
3.0	0.00000	15.5	0.50115
3.5	0.00000	16.0	0.40426
4.0	0.00000	16.5	0.30736
4.5	0.00000	17.0	0.21565
5.0	0.01100	17.5	0.12394
5.5	0.02200	18.0	0.07235
6.0	0.04400	18.5	0.02076
6.5	0.12753	19.0	0.01038
7.0	0.21985	19.5	0.00000
7.5	0.31218	20.0	0.00000
8.0	0.40898	20.5	0.00000
8.5	0.50579	21.0	0.00000
9.0	0.58828	21.5	0.00000
9.5	0.67078	22.0	0.00000
10.0	0.72998	22.5	0.00000
10.5	0.78919	23.0	0.00000
11.0	0.81985	23.5	0.00000
11.5	0.85051	24.0	0.00000
12.0	0.85009		

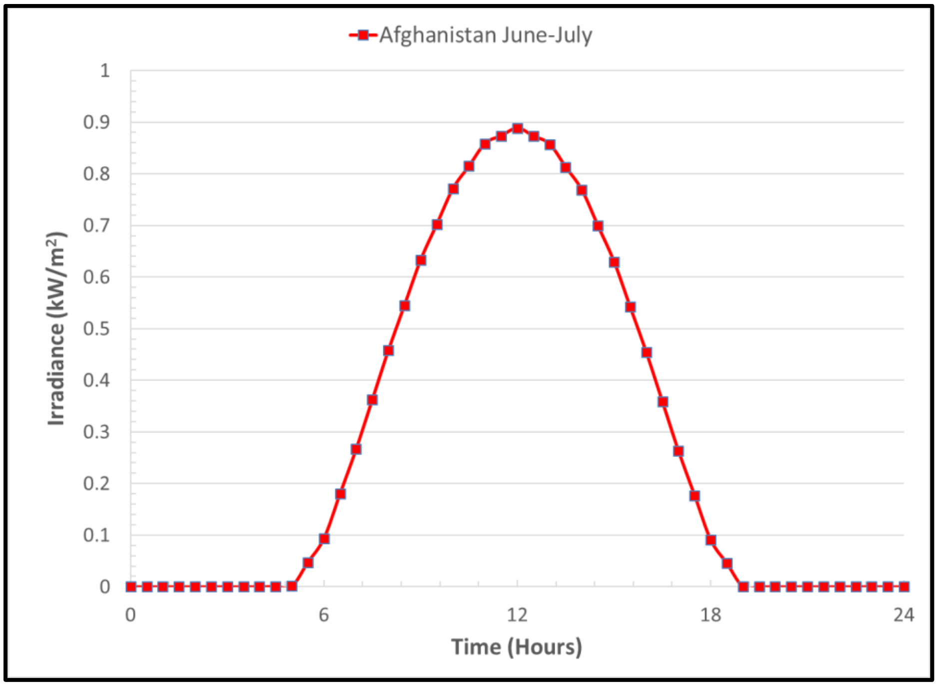

Figure 5. Sample solar resource definition.

(2) Cycle Definition. During testing under a steady state load, as defined in the performance document, a system cycle with renewable inputs shall be defined as follows:

(a) Both of the following conditions must exist at the start of a cycle and will be used as the beginning reference point for the period of analysis:

1 A cycle shall start at the "Low SOC" or "Generator On" threshold, as defined by the system's automation set points.

2 A cycle shall start in a pre-dawn, zero-irradiance condition (this time should be consistent between load steps and for all systems evaluated under a performance document).

(b) A full cycle must include both of the following:

1 A minimum of one full diurnal cycle.

2 A minimum of one full charge and discharge of the energy storage device as defined by the system's automation set points.

(c) Both of the following conditions must exist to conclude a cycle:

1 The solar resource shall be in a post-dusk, zero-irradiance condition, which concludes a full 24-hour diurnal cycle.

2 The system shall reach the “Low SOC” or “Generator On” threshold, as defined by the system’s automation set points, during a post-dusk, zero irradiance condition (Note: if this condition is not met, continue until it is. This point will determine the end time for the period of analysis).

(3) Minimum Test Duration. The test duration shall consist of a minimum of three consecutive diurnal cycles and at least three full charge and discharge cycles. If the energy provided by solar is significantly greater than the total energy utilized by the external load during the minimum test duration, the test engineer may conclude or extend a given load step at his or her discretion. A cycle is concluded at the end of a full 24-hour diurnal period; however, the period of analysis will conclude at the last occurrence of a “Low SOC” or “Generator On” threshold during the post-dusk, zero irradiance period of the third, or later, diurnal cycle. The start and end conditions for the data collection period and the period of analysis of a representative hybrid system with a simulated solar resource, loaded at 7 kilowatt (kW), are shown in Figure 6.

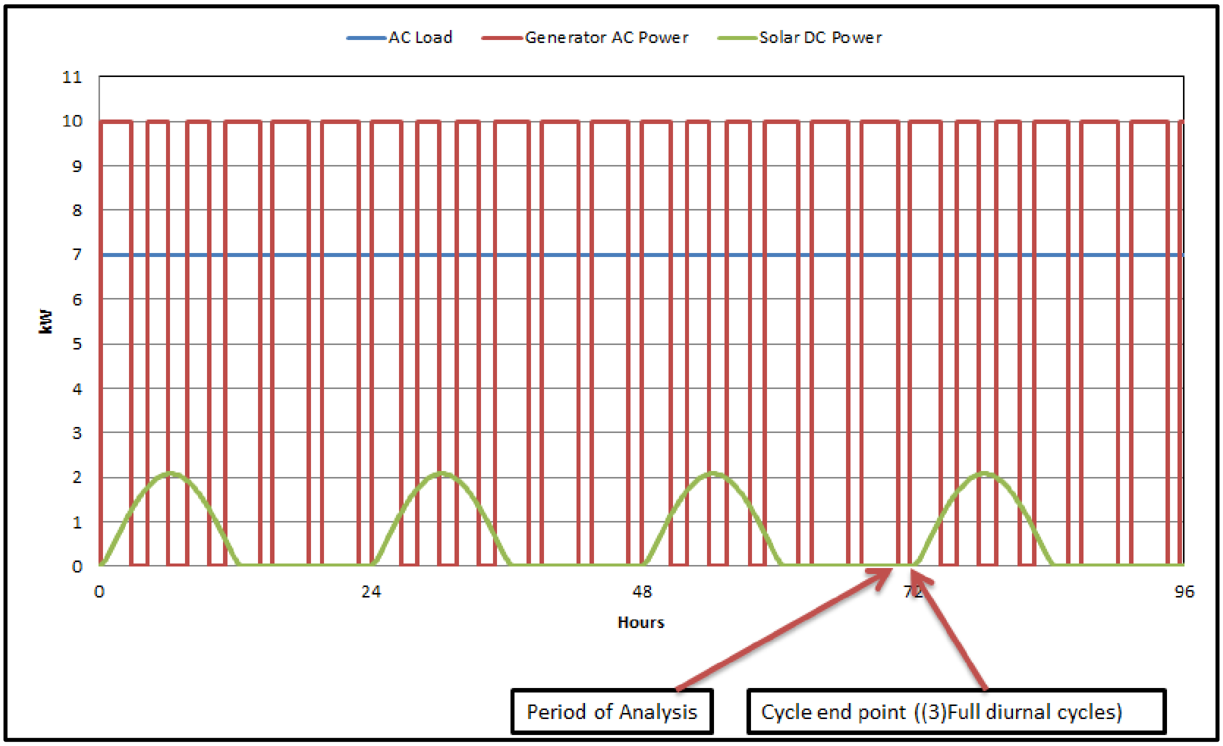

Figure 6. Critical test and analysis parameters with respect to system cyclic behavior.

4.2.2 Data Required.

The data required to properly analyze and characterize system performance, including fuel consumption and solar utilization, may vary from system to system depending on the technology being evaluated and the system configuration. Basic data collection requirements (Table 6) should be assessed before testing. Data parameters that define the system states should be recorded along with data parameters specified for use in the calculations defined in this section. These parameters will be used primarily for identifying the period of analysis but may also be used in the analysis of performance metrics.

TABLE 6. GENERAL DATA DEFINITION FOR MEASURING SYSTEM PERFORMANCE

DATA PARAMETER	OPERATION CONDITION	DATA COLLECTION
Test Duration and Period of Analysis (Including Solar)		
Generator “On/Off” signal	“Low SOC” and “High SOC” thresholds	Controller area network (CAN) signal, generator voltage, or current
Solar	Solar time of day	Solar voltage and current
Battery	Battery Status and SOC	Battery voltage and current, as well as SOC data, can be acquired from the battery management system (BMS) of the THPS.
Test Duration and Period of Analysis (Without Solar)		
Generator “On/Off” signal	“Low SOC” and “High SOC” thresholds	CAN signal, generator voltage or current
Battery	Battery Status and SOC	Battery voltage and current, as well as SOC data, can be acquired from the BMS of the THPS.
Solar Utilization		
Solar	Measured and estimated solar power	Measured solar voltage and current; estimated solar power curve

4.2.3 Data Presentation.

a. Fuel Consumption.

(1) Representative daily or hourly average fuel consumption is the primary data metric recommended in Section 4.2 of this TOP; however, the potential for system inaccuracies drives the need for higher fidelity data acquisition and analysis. Additional data not defined in this section may be necessary to confirm consistent system behavior during testing.

(2) Several methods exist for determining real-time fuel consumption with respect to load. The procurement agency should select a method before testing, and the same method should be used to evaluate all technologies developed under the same performance document.

The following methods are all acceptable ways to determine instantaneous or real-time fuel consumption for use in the calculation of representative fuel consumption for hybrid power systems.

(a) Average Fuel Weight. When measuring fuel consumption through instantaneous fuel weight, the diesel fuel driven generator should be plumbed to an auxiliary fuel tank, which can be isolated from the generator. During this test, the total fuel weight will be measured for the duration of each cycle and fuel consumption at a given load will be calculated as shown in Equation 1):

$$Fuel\ Rate_{Hybrid} = \frac{Weight_{fuel_{PoA}}}{t_{PoA}} \qquad \textit{(Equation 1)}$$

where t_{PoA} refers to elapsed time during the period of analysis.

(b) Measured Mass Fuel Flow. Procedures for calculating measured mass fuel flow, as detailed in TOP 02-2-603A[5], are shown in Equation 2):

$$Average\ Fuel\ Usage\ Rate_{in\ pph} = \frac{\left(Measured\ Fuel\ Volume_{in\ cm^3}\right)(SG)(7.92)}{Elapsed\ Time_{in\ s}} \qquad \textit{(Equation 2)}$$

where:
pph = pounds per hour.
SG = specific gravity of fuel (function of temperature).

Comparison of fuel volumes among vehicles and multiple test points can be accomplished by correcting to a standard temperature. Fuel consumption measurements from the installation fuel pump (uncorrected for fuel temperature) can be corrected for temperature to an equivalent volume at a standard temperature of 60 °Fahrenheit (°F) using Equation 3):

$$V_{F60} = \frac{SG_{TT}}{SG_{60}} V_{FTT} \qquad \textit{(Equation 3)}$$

where:
V_{F60} = the equivalent volume of fuel if it was measured at 60 °F.
SG_{TT}= the specific gravity of the fuel at a given temperature.
SG_{60}= the specific gravity of the fuel at 60 °F.
V_{FTT}= the volume of fuel pumped into the tank at a given fuel temperature.

(c) Calculated Fuel Consumption. There is an inherent performance variability of diesel generators; this calculation of fuel consumption allows the test engineer to reduce the potential for error when comparing similar technologies. For this method, fuel consumption curves from the Generator Fuel Consumption and Exhaust Study of the Advanced Medium Mobile Power Sources (AMMPS) and Tactical Quiet Generator (TQG) Sets, Report No.: ATC-

11770[6], should be used in conjunction with the generator's power data (kW) as specified in this document.

$$Fuel\ Rate_{Hybrid} = \frac{\sum(((C_1)*P_{gen_n}{}^2+(C_2)*P_{gen_n}+C_3)*(t_{n+1}-t_n))}{t_{PoA}} \qquad \textit{(Equation 4)}$$

where:

C_1, C_2, and C_3 = constants for the fuel consumption curve for the specific generator used by the system.
$P_{gen\ n}$ = the power generated by generator.
t_n = elapsed time at every instance of recorded data.
t_{PoA} = the period of analysis.

An example of a fuel consumption analysis for a hybrid system without renewable power generation compared with that of a traditional generator set is shown in Figure 7.

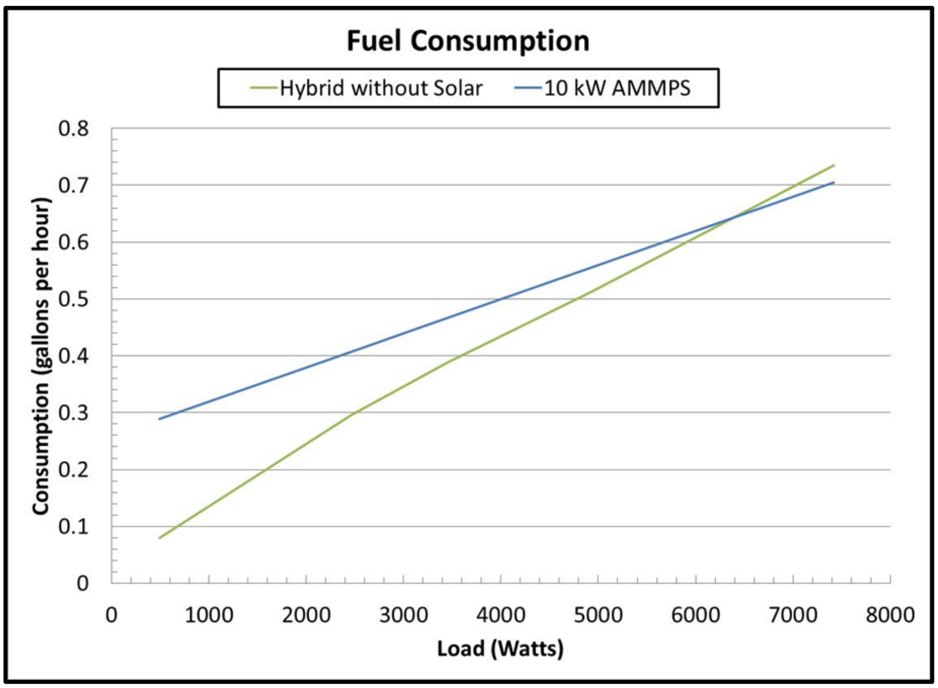

Figure 7. Fuel consumption rate in gallons per hour (gal/hr).

b. Solar Utilization. Solar utilization characterization should be performed during cycle testing with solar. Test setup, cycle definition, and test duration correspond to those used for cycle testing with solar. Solar utilization is defined as the system's ability to utilize an available solar resource and is expressed in terms of a percentage of the total energy available to the system. Collected data must indicate the amount of solar power available and the amount of solar power being accepted by the system. Voltage and current data should be collected at the output of the simulated photovoltaic array and compared with the available voltage and current as defined by the solar array simulator.

(1) Solar utilization must be calculated using Equation 5:

$$Solar\ Utilization = \frac{E_U}{E_A} \qquad \text{(Equation 5)}$$

where:
EU = the solar energy utilized by the system.
EA = the solar energy available to be utilized by the system.

(2) A comparison of the available solar power with the actual solar power used by a system during a one-cycle run at a specific load level is shown in Figure 8. The total solar energy should be obtained from the solar simulator specified in Section 2.2.2.c, the system's solar technology, and the procurement document's defined solar irradiance curve.

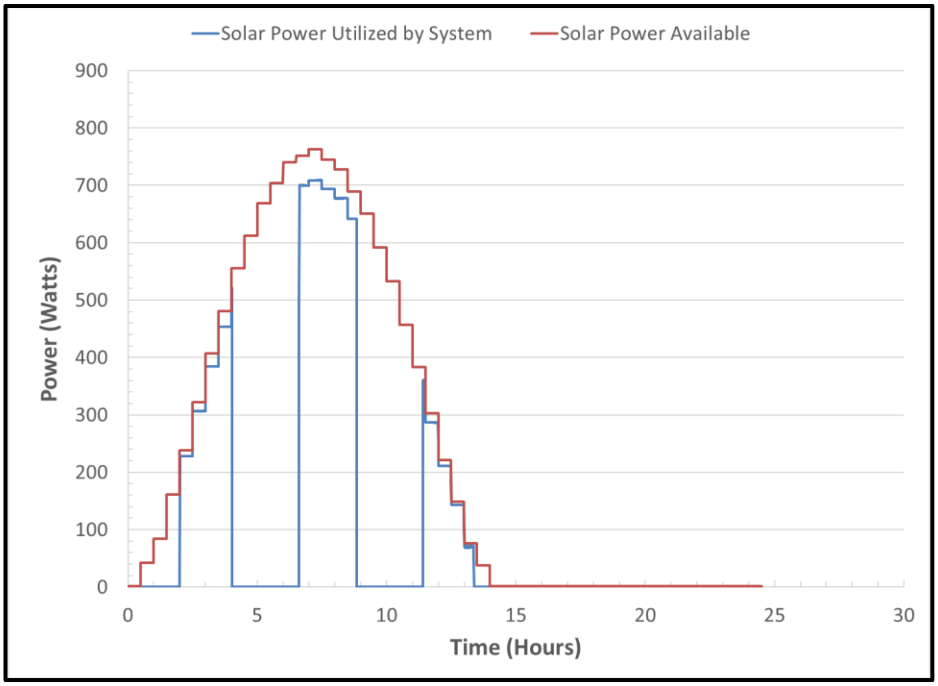

Figure 8. One diurnal cycle solar power profile for a hybrid system.

(3) An example of a solar utilization assessment for a hybrid power system that is unable to utilize solar during generator operation is shown in Figure 9. In this case, the solar utilization negatively correlates to generator runtime, which increases as load increases.

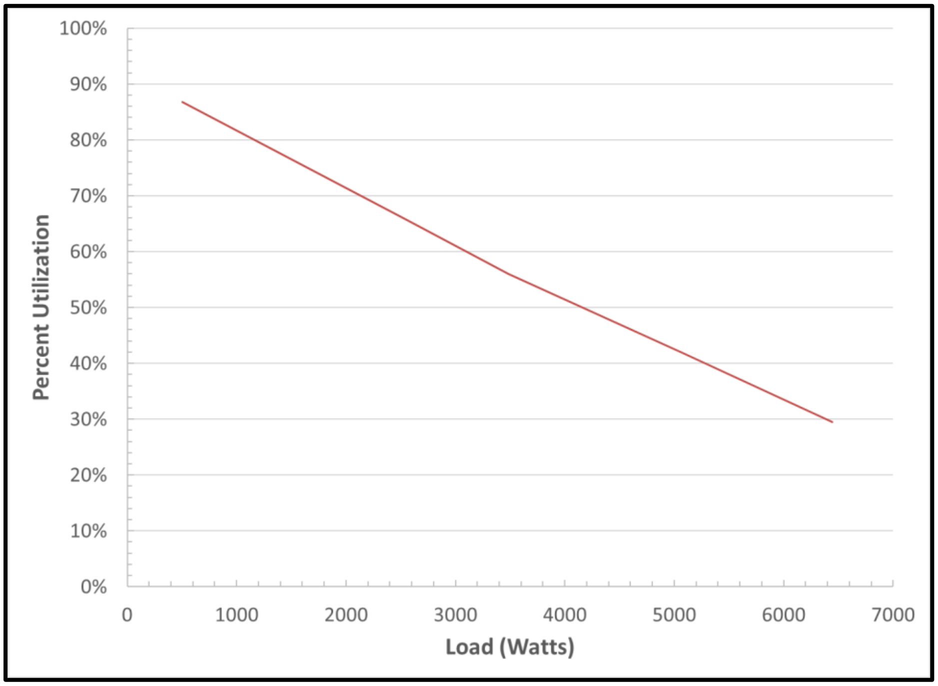

Figure 9. Hybrid system solar utilization at different load levels.

5. DATA REQUIRED.

Data required are described in Section 4: Test Procedures.

6. PRESENTATION OF DATA.

Examples of how data can be presented are provided in Section 4, as Figures 1-9. The format for the final data presentation should be agreed upon by the customer, evaluating agency, and the test agency prior to test initiation.

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APPENDIX A. GLOSSARY.

Term	Definition
Application of load	Electrical load applied instantaneously to the power source through the use of a single contactor; the load transition is typically from no load to rated load.
Beta temperature correction factor	A temperature correction factor used to adjust the solar output based on the actual panel temperature and reference temperature correlation.
Fill factor	The ratio of solar power output to the product of the open circuit voltage and short circuit current of the panel.
High SOC threshold	The maximum SOC value at which a system's battery is autonomously charged by a generator or logistics fuel consuming device.
Load application	A load introduced to the system under test, at the system output under test, in accordance with the configuration specified in the performance document.
Low SOC threshold	The minimum allowable SOC value before a system will autonomously use a logistics fuel consuming generator to support system load and charge batteries.
Maximum continuous load	The highest load (kW) at which the system is capable of cycling without a renewable input.
Maximum deviation	The largest recorded deviation from a system's rated voltage or frequency during a transient event captured by the data acquisition methods specified for a given test.
Primary power source	The prime generator for the system under all operational scenarios. This would most likely be a logistics fuel consuming generator.
Rated load	The rating (kW) of the diesel generator or primary logistics fuel consuming power source.
Recovery time	How long it takes voltage and frequency to return to a regulation stability threshold after exceeding that threshold.
Reference irradiance	The value at which the rated solar panel output of a solar simulator occurs.
Reference temperature	The panel array temperature at which the rated solar panel output of a solar simulator occurs.

APPENDIX A. GLOSSARY.

Term	Definition
Regulation and stability	A power system's ability to maintain rated voltage and frequency over a period of time specified by the test being performed.
Rejection of load	Electrical load removed instantaneously from the power source through the use of a single contactor; the load transition is typically from rated load to no load.
Solar output voltage	The output voltage at the maximum power conditions.
Solar power output	The power output at the reference irradiance and reference panel temperature.
Source switching	The transition between power sources which govern the AC bus on which the system is supporting its primary load.
Spike, overshoot	An increase in voltage or frequency in response to power source switching or the application or rejection of a load.
Spike, undershoot	A decrease in voltage or frequency in response to power source switching or the application or rejection of a load.
SOC	The percentage of the total energy capacity of the system's battery that is still available to discharge.
Steady-state load	A constant load applied to the system's output for a duration of time dictated by the specific test being performed.
Transient load	An instantaneous load change to the output terminals of a power system; may be specified as application or rejection of load.

APPENDIX B. ABBREVIATIONS.

AC	alternating current
AMMPS	Advanced Medium Mobile Power Sources
BMS	battery management system
CAN	controller area network
DC	direct current
EMC	Electromagnetic Compatibility
°F	degrees Fahrenheit
gal/hr	gallons per hour
HZ	Hertz
IEC	International Electrotechnical Commission
kW	kilowatt
MIL-STD	Military Standard
NIST	National Institute of Standards and Technology
NL	no load
pf	power factor
PV	photovoltaic
RL	rated load
RMS	root mean square
s	second
SAS	solar array simulation
SOC	state of charge
THPS	tactical hybrid power sources
TOP	Test Operations Procedure
TQG	tactical quiet generator
V	voltage

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APPENDIX C. REFERENCES.

1. MIL-STD-705D, Department of Defense Test Method Standard: Mobile Electric Power Systems, 22 November 2016.

2. MIL-STD-1332B, Military Standard: Definitions of Tactical, Prime, Precise, and Utility Terminologies for Classification of the Department of Defense Mobile Electric Power Engine Generator Set Family, 13 March 1973.

3. IEC TR 61000-4-30, Edition 3, Electromagnetic Compatibility (EMC), February 2015.

4. MIL-STD-810G (with Change 1), Department of Defense Test Method Standard: Environmental Engineering Considerations and Laboratory Tests, 15 April 2014.

5. TOP 02-2-603A, Vehicle Fuel Consumption, 10 May 2012.

6. Wills, J., Final Report for the Generator Fuel Consumption and Exhaust Study of the Advanced Medium Mobile Power Sources (AMMPS) and Tactical Quiet Generator (TQG) Sets, ATEC Project No. 2014-DT-ATC-MCSPT-F9542, Report No. ATC-11770, U.S. Army Aberdeen Test Center, May 2015.

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APPENDIX D. APPROVAL AUTHORITY.

CSTE-TM 22 August 2018

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 09-2-290 Power Quality and Efficiency Testing of Tactical Hybrid Power Sources (THPS), Approved for Publication

1. TOP 09-2-290 Power Quality and Efficiency Testing of Tactical Hybrid Power Sources (THPS), has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

The test procedures in this TOP should only be followed when the procurement agency determines the procedures from Military Standard-705D, Test Method Standard for Mobile Electric Power Systems, are not applicable for the system under test. Two specific procedures for the testing of THPS are outlined in this TOP: Power Quality Characterization and Energy Efficiency (Fuel and Solar). These procedures are to be used as a framework for setup, testing, and analysis to minimize variability in results despite inherent variability in system design and operation.

2. This document is approved for publication and will be posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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RAYMOND G. FONTAINE
Associate Director, Test Management Directorate (G9)

FOR

MICHAEL J. ZWIEBEL
Director, Test Management Directorate (G9)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-TM), U.S. Army Test and Evaluation Command, 6617 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Support Equipment Division (TEDT-AT-WFE), U.S. Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, MD 21005-5059. Additional copies can be requested through the following website: https://www.atec.army.mil/publications/documents.html, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.