Assessment of Retrofit Energy-Saving Devices

Final Report 10-07
April 2010

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Energy Research and
Development Authority

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Assessment of Retrofit Energy-Saving Devices

Final Report

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ABSTRACT

This report summarizes the final results of 2007-2008 research by EPRI regarding the performance of two select retrofit energy-savings devices. The research findings and analysis confirm the need for independent measurement and verification of retrofit energy savings devices. The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment.

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SUMMARY

INTRODUCTION

This report summarizes the final results of 2007-2008 research by EPRI regarding the performance of two select retrofit energy savings devices. The research findings and analysis confirm the need for independent measurement and verification of retrofit energy savings devices. The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment.

BACKGROUND

The past two decades have seen the introduction of a number of new technologies, such as retrofit energy-savings devices, which are intended to save energy. Retrofit energy-savings devices are added after-the-fact to existing commercial and industrial electrical systems with the intent to improve energy efficiency, usually without directly affecting end-use equipment. Devices have been offered to retail outlets, supermarkets, universities, manufacturing facilities, and other commercial and industrial enterprises with a general intent that energy consumption will fall, other factors being held constant. Claims or implications of reduced energy bills, electric equipment protection, and other electrical system performance improvements are often associated in connection with these devices. EPRI was selected to perform a limited study to survey existing devices, select a limited number for further evaluation, establish protocols for examining energy savings and other potential understood benefits of the technologies, and assess the need for further independent evaluation of these types of devices. Two technologies were selected in the limited study for an evaluation of energy efficiency performance and other features.

OBJECTIVES

The goal of the project is to produce an assessment of the energy savings capabilities of certain technologies used within retrofit energy-saving devices.

APPROACH

Survey potential technologies for evaluation and develop a candidate list with emphasis placed on those technologies for which the California Energy Commission (CEC) and NYSERDA have received inquiries. Create selection criteria from which to systematically reduce the number of potential products for testing down to two, which met the budget constraints of the project.

Develop testing protocols and procedures for each technology selected for independent testing.

Select an appropriate testing site: laboratory, field, or both. For field locations, work with the host to coordinate contractual and logistic issues.

Perform testing and evaluation of identified technologies and products using the established protocols and procedures.

Draft a report that includes results and observations from the testing performed.

RESULTS

The two products selected for testing were the Mini-EVR™ manufactured by Utility Systems Technologies, Inc. (UST) and the Model CMES-3D/480 Power-Enhancement Device by USES Manufacturing Incorporated (USES). The Mini-EVR™ was compared with a constant voltage source (CVS) manufactured by SolaHD. Summary results for the tests conducted pursuant to the protocols described herein for each are provided below.

SUMMARY RESULTS - Mini-EVR™

The table below summarizes the results of the testing for both the SOLA CVS and Mini-EVR™.

	SOLA CVS	Mini-EVR™
Test 1: Operational Voltage Range Claimed maximum variation at the output Measured maximum variation at the output	 ±1% ±2.68%	 ±3% ±4.34%
Test 2: Efficiency Claimed maximum efficiency Measured maximum efficiency(instantaneous) Measured minimum efficiency (instantaneous)	 92% 90.72% @ 3 kW 67.94% @ 600 W	 99% 97.47% @ 1.8 kW 94.84% @ 600 W
Test 3: Response Time Claimed response time	Not specified.	1 cycle typical (1.5 cycle max) regardless of load or load power factor
Measured response time during a temporary (5 cycle) undervoltage	Within 1.5 cycles	5 cycles @ 1.5 kW 4 cycles @ 3 kW
Measured response time during a temporary (5 cycle) overvoltage	Within 1.5 cycles	Greater than 5 cycles at both 1.5 kW and 3 kW

SUMMARY RESULTS - USES Devices

Field testing indicates that the devices manufactured by USES Manufacturing, Inc. (USES) devices did not impact motor power consumption within the measurement capabilities of this effort. Voltage and current distortion remained unchanged with or without the USES devices. The USES devices did provide Volt-Amperes Reactive (VAR) support for the motor load, improving the power factor and decreasing the reactive currents in the feed wires to the motor control center, which would lead to a reduction in wiring losses in the feed circuit to the motor control center.

1
OBJECTIVE

PROJECT OBJECTIVES

The past two decades have seen the introduction of retrofit energy-saving devices (RESD) often associated with various claims and indications of benefits, including reduced energy costs. At present, nationally-recognized standards and protocols for testing do not exist, making verification of RESD performance difficult. The project will address this problem by developing a protocol, testing, and reporting results for one or more retrofit energy saving devices. The results will compare measured performance to performance claims by following the developed protocol.

The project goals and objectives are listed in Table 1.

Table 1. Project Goals and Objectives

Goal	Objectives
To produce an assessment of the energy savings capabilities of technologies used within two retrofit energy-saving devices.	• Survey potential technologies for evaluation and develop a candidate list with emphasis placed on those technologies for which the CEC and NYSERDA have received inquiries. Create selection criteria from which to systematically reduce the number of potential products for testing down to two that meet the budget constraints of the project. • Develop testing protocols and procedures for each technology selected for independent testing. • Select an appropriate testing site: either laboratory, field, or both. For field locations, work with the host to coordinate contractual and logistic issues. • Perform testing and evaluation of identified technologies and products using the established protocols and procedures. • Draft a report that includes results and observations from the testing performed.
Provide information that will be made publically available.	• Prepare and publish a final report. • Perform technology transfer tasks for the prospective buyers of retrofit energy-saving technology within the State of NY and the State of California.

2
SELECTION CRITERIA

The following is the selection criteria as shown in Figure 1 used to cull the list of RESD devices:

- A device that is retrofit to an existing and otherwise fully operation end-user installation. Such devices are, in general, not an available option from the original equipment manufacturer (OEM).
- A device that provides power conditioning including but not limited to either voltage regulation and/or surge suppression.
- Devices that the manufacturer or vendor claims or indicates will, at a minimum, save energy such that the user's electric bill will decrease. Other notable claims or indicated benefits for the device may also include power quality benefits or surge suppression.
- A device that has electricity as its main input and output and connects to an electrical circuit either in series or in parallel between the utility supply and the load.
- A further requirement for this project is that the device not be significantly addressed by voluntary efficiency organizations such as ENERGY STAR. Moreover, nationally recognized standards and protocols for measurement and verification either do not exist or are perceived to be inadequate.
- The device should be a series or parallel retrofit, or be designed to replace connected power conditioners that offer energy saving benefit.
- The device should be a power converter or conditioner.

An ideal candidate for evaluation under this project will meet the following criteria:

- The device meets the project's definition of an RESD technology as shown in Figure 1
- The technology has not been exhaustively tested already by EPRI or a related non-profit, government lab, or university facility, or has not been tested for at least 5-10 years
- A field installation exists with the following attributes:
    - Validated by the vendor as producing the desired energy savings
    - Accessible for field testing

One or more RESD units can be removed and transported to a laboratory setting for further evaluation.

3

SELECTION MATRIX

A selection matrix was created to provide a method by which the list of products could be trimmed. In order to be selected, the product must meet the definition criteria shown in Figure 1 as a screen capture. The specific criterion is a weighted number.

	No.		Weight factor	Rating Detail
Definition	1	A device that is designed for retrofit to an existing end-user application. Such devices are, in general, not an available option from the original equipment manufacturer (OEM).		1 = Possible to retrofit 0 = Not possible to retrofit or not known
	2	A device that provides power conditioning including but not limited to either voltage regulation and/or surge suppression.		1 = Has Power Conditioning Capability 0 = None or Limited Power Conditioning Capability or Information not found
	3	A device that the manufacturer or vendor claims will, at a minimum, save energy such that the user's electric bill will decrease. Other notable claims for the device may also include power quality benefits or surge suppression.		1 = Manufacturer claims power savings. 0 = Manufactuer does not claim power savings.
	4	A device that has electricity as its main input and output and connects to an electrical circuit either in series or in parallel between the utility supply and the load.		1= Has electricity as its main input and output. 0 = No or not known
	5	A further requirement for this project is that the device not be significantly addressed by voluntary efficiency organizations such as Energy Star. Moreover, nationally recognized standards and protocols for measurement and verification either do not exist or are inadequate.		1 = Not Addressed 0 = Addressed
	6	The technology has not already been exhaustively tested either by EPRI or a related non-profit, government laboratory, university facility, or has not been tested for at least five to ten years.		1 = Not Tested 0 = Tested
Specific Criteria	7	A field installation exists.	2	1 = Installation exists 0 = Installations do not exist or are not known
	8	The field installation has been validated by the vendor as producing energy savings.	1	1 = validated by vendor 0 = Not validated by vendor or not known
	9	The field installation is accessible for field testing.	1	1 = accessible for field testing 0 = not accessable for testing, or not known
	10	One or more RESD units can be removed and transported to a laboratory setting for further evaluation.	2	1 = Available for laboratory testing 0 = Not available for laboratory testing, or not known
	11	Sponsor Interest	2	1 = High sponsor 0 = Not high sponsor interest
				Overall rating

Figure 1. Screen Capture of Selection Matrix

4
TEST RESULTS – MINI-EVR™

4.1 INTRODUCTION

The objective of the laboratory testing was to measure basic performance parameters of ferroresonant transformers (alternately called a constant voltage source (CVS)) and compare the results to a product using tap-switching technology called the "Mini-EVR™," which is a product commercially offered as a replacement for ferroresonant transformers. Ferroresonant transformers have long been used as power conditioners and if ferroresonant transformers are replaced by solid-state tap-changers such as the Mini-EVR™, energy savings may result. Given this, EPRI performed three tests; efficiency, operating voltage range, and response time.

4.2 DEVICE DESCRIPTION

The Mini-EVR™ is manufactured by Utility Systems Technologies, Inc. (UST) in Latham, New York. A photograph of the device is given in Figure 2 with specifications given in Appendix E. The SOLA CVS is manufactured by SOLA/Hevi Duty, a member of the EGS Electrical Group, LLC. A photograph of the device is given in Figure 3 with specification given in Appendix D. Both the Mini-EVR™ and the SOLA CVS used for this test are single-phase devices rated at 3 kVA. Thus, the maximum loading will be 3 kW (power factor =1) for various tests performed.

Figure 2. Photograph of the Mini-EVR™ Manufactured by Utility Systems Technologies, Inc.

Figure 3. Photograph of the SOLA CVS Manufactured by SOLA/Hevi Duty

4.3 OPERATING VOLTAGE RANGE TEST

4.3.1 Objective

The objective is to determine the performance of the device over a range of input voltages (96 V to 132 V) for various loading conditions (0-100% in 25% increments). Test equipment and measured parameters are listed in Table 2.

4.3.2 Setup

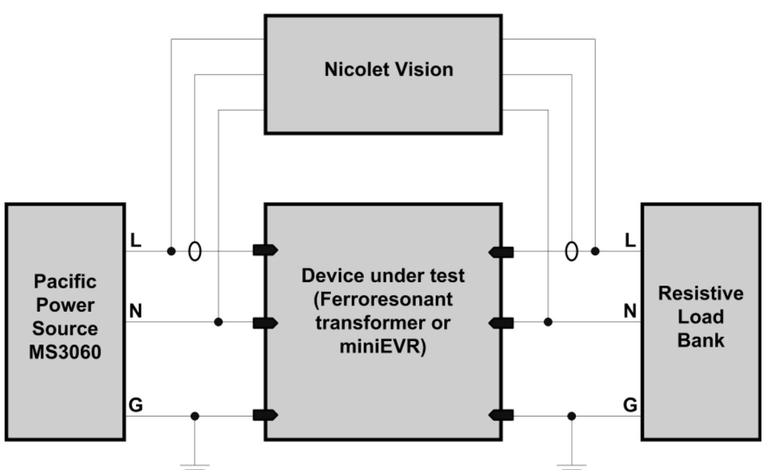


Figure 4. Test Setup for the Input Voltage Range Test

Table 2. Test Set-Up Equipment and Monitored Parameters

Load Description	Equipment	Parameters to be Monitored
Variable resistive load	• Pacific Power Source (MS3060) • Nicolet Vision (Power Analyzer) • Resistive Load Bank	• Input voltage • Output voltage

4.3.3 Procedure

1. Use the test setup shown in Figure 4.
2. Configure the device for no-load.
3. Set the source voltage at 120 V and monitor and record the output voltage.
4. Reduce the source voltage in 1-V increments down to 96 V recording input and output voltage at each increment.
5. Set the source voltage again at 120 V. Increase the voltage up to 132 V in 1-volt increments recording input and output voltage at each increment.
6. Repeat steps three to five for loading of 1500 W, 2250 W, and 3000 W.

4.3.4 Expected Results

For the SOLA CVS transformer the manufacturer suggests that the output voltage stays within 1% of the rated voltage (120 V) for an input voltage variation from -20% to +10% (appendix D). The expected output voltage for an input voltage variation is shown in Figure 5.

For the Mini-EVR™, the manufacturer suggests that a maximum variation of ±3% will occur at the output voltage if the input voltage stays within +10/-25% of the rated voltage (120 V) (appendix E). The expected input/output behavior of the Mini-EVR™ is shown in Figure 6.

Graphs shown in Figure 5 and Figure 6 demonstrate the boundaries of the input and output voltages. The input voltage range of the Mini-EVR™ is 88-132 V, whereas it is 96-132 V for the SOLA CVS. Because the CVS has a narrower input voltage range, the test will be done according to the CVS specification.

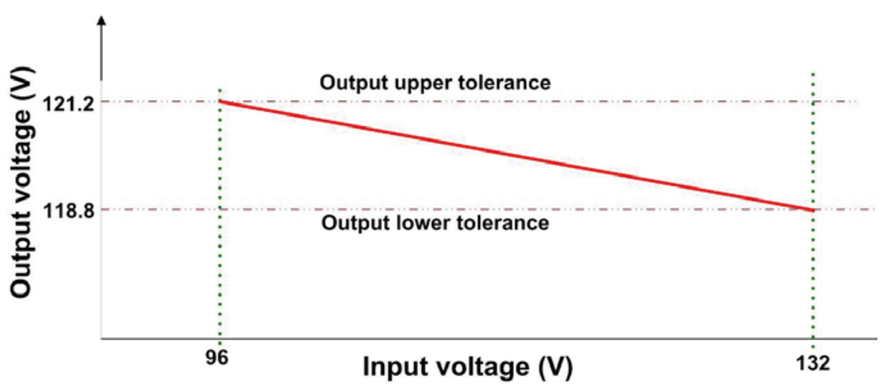


Figure 5. Expected Output Voltage Characteristics of the SOLA CVS. (Voltages are not drawn according to scale)

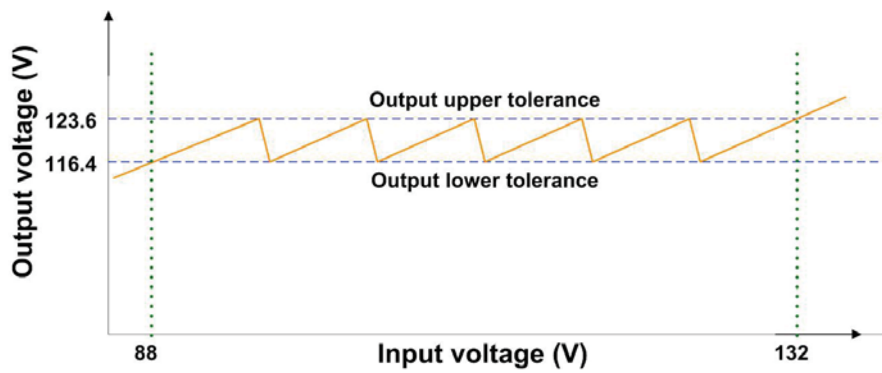


Figure 6. Expected Output Voltage Characteristics of the Mini-EVR™. (Voltages are not drawn according to scale).

4.3.5 Results

Table 3 lists the results of the measurements for the SOLA CVS for varying input conditions and loading[1]. The data in Table 3 were used to plot a graph that shows the input-output relationship of the SOLA CVS (Figure 7).

Table 3. Test Results of the Input Voltage Range Test for SOLA CVS

Vin(V)	Vout (V) at No Load Condition	Vout (V) at 750 W	Vout (V) at 1500 W	Vout (V) at 2250 W	Vout (V) at 3000 W
120	119.12	118.65	118.94	119.49	119.89
96	122.2	121.7	121.9	121.95	119.79
97	122.07	121.62	121.76	121.89	119.92
98	121.96	121.5	121.65	121.86	120.05
99	121.83	121.38	121.55	121.81	120.14
100	121.7	121.27	121.44	121.74	120.21
101	121.58	121.14	121.33	121.68	120.3
102	121.45	121.02	121.2	121.57	120.36
103	121.32	120.9	121.09	121.51	120.43
104	121.19	120.77	120.97	121.41	120.48
105	121.06	120.64	120.85	121.31	120.5
106	120.93	120.5	120.73	121.23	120.52
107	120.79	120.38	120.6	121.13	120.53
108	120.66	120.24	120.47	121.02	120.53
109	120.52	120.11	120.34	120.91	120.52
110	120.39	119.98	120.21	120.8	120.49
111	120.25	119.84	120.08	120.67	120.45
112	120.11	119.71	119.95	120.55	120.4

[1] Data sequence organized to facilitate graphing.

Vin(V)	Vout (V) at No Load Condition	Vout (V) at 750 W	Vout (V) at 1500 W	Vout (V) at 2250 W	Vout (V) at 3000 W
113	119.97	119.57	119.81	120.42	120.35
114	119.83	119.43	119.67	120.3	120.28
115	119.69	119.29	119.53	120.16	120.2
116	119.55	119.15	119.39	120.04	120.12
117	119.39	119.01	119.25	119.91	120.04
118	119.25	118.86	119.11	119.76	119.95
119	119.11	118.72	118.96	119.62	119.85
120	118.96	118.58	118.82	119.49	119.75
121	118.81	118.43	118.68	119.34	119.64
122	118.66	118.28	118.53	119.2	119.51
123	118.51	118.14	118.38	119.05	119.39
124	118.37	118	118.24	118.9	119.26
125	118.21	117.85	118.09	118.75	119.15
126	118.06	117.7	117.94	118.6	119
127	117.92	117.55	117.79	118.47	118.87
128	117.77	117.39	117.63	118.3	118.74
129	117.61	117.24	117.42	118.16	118.59
130	117.46	117.09	117.26	118	118.44
131	117.31	116.94	117.1	117.84	118.3
132	117.16	116.79	116.94	117.69	118.15

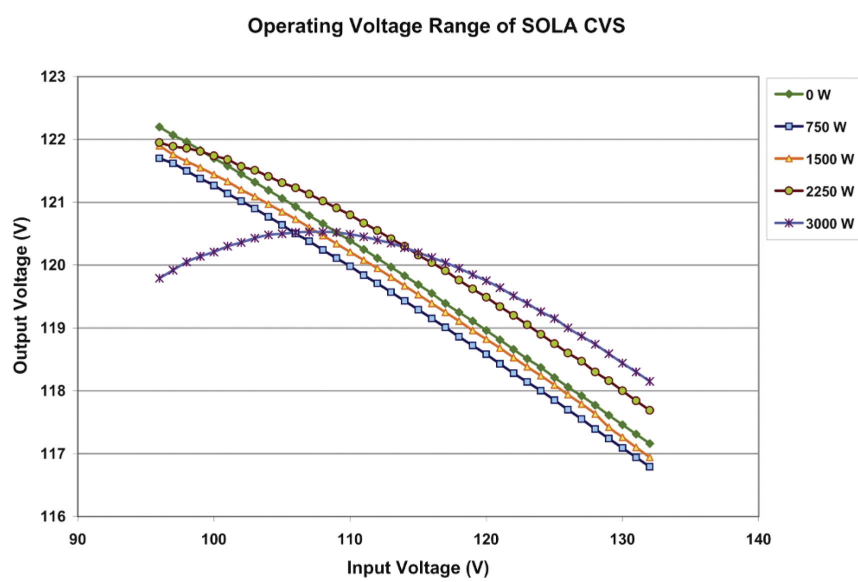


Figure 7. The Input/Output Voltage Relationship of the SOLA CVS Transformer for Various Loading Conditions

Mini-EVR™: Table 4 lists the results of the measurements for the Mini-EVR™ for varying input conditions and loading[2]. Figure 8 is a plot of the data.

Table 4. Recorded Data for Mini-EVR™

Vin(V)	Vout(V) at No Load	Vout(V) at 750 W	Vout(V) at 1500 W	Vout(V) at 2250 W	Vout(V) at 3000 W
120	120.14	119.31	118.88	117.71	116.84
96	120.5	119.32	118.75	117.9	116.9
97	121.77	120.8	119.86	119.12	118.1
98	123.03	122.04	121.22	120.35	119.31
99	124.29	123.3	122.45	121.57	120.5
100	119.31	124.54	118.01	122.79	121.71
101	120.51	119.84	119.18	118.39	117.58
102	121.72	121.03	120.36	119.56	118.72
103	122.91	122.2	121.55	120.84	119.88
104	116.9	123.39	115.59	122.01	121.15
105	118.02	117.41	116.58	115.82	114.79
106	119.16	118.53	117.7	116.91	115.98
107	120.3	119.65	118.8	118.02	117.05
108	121.41	120.77	119.9	119.12	118.14
109	122.55	121.88	121	120.2	119.22
110	123.68	123	122.24	121.3	120.3
111	117.42	117.52	116.87	116.16	115.42
112	118.51	118.58	117.92	117.2	116.45
113	119.58	119.65	118.96	118.23	117.48
114	120.65	120.7	120.02	119.28	118.51
115	121.73	121.76	121.06	120.43	119.55
116	122.97	122.82	122.12	121.48	120.56
117	124.04	123.88	123.17	122.52	121.61
118	125.13	124.95	124.21	123.46	122.63
119	119.14	118.42	117.88	117.3	116.59
120	120.13	119.41	118.87	118.29	117.56
121	121.14	120.41	119.86	119.27	118.53
122	122.13	121.41	120.86	120.25	119.51
123	123.14	122.41	121.84	121.23	120.59
124	124.14	123.4	122.74	121.22	121.56
125	125.15	124.39	123.82	123.19	122.53
126	119.01	117.52	116.94	116.29	115.59
127	119.94	118.47	117.87	117.3	116.5
128	120.87	119.4	118.78	118.12	117.41

[2] Data sequence organized to facilitate graphing.

Vin(V)	Vout(V) at No Load	Vout(V) at 750 W	Vout(V) at 1500 W	Vout(V) at 2250 W	Vout(V) at 3000 W
129	121.8	120.33	119.71	119.14	118.32
130	122.74	121.27	120.65	120.05	119.24
131	123.68	122.19	121.67	120.98	120.14
132	124.61	123	122.49	121.9	121.06

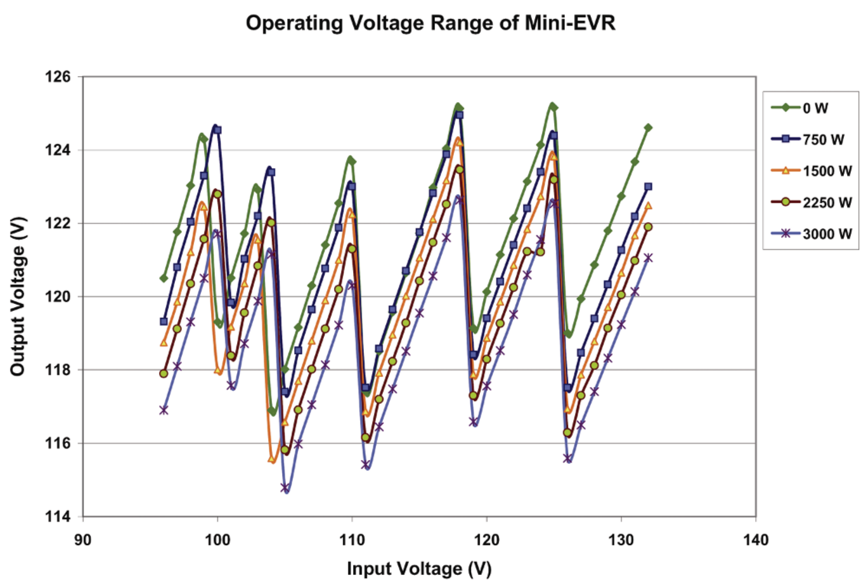


Figure 8. The Input/Output Voltage Relationship of the Mini-EVR™ for Various Loading Conditions

4.3.6 Summary

The results of the operating voltage range measurements are summarized in Table 5.

Table 5. Laboratory Data Compared With the Claimed Performance Data

Device Name	Claimed Maximum Variation	Maximum Variation Found in the Test	Minimum Variation Found in the Test
SOLA CVS	±1%	±2.68%	±1.54%
Mini-EVR™	±3%	±4.34%	±3.48%

4.4 Efficiency

4.4.1 Objective

The objective of the test is to measure the efficiency of the device at multiple load conditions. Two methods are used; instantaneous and cumulative (24-hour).

4.4.2 Setup

Table 6 lists the equipment used. Figure 9 illustrates the how the equipment is connected.

Table 6. Set-Up

Load Description	Equipment	Parameters to be Monitored
Variable resistive load	• Pacific Power Source • Voltech PM-100 Power Analyzer	• Input: Voltage, Current, Power • Power Factor • Output: Voltage, Current, Power

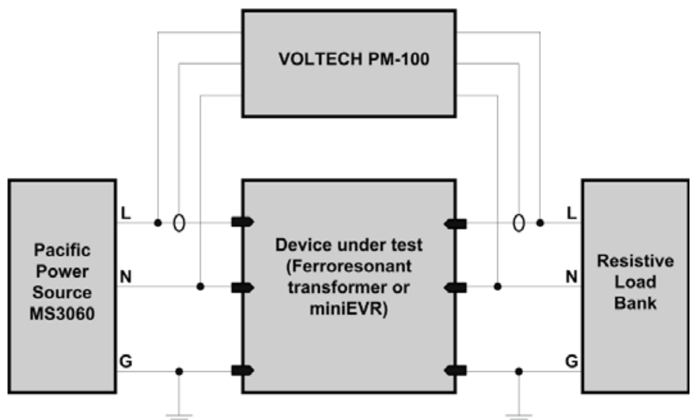


Figure 9. Test Set-Up for Efficiency Measurement

4.4.3 Procedure

The procedure is as follows:
Part A:

1. Use the test setup shown in Figure 9 with the devices listed in Table 6.

1. Configure the device for operation at 600 W.

2. Set the source voltage at 120 V.

3. Incrementally increase the voltage from 96 V to 132 V. Monitor and take readings of the input and output power.

4. Repeat steps three and four with the following loads: 1200 W, 1800 W, 2400 W, and 3,000 W.

Part B:

5. Set the input voltage at 120 V. Set the output load for 1500 W. Log total input energy consumption for 24 hours.

4.4.4 Expected Results

SOLA CVS: The claimed maximum efficiency of the SOLA CVS transformer is 92% according to the specifications (appendix D)

Mini-EVR™: The claimed efficiency of the Mini-EVR™ is 99% (appendix E).

4.4.5 Results (Part A)

The data in Table 7 list the results of the efficiency measurement for the SOLA CVS for various input voltages and loading conditions. Figure 10 shows a plot of the data.

Table 7. Test 2 Data of SOLA CVS Showing the Efficiency of the Device at Various Operating Points

Vin	Eff. at 600 W	Eff. at 1200 W	Eff. at 1800 W	Eff. at 2400 W	Eff. at 3000 W
96	73.09	83.93	87.83	89.80	90.70
97	73.01	83.88	87.82	89.77	90.70
98	72.90	83.82	87.79	89.77	90.72
99	72.81	83.78	87.77	89.75	90.72
100	72.71	83.72	87.75	89.73	90.72
101	72.60	83.66	87.71	89.73	90.71
102	72.50	83.60	87.65	89.69	90.72
103	72.40	83.53	87.62	89.67	90.71
104	72.29	83.47	87.57	89.65	90.70
105	72.19	83.38	87.54	89.64	90.70
106	72.06	83.27	87.50	89.62	90.68
107	71.94	83.26	87.37	89.59	90.68
108	71.81	83.19	87.39	89.56	90.67
109	71.70	83.10	87.34	89.52	90.65
110	71.59	83.03	87.29	89.49	90.64
111	71.47	82.96	87.25	89.50	90.62
112	71.33	82.88	87.20	89.45	90.61
113	71.20	82.79	87.15	89.39	90.56
114	71.10	82.71	87.09	89.37	90.60
115	70.95	82.64	87.03	89.33	90.55
116	70.83	82.54	86.96	89.28	90.52
117	70.68	82.46	86.91	89.23	90.49
118	70.54	82.36	86.86	89.20	90.47
119	70.40	82.28	86.78	89.15	90.44
120	70.26	82.17	86.72	89.10	90.41
121	70.10	82.08	86.64	89.04	90.41
122	69.94	81.97	86.56	89.00	90.32
123	69.78	81.86	86.50	88.93	90.29
124	69.58	81.75	86.43	88.88	90.26
125	69.43	81.71	86.32	88.83	90.21
126	69.25	81.52	86.25	88.75	90.16
127	69.04	81.36	86.14	88.67	90.15
128	68.85	81.24	86.03	88.60	90.04
129	68.64	81.10	85.95	88.52	89.96

Vin	Eff. at 600 W	Eff. at 1200 W	Eff. at 1800 W	Eff. at 2400 W	Eff. at 3000 W
130	68.40	80.94	85.83	88.42	90.17
131	68.18	80.77	85.71	88.34	89.87
132	67.94	80.60	85.59	88.24	89.79

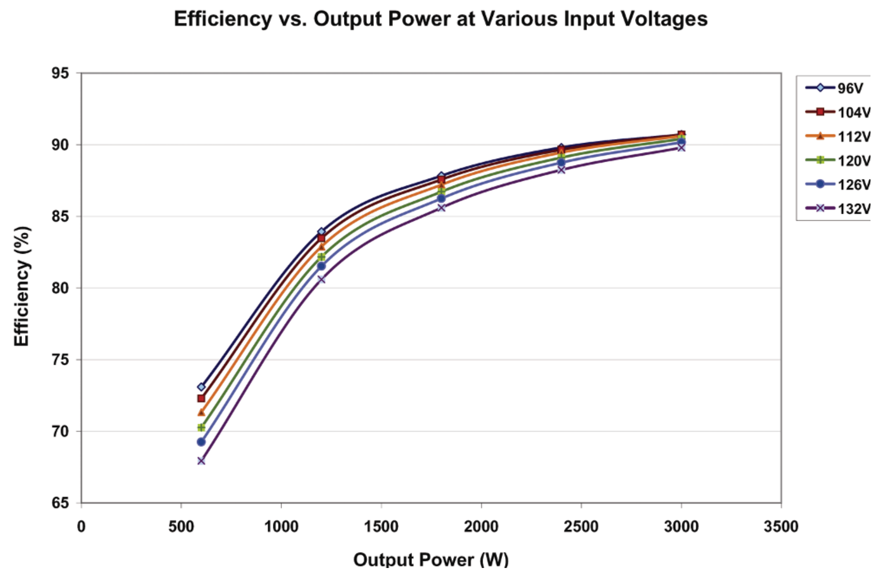


Figure 10. Efficiency of the SOLA CVS as a Function of Output Power

The data in Table 8 list the results of the efficiency measurement for the Mini-EVR™ for various input voltages and loading conditions. Figure 11 shows a plot of the data.

Table 8. Test 2 Data of Mini-EVR™ Showing the Efficiency of the Device at Various Operating Points

Vin	Eff. at 600 W	Eff. at 1200 W	Eff. at 1800 W	Eff. at 2400 W	Eff. at 3000 W
96	94.84	96.23	96.31	96.01	95.52
97	94.93	96.15	96.33	95.96	95.52
98	94.89	96.23	96.35	96.05	95.52
99	94.84	96.15	96.27	95.97	95.48
100	94.93	96.18	96.34	96.59	96.15
101	95.58	96.64	96.84	96.55	96.15
102	95.52	96.78	96.85	96.65	96.16
103	95.61	96.76	96.81	96.56	96.17
104	95.69	96.75	96.82	96.41	95.86
105	96.04	96.90	96.76	96.43	95.82
106	95.95	96.80	97.30	96.38	95.83
107	96.03	96.81	96.78	96.36	95.84
108	96.10	96.83	96.73	96.39	95.85
109	96.02	96.81	96.74	96.41	95.83
110	96.09	96.79	96.74	96.84	96.44
111	96.36	97.23	97.21	96.86	96.43

Vin	Eff. at 600 W	Eff. at 1200 W	Eff. at 1800 W	Eff. at 2400 W	Eff. at 3000 W
112	96.59	97.28	97.20	96.87	96.40
113	96.49	97.17	97.15	96.89	96.43
114	96.39	97.30	97.19	96.90	96.43
115	96.46	97.27	97.14	96.87	96.39
116	96.67	97.24	97.19	96.89	96.45
117	96.57	97.21	97.19	96.87	96.45
118	96.49	97.25	97.23	97.27	96.83
119	96.57	97.44	97.47	97.24	96.82
120	96.63	97.40	97.46	97.20	96.87
121	96.68	97.36	97.45	97.21	96.86
122	96.58	97.40	97.44	97.21	96.81
123	96.33	97.37	97.48	97.22	96.68
124	96.54	97.41	97.42	97.18	96.70
125	96.60	97.45	97.40	97.23	96.84
126	96.05	97.07	97.10	96.90	96.50
127	95.95	96.96	97.10	96.83	96.43
128	96.02	96.92	97.09	96.84	96.48
129	95.92	96.97	97.08	96.85	96.47
130	95.83	97.01	97.07	96.89	96.46
131	95.90	97.06	97.12	96.86	96.45
132	96.10	97.03	96.96	96.83	96.48

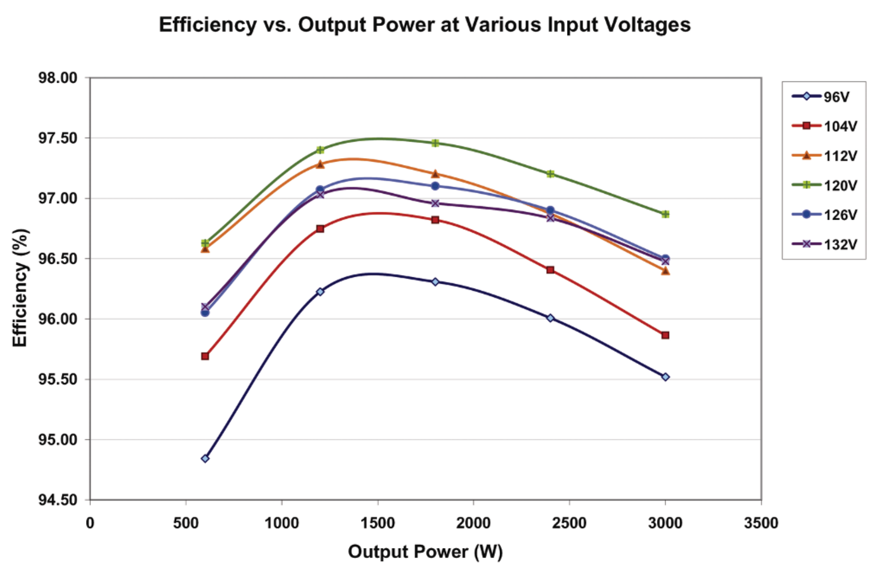


Figure 11. Plot of Mini-EVR™ Efficiency as a Function of Output Power

4.4.6 Results: Part B

The data in Table 9 lists the results of the 24-hour efficiency measurement for the SOLA CVS and Mini-EVR™ at 50% loading.

Table 9. Test Results of Part B Showing the Efficiency of SOLA and Mini-EVR™ Averaged Over a 24-Hour Period

Device Name	Input Voltage (V)	Connected Load (W)	Time Duration (H)	Input Energy (W-hr)	Output Energy (W-hr)	Energy Efficiency @ 1500 W (%)
SOLA CVS	120	1500.9	24	42331	35870	84.7
Mini-EVR™	120	1494.6	24	36801	35900	97.6

4.4.7 Summary.

The efficiency results are summarized in Table 10.

Table 10. Summary of Efficiency Results

Device Name	Claimed Efficiency	Maximum Efficiency Found in the Test	Minimum Efficiency Found in the Test	24 hour Energy Efficiency @ 1500 W (%)
SOLA	92% (maximum)	90.72% @ 3000 W	67.94% @ 600 W	84.7
Mini-EVR™	99%	97.48% @ 1800 W	94.84% @ 600 W	97.6

4.5 Response Time

4.5.1 Objective

The objective of this basic performance test is to measure the response time of the device under test when subjected to a temporary undervoltage (sag) and overvoltage (swell) [1].

4.5.2 Setup

Table 11 lists the equipment used. Figure 12 illustrates how the equipment is connected.

Table 11. Test set-up.

Load Description	Equipment	Parameters to be Monitored
Variable resistive load	• Caterpillar Generator • 100-A sag/swell generator • Nicolet Vision	• Input voltage waveform • Output voltage waveform

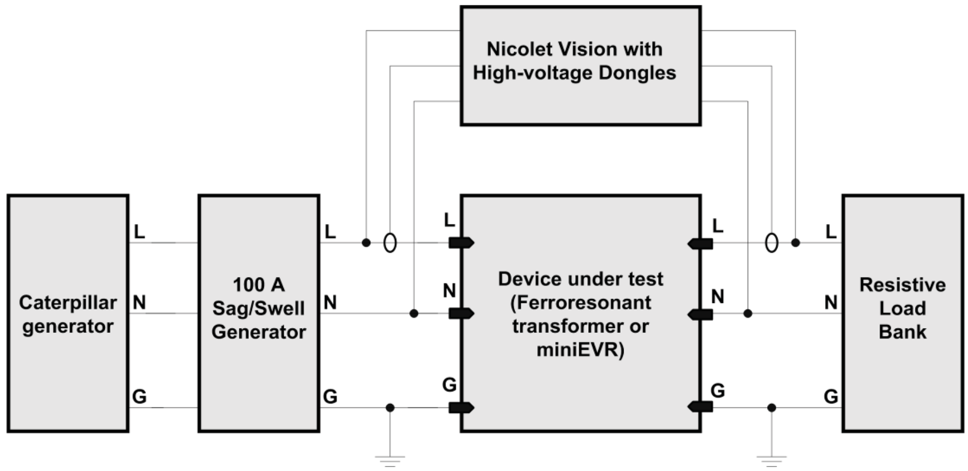


Figure 12. Setup for Test of Response Time

4.5.3 Procedure

1. Use the test setup shown in Figure 12 with equipment listed in Table 11.

Part A (Sag):

2. At no load, configure the sag/swell generator for 75% of nominal voltage (90 VRMS).
3. In the software of the sag/swell generator, set the sag duration for five cycles starting at 0 degrees.
4. Initiate the sag.
5. Record the waveforms of the input and output voltage before, during, and after the event (sag or swell).

Part B (Swell):

6. Configure the sag/swell generator at 150% (180 VRMS) of nominal voltage.
7. In the software of the sag/swell generator, set the duration for five cycles starting at 0 degrees.
8. Initiate the swell.
9. Record the waveforms of the input and output voltage before, during, and after the event (sag or swell).
10. Repeat steps two to nine for load settings of 25%, 50%, 75%, and 100 % (750 W, 1500 W, 2250 W, and 3000W)

4.5.4 Expected Results

It is unclear from the specifications for the SOLA CVS (appendix D) how the unit may respond. The manufacturer's specifications for the Mini-EVR™ indicate one cycle typical (1.5 cycle max) regardless of load or load power factor (appendix E).

4.5.5 Results: Part A (Sag)

SOLA CVS: Figure 13 shows the input and output voltages of a SOLA CVS for 50% (1500 W) loading. Figure 14 shows the input and output voltages for 100% (3000 W) loading.

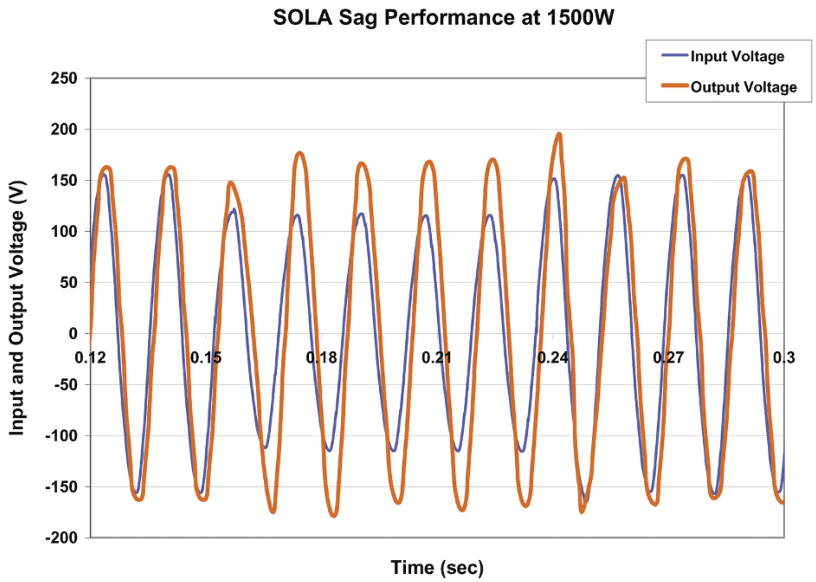


Figure 13. SOLA CVS Input and Output Voltage Waveforms at 1500 W Loading; Before, During, and After a Voltage Sag of 5-Cycle Duration

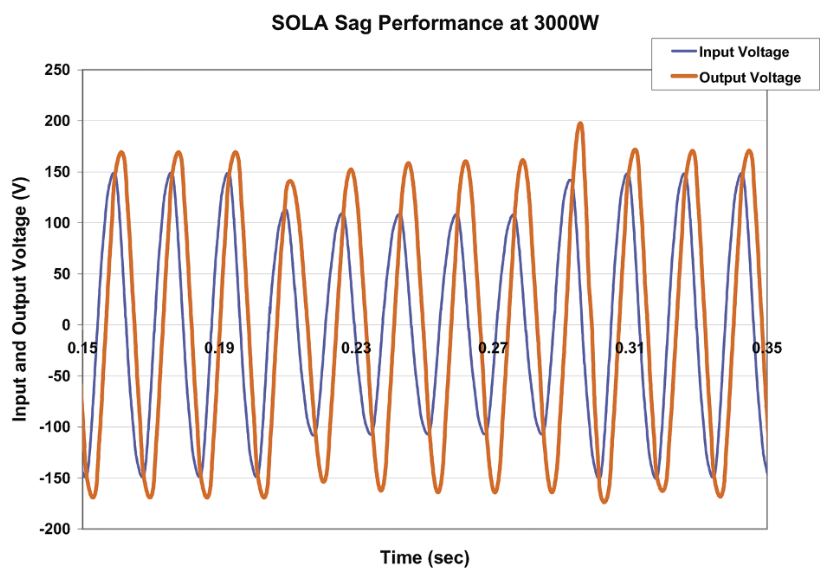


Figure 14. SOLA CVS Input and Output Voltage Waveforms at 3000 W Loading; Before, During, and After a Voltage Sag of 5-Cycle Duration

Mini-EVR™: Figure 15 shows the input and output voltages of a Mini-EVR™ for 50% (1500 W) loading condition. Figure 16 shows the input and output voltages for 100% loading condition.

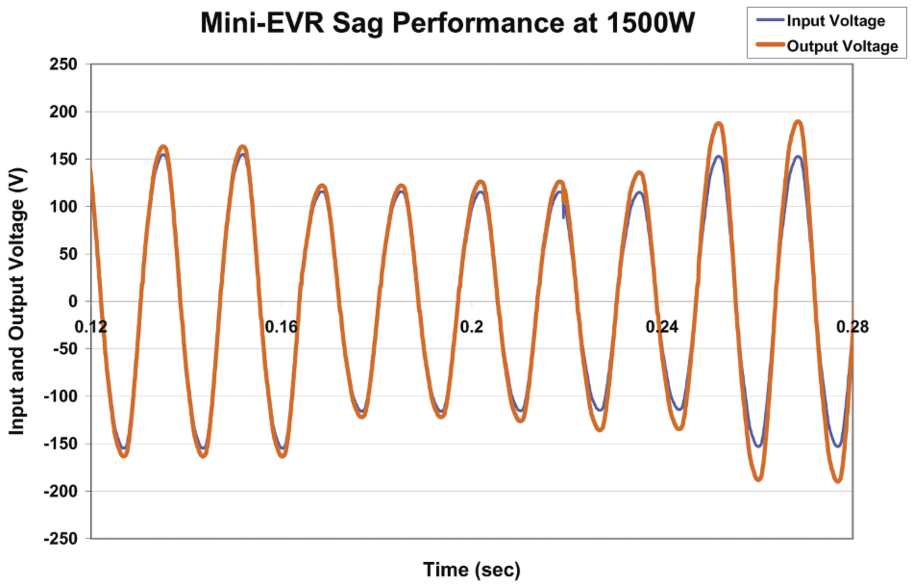


Figure 15. Mini-EVR™ Input and Output Voltage Waveforms at 1500 W Loading; Before, During, and After a Voltage Sag of 5-Cycle Duration

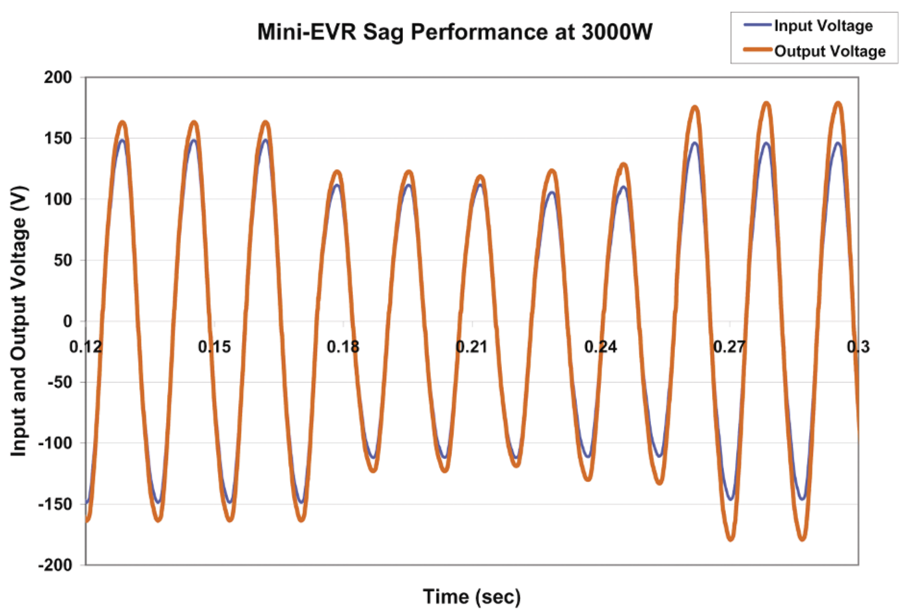


Figure 16. Mini-EVR™ Input and Output Voltage Waveforms at 3000 W Loading; Before, During, and After a Voltage Sag of 5-Cycle Duration

4.5.6 Results: Part B (Swell)

SOLA CVS: Figure 17 shows the input and output voltages of a SOLA CVS for 50% (1500 W) loading condition. Figure 18 shows the input and output voltages for 100% loading condition.

Figure 17. SOLA CVS Input and Output Voltage Waveforms at 1500 W Loading; Before, During, and After a Voltage Swell of 5-Cycle Duration.

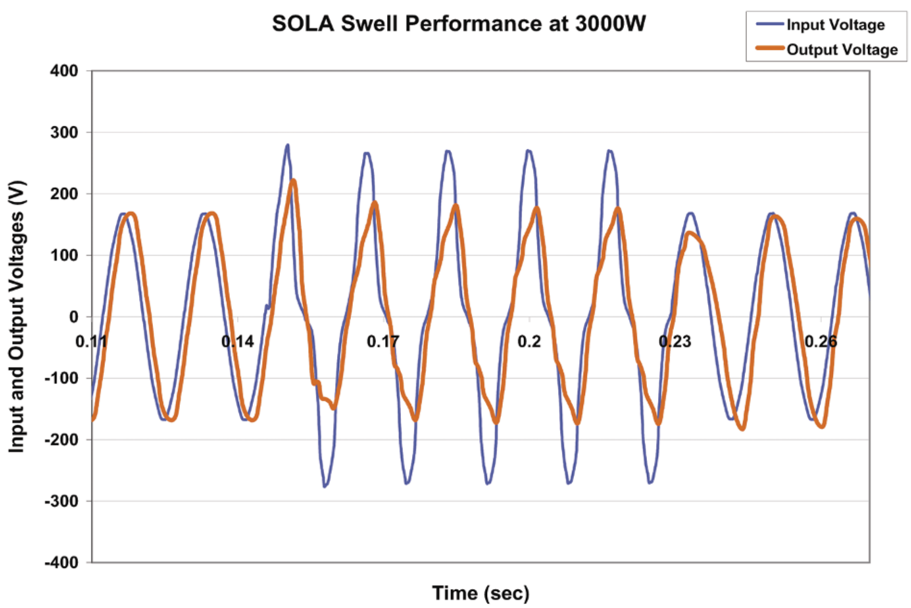


Figure 18. SOLA CVS Input and Output Voltage Waveforms at 3000 W Loading; Before, During, and After a Voltage Swell of 5-Cycle Duration.

Mini-EVR™: Figure 19 shows the input and output voltages of a Mini-EVR™ for 50% (1500 W) loading condition. Figure 20 shows the input and output voltages for 100% loading condition.

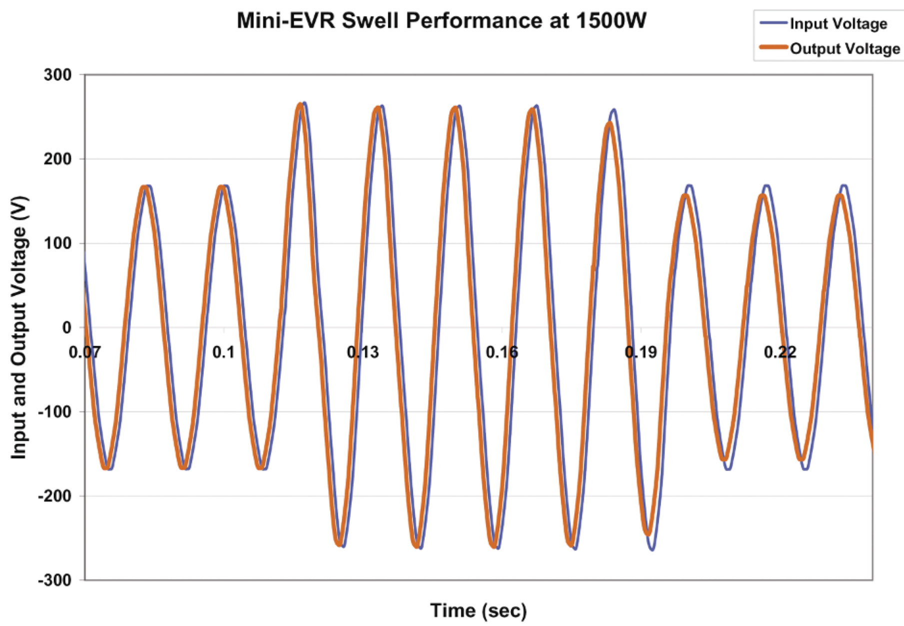


Figure 19. Mini-EVR™ Input and Output Voltage Waveforms at 1500 W Loading; Before, During, and After a Voltage Swell of 5-Cycle Duration.

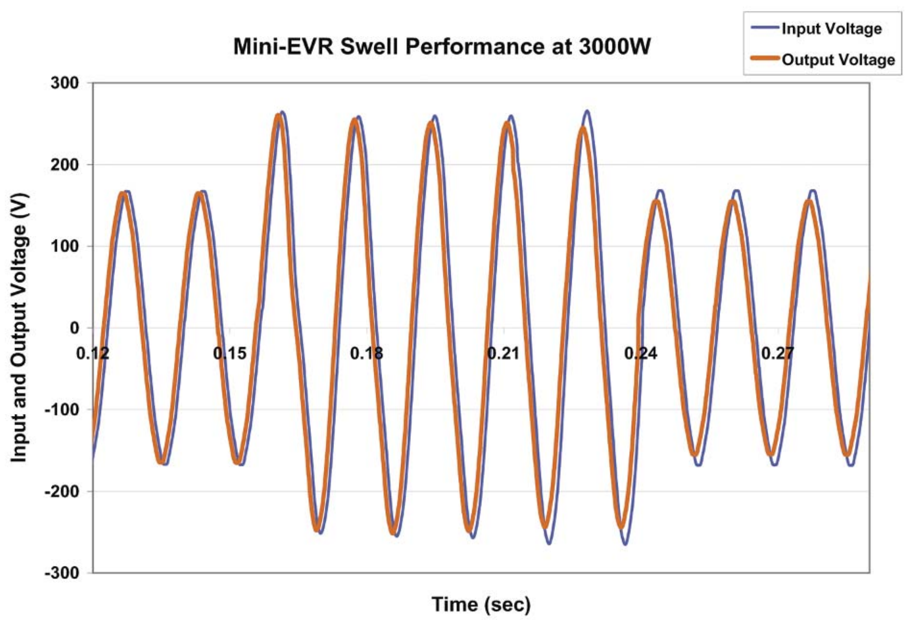


Figure 20. Mini-EVR™ Input and Output Voltage Waveforms at 1500 W Loading; Before, During, and After a Voltage Swell of 5-Cycle Duration.

4.5.7 Summary

The results of the sag and swell testing are summarized in Table 12.

Table 12. Summary of the Voltage Sag/Swell Testing

	SOLA CVS	Mini-EVR™
Test 3: Response Time Claimed response time	Not specified.	1 cycle typical (1.5 cycle max) regardless of load or load power factor
Measured response time during a temporary (5 cycle) undervoltage	Within 1.5 cycles	5 cycles @ 1.5 kW 4 cycles @ 3 kW
Measured response time during a temporary (5 cycle) overvoltage	Within 1.5 cycles	Greater than 5 cycles at both 1.5 kW and 3 kW

4.6 COMPREHENSIVE TESTING SUMMARY

Results of all tests for the SOLA CVS and Mini-EVR™ are provided in Table 13.

Table 13. Result Summary.

	SOLA CVS	Mini-EVR™
Test 1: Operational Voltage Range Claimed maximum variation at the output Measured maximum variation at the output	 ±1% ±2.68%	 ±3% ±4.34%
Test 2: Efficiency Claimed maximum efficiency Measured maximum efficiency (instantaneous) Measured efficiency (24-hour)	 92% 90.72% @ 3 kW 84.74% @ 1.5 kW	 99% 97.47% @ 1.8 kW 97.55% @ 1.5 kW
Test 3: Response Time Claimed response time	Not specified.	1 cycle typical (1.5 cycle max) regardless of load or load power factor
Measured response time during a temporary (5 cycle) undervoltage	Within 1.5 cycles	5 cycles @ 1.5 kW 4 cycles @ 3 kW
Measured response time during a temporary (5 cycle) overvoltage	Within 1.5 cycles	Greater than 5 cycles at both 1.5 kW and 3 kW

5
TEST RESULTS -USES

5.1 EXECUTIVE SUMMARY

EPRI conducted an on-site analysis of a retrofit energy-savings device (RESD) manufactured by USES Manufacturing Incorporated (USES). The device tested was a Model CMES-3D/480 Power-Enhancement Device. Testing was conducted on site in an operational Waste Water Treatment Plant (WWTP) in Glens Falls, New York. A 186 kW (250 HP) motor load in the facility operated in parallel with a pair of USES devices selected for evaluation. The power consumption and other electrical parameters for the motor load were measured with and without the USES devices in circuit. Data collected indicates the USES device is capacitive in nature and thus provides power factor correction for the motor load. Measurement of total power consumed by the motor load indicated that the USES device did not change power consumption within the measurement capabilities of the test instrumentation. A standard deviation for the motor-load power measurements of less than 0.34% was measured for six sets of data taken with and without the USES devices (two data sets for no USES device; two data sets with 1 USES device; and two data sets with two USES devices). Plots of the data indicated a drift in the measured power that stabilized after about 40 minutes of system operation. The last four sets of data collected exhibited a standard deviation of measured power of less than 0.1%. Voltage and current distortion were unaffected by the USES devices. Accuracy of the power measurement was calculated to be better than 1%.

5.2 OVERVIEW

This report summarizes the in situ evaluation of the USES Model CMES-3D/480 Power-Enhancement Device (Figure 21). The evaluation was conducted on-site at the Glens Falls, New York Waste Water-Treatment Plant (WWTP) on October 28th and November 10th of 2008.

Figure 21. USES A.C. Power Conditioner Label

5.3 WASTE WATER-TREATMENT FACILITY INSTALLATION DETAILS

There are five USES devices installed and in operation at the Glens Falls, New York Waste Water-Treatment Facility.

The USES devices are deployed as follows:

- One USES device is installed on a 56 kW (75-hp) compressor motor system for the incinerator.
- Two USES devices are installed on a 186 kW (250-hp) fluidizer bed blower motor system for the incinerator.
- Two USES devices are installed on MCC, -4A and -4B (see Figure 22), serving the main building.

Power is provided as 480 Vac, three-phase delta.

The 56 kW compressor runs with a variable load and is in an area prone to water spillage. Because of the non-constant loading of the compressor and the water spillage issue, evaluation of this USES device was not conducted.

The 186 kW fluidizer bed blower operates at full speed with a nearly constant load when in operation. An air intake throttle valve, which is adjusted once or twice per 8-hour shift, has a minor impact on the loading of the blower. Given the near constant load profile, this blower was chosen to be instrumented for USES device performance evaluation.

The two final USES devices are installed at MCC-4A and -4B (Figure 22) and would be difficult to instrument because breaking wiring connections would require dropping power to the entire building.

Wiring diagrams for the WWTP USES device installations are shown in Figure 22 through Figure 24. Figure 22 shows a facility one-line diagram. Figure 23 shows the local wiring for the 186 kW fluidizer bed blower. Figure 24 shows the power feed detail for the 56 kW compressor. The 186 kW fluidizer bed blower is fed from MCC-B indicated as *[A]* in Figure 22. The blower control box feed resides at *[B]* in Figure 22 (also shown in Figure 23). The 56 kW compressor is fed from MCC-4A indicated as *[C]* in Figure 22. In order to capture potential energy savings gained by reduction of harmonic currents in wiring, it was initially planned that data would be collected near the mains transformer at point *[A]* in Figure 23 for the 186 kW fluidizer bed blower. During the second on site visit, review of the facility indicated that collection of data at location *[A]* would be problematic. This location was outdoors in an uncovered location and combined access to both the 480 V circuits and the medium voltage feed to the facility. The combination of rain and the potential exposure to medium voltage wiring led to the decision to only meter data at location *[B]*. Metering power at location *[A]* would have also been complicated by additional loads also fed from MCC-B. These loads included:

- Two each: ash pumps; 12 kW (15 hp); cycling on/off at 15-minute intervals
- One each: sludge cake pump; 15 kW (20 hp); on during incinerator operation
- Outside cake-handling equipment, which can be turned off during our tests

These additional loads would have caused power fluctuations in measured data that would need to be accounted for in the USES device on/off comparison tests. Measurement at location *[B]* in Figure 23 allowed for a stable load to be monitored while switching the USES devices in and out of the circuit.

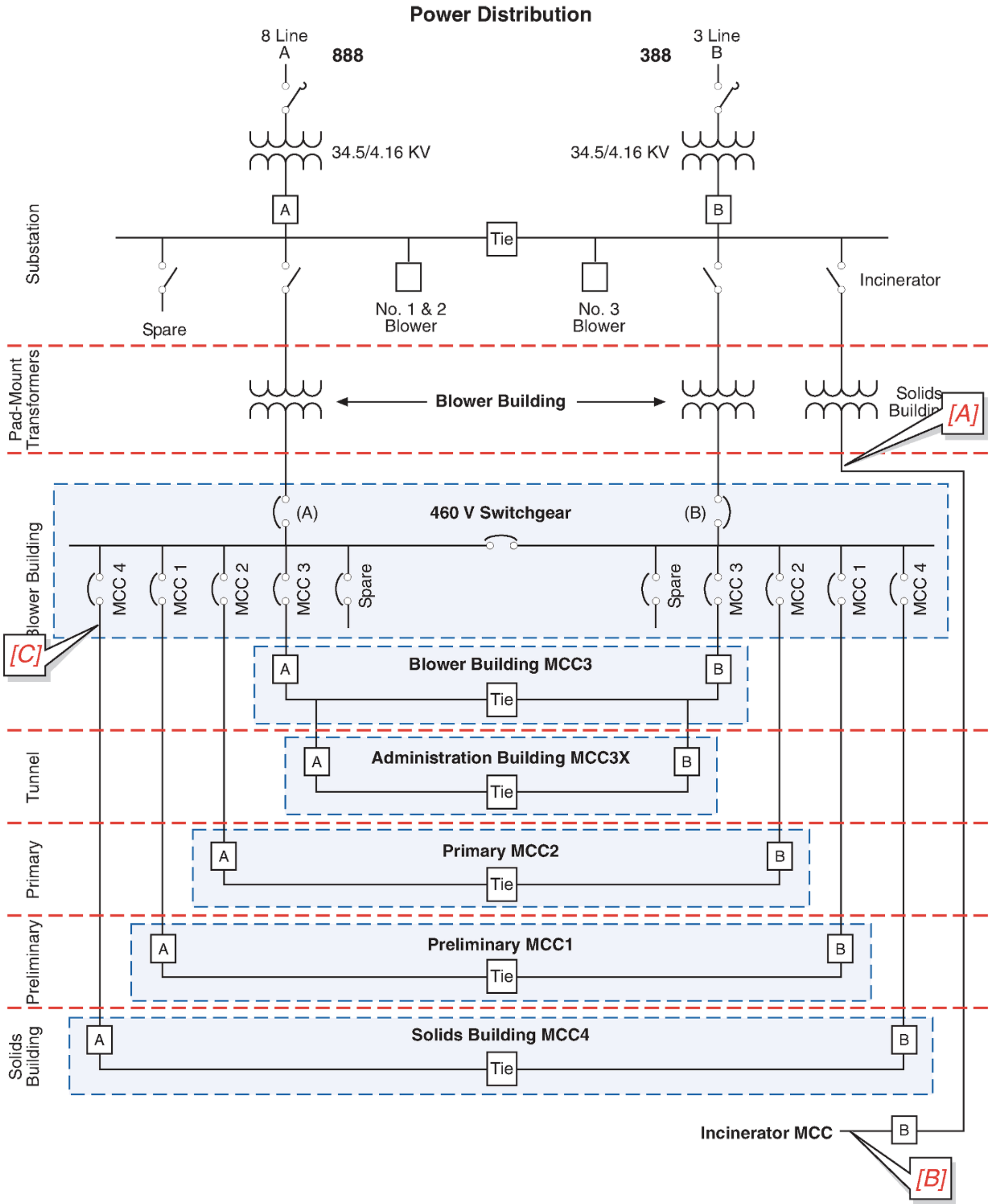


Figure 22. Glens Falls WWTP Main Power Distribution One-Line Diagram

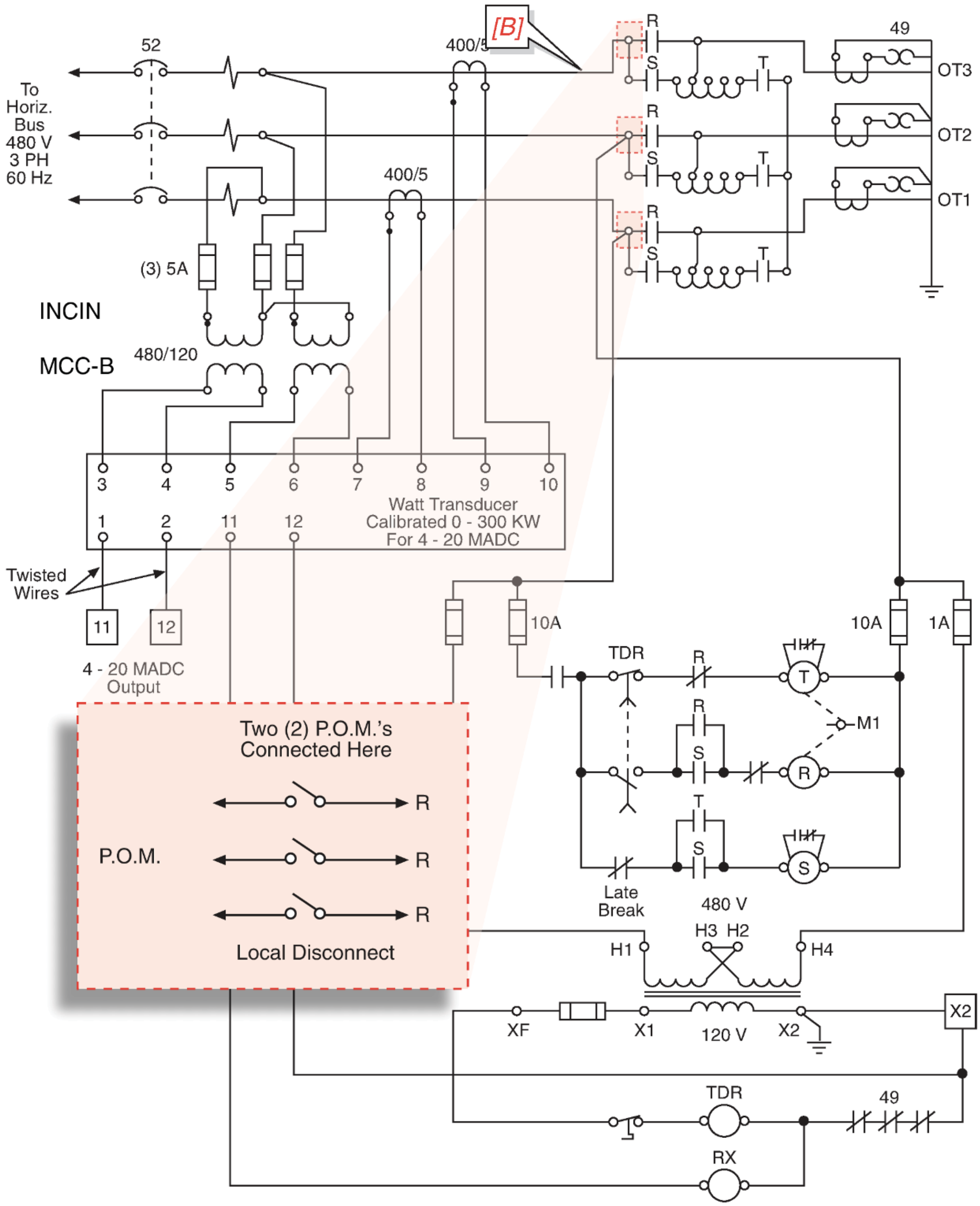


Figure 23. 186 kW (250-hp) Blower Motor Installation Wiring Diagram (P.O.M. Refers to the USES Device)

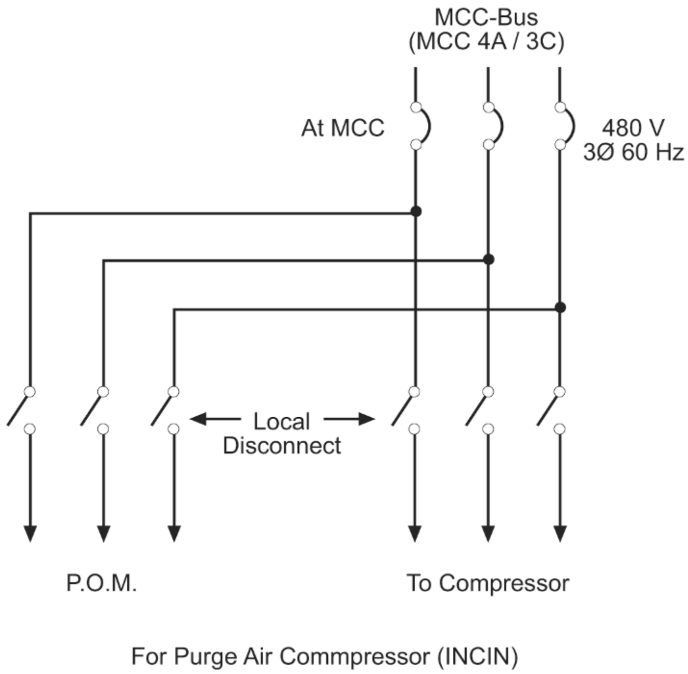


Figure 24. 56 kW (75-hp) Compressor Motor Wiring Diagram

5.4 FIELD DATA COLLECTION LOCATION

Three on-site visits to the Waste Water Treatment Plant were conducted. The first visit resulted in the initial test plan used during the following two visits. The second visit was used to collect and analyze data. The third visit allowed for additional data collection.

As previously stated, data was collected only for location *[B]*, which is shown in Figure 25. The Power Factor Correction (PFC) cabinet located to the right of the motor control cabinet was found to be non-functional and was disconnected during testing.

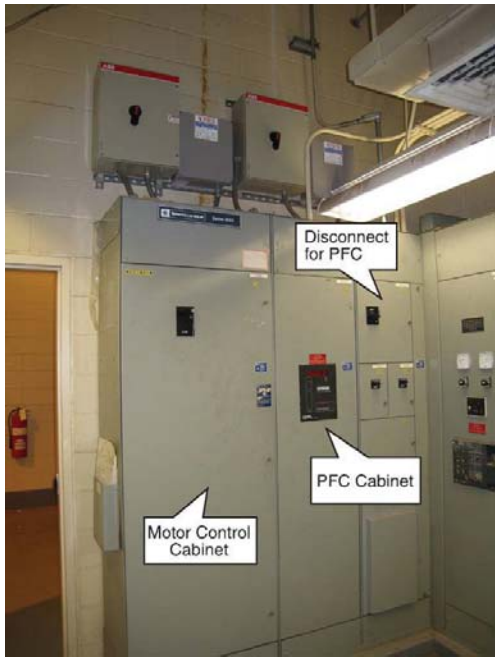


Figure 25. Exterior of 186 kW Motor Control Cabinet (The Two USES Devices can be seen above the Motor Control Cabinet)

Figure 26 shows a photograph of the interior of the 186 kW motor control cabinet described in Figure 23 and shown in Figure 25.

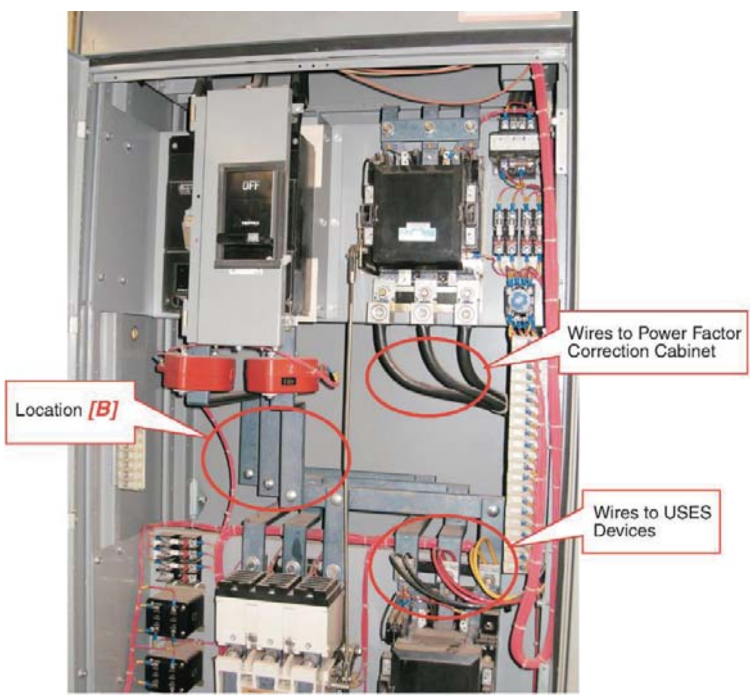


Figure 26. Interior of the Motor Control Cabinet for the 186 kW Motor (Location *[B]* in Figure 23)

Figure 27. Close Up View of Wiring to the USES Devices

A large three conductor bus bar constitutes location *[B]* as shown in Figure 26. The parallel connections to the two USES devices can be seen to the lower right of the photo (black, red and yellow wires) and in the close-up view of Figure 27.

EPRI test equipment was installed in such a way that cabinet doors were closed during data collection to ensure safety.

During the second visit to the Waste Water Treatment Facility on October 28th, equipment issues limited the useful data collected. The trip proved to be very useful in determining where and how to collect the data on the third visit. All data reported in the following sections (with the exception of motor temperature data) were taken on the third visit to the facility (November 10th).

No photos of the interior of the USES devices were taken as the USES device enclosures were secured with “tamper-proof” security screws and tape labels indicating that if the units were opened the warranty would be voided. The USES device is patented under US Patent # 5,105,327.

Figure 28. USES Case Detail Showing Security Screws and Tape Seal

5.5 TEST PROCEDURES

Five key tests were identified for this evaluation. This set of five tests was broken down into two test procedures within the test plan. The first test and its related test procedure were combined. The remaining four tests were combined in a single test procedure in order to streamline data collection. Each test was independently described within the procedure allowing the rationale, purpose, and expectations for each test to be clearly enumerated. The combining of data collection for the last four tests minimized the need to reconfigure the test hardware and allowed a more efficient use of the WWTP facility time. Data-collection log sheets were used as a guide during performance of the test procedures. A general notebook was maintained for logging operator notes, sketches, and any other material pertinent to documenting the data. A digital camera was used to document the hardware test setups whenever applicable.

While many of the parameters to be measured are closely related, such as distortion to wiring losses and efficiency or power factor to total current, parameters were individually measured and recorded.

There were two USES devices located at the 186 kW fluidizer bed blower. These devices were wired in parallel (shunt) with the motor load. Within the test plan, whether one or both of the USES devices are connected at the blower, the descriptions use the term “USES device” (the singular form) for clarity.

5.6 BASELINE POWER MEASUREMENT TEST PROCEDURE

5.6.1 Rationale

This test is performed to quantify the power consumption stability of the 186 kW fluidizer bed blower. Referring to Figure 22, it is known that several ancillary loads share the 186 kW blower power feed at *[A]*. Also, the airflow provided by the blower is adjusted and may impact load power at *[A]* and *[B]*. The impact of these variations on power stability will be assessed.

Metering power at location *[A]* will be complicated by additional loads that are also fed from MCC-B. These loads include:

- two-each Ash Pumps; 12 kW (15 hp); cycling on/off at 15-minute intervals
- one-each Sludge Cake Pump; 15 kW (20 hp); on during incinerator operation
- Outside Cake-Handling equipment

The Outside Cake-Handling equipment will be turned off during testing. The remaining additional loads must be accounted for in the USES device on/off comparison tests. Power measurements at location *[A]* may require synchronization with the two Ash Pumps because their cycle time is shorter than the anticipated data collection time for power and energy.

Metering power at location *[B]* will be impacted by airflow adjustments made to the 186 kW fluidizer bed blower during operation. These adjustments are generally done only once or twice per eight hour shift and therefore should be readily accommodated during testing. An instrumentation signal is available from the airflow controls that can be monitored to note the state of the airflow. If possible, this signal will be included in the logged data during testing.

5.6.2 Purpose

1. Establish a baseline of power consumption and energy usage for the 186 kW fluidizer bed blower.

2. Characterize the power measurement statistics (mean, max, min, and standard deviation) to quantify expected variation of power measurements in the facility especially at location *[A]*.

3. Quantify the power fluctuation at location *[B]* in relation to the state of the blower airflow.

4. Measure power at locations *[A]* and *[B]* to allow characterization of ancillary loads and verify the proper operation of the data-acquisition hardware.

5. Establish a statistical base for understanding measured power data with and without the USES device.

5.6.3 Expected Results

Power measurements at location *[A]* will vary with ancillary loads. These will be characterized to establish the basic power measurement statistics. Power measured at location *[B]* should match the data from location *[A]* less the ancillary load and cable-loss power. The power measured at location *[B]* will vary only with the blower loading.

5.6.4 Test Procedure

(Use data log sheet for recording data and notes)

1. Disable all five USES devices in the facility (using disconnect switches at each device).

2. For safety, REMOVE SYSTEM POWER during installation of test hardware.

3. Install current transformers at location *[A]* in Figure 22 (see also Figure 29).

4. Use voltage probes to measure a known voltage to verify operation. Then install voltage probes at location *[A]* in Figure 22. Compare voltage readings with a calibrated handheld voltage meter. Record the rms voltage read by the handheld meter, the Fluke 43 and the Voltech PM3000.

5. With all USES devices disconnected, during operation of the 186 kW (250-hp) fluidizer blower, monitor the power at location *[A]*. Note the level of the power fluctuation and the time characteristics of the fluctuation. Record the rms power at 10-second, 60-second, and five-minute intervals from both the Fluke 43 and Voltech PM3000 meters. Take approximately 10 samples for each time scale. Store a screen shot from the Fluke 43 in scope mode showing the voltage and current on 10ms/div and 100ms/div time scales. Adjust the channel gains such that each trace spans at least two divisions. Use this data to establish the baseline power change that can be seen at location *[A]* and the time duration and timing needed to accumulate valid data statistics.

6. Crosscheck data from the Fluke 43 with the Voltech power analyzer.

7. With all USES devices disconnected and during operation of the 186 kW (250-hp) fluidizer bed blower, record voltage and current waveforms at location *[A]* using the Fluke 43. Store screen shots from the Fluke 43B for Power and Harmonic modes. Also record voltage, current, power, true power factor, displacement power factor, voltage THD, current THD, power, and integrated power (energy in kWh) at location *[A]* over the operation cycle from both the Fluke 43 (except energy) and the Voltech 3000. Energy data should be accumulated over the period of time and using the timing established in Step 5 using the Voltech PM3000.

8. Install current transformers at location *[B]* in Figure 23 (see also Figure 25).

9. Use voltage probes to measure a known voltage to verify operation. Then install voltage probes at location *[B]* in Figure 23. Compare voltage readings with a calibrated handheld voltage meter. Document the installation of the test equipment with digital photos.

10. With all USES devices disconnected and during operation of the 186 kW (250-hp) fluidizer bed blower, record voltage and current waveforms at location *[B]*. Also record voltage, current, power, true power factor, displacement power factor, voltage THD, current THD, power, and integrated power (energy in kWh) at location *[B]* over the operation cycle. Data should be accumulated over the period of time and using the timing established in Step 5. Record waveforms as noted in Steps 5 and 7.

11. Crosscheck data as in Step 6.

Test Setup Requirements: A Voltech PM3000A power analyzer will be used to make the primary test measurements. A Fluke 43-Powermeter will be used to record time domain voltage and current waveforms as well as provide a crosscheck of the PM3000A data. The Voltech power analyzer and the Fluke power meter should be installed in proximity to the cabinets at locations *[A]* and then at location *[B]*. Test locations will be documented with digital photographs and hand sketches of connections for use in the summary report. The test equipment setup completed under this portion of the test plan will be used for all other tests described in Procedure 2.

Equipment should be installed as shown in Figure 29. Prior to data collection, a calibrated handheld voltage meter will be used to verify the proper operation of the data-acquisition hardware (as in Steps 4 and 9, above).

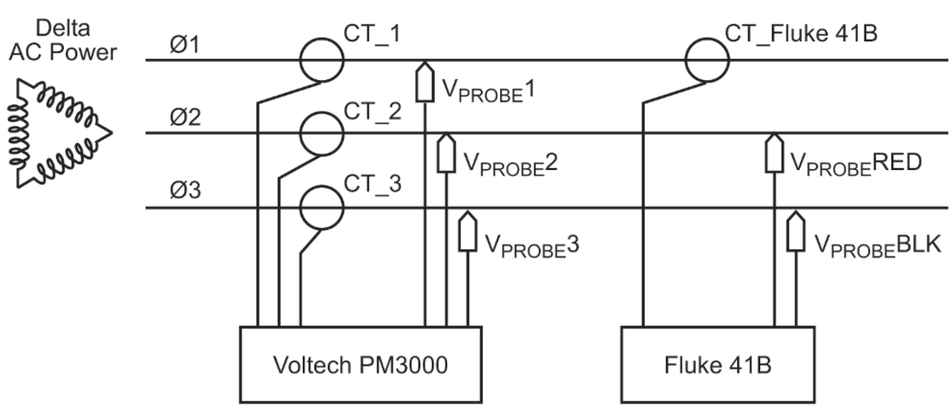


Figure 29. Test Equipment Installation Diagram

The actual installed locations of the test probes are shown in Figure 30 through Figure 32. During the field test, the Fluke 43 current probe was installed on Phase 3 with voltage probes on Phases 1 and 2. A ground reference connection was used to the PM3000 as pictured in Figure 32 (this connection is not shown in Figure 29).

Figure 30. Location of the Test Probes (Note that the Cables were Routed through the Lower Kick-Panel that was Removed During Testing)

Figure 31. Detail of Probe Location on Bus Bar. Terminal Block used for Voltage Monitor Probes was Verified to be Wired to the Main Bus Bar by Visual Inspection and by using an Ohmmeter.

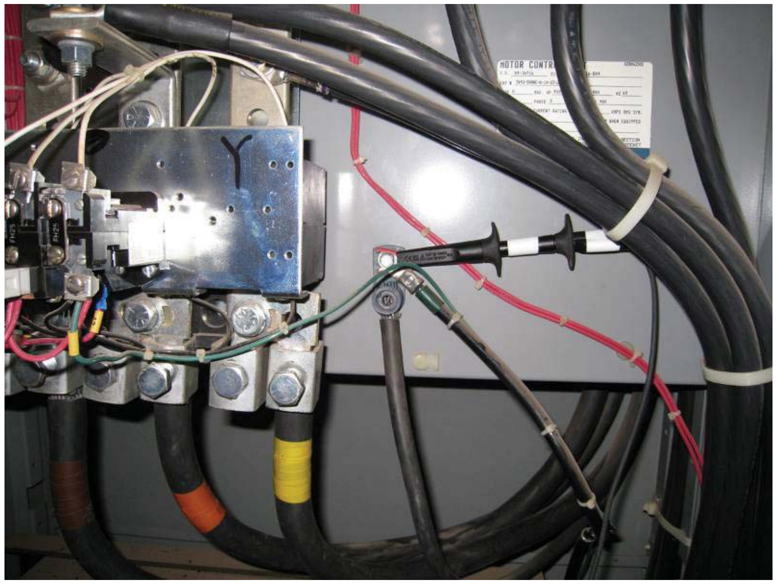


Figure 32. Detail of Ground Reference Connection to the PM3000 Analyzer

5.6.5 Deviations from Test Plan and Rationale

Data collection at location *[A]* was not performed due to the risk of exposure to medium voltage contained in a cabinet located in an outdoor location and wet weather. This eliminated Steps 3 through 7 of the procedure and the issue of time-varying ancillary loads impacting collected data.

In Step 10 the time scales were modified as it was found to be easier to visually monitor the PM3000 readout and note the variation of the parameters. Total energy data (integrated power in kWh) was logged over 10 minute intervals because it was observed that the power measurements were very steady (variation less than 1% over several minutes of observation).

5.6.6 Results

Voltage and current were crosschecked (illustrated in Figure 33) as per Step 11 at location *[B]* at 9:00 am, just after the blower was first started. The Fluke 43 reported 180.8 Arms and 469.9 Vrms. The PM3000 reported 178.43 Arms and 471.4 Vrms.

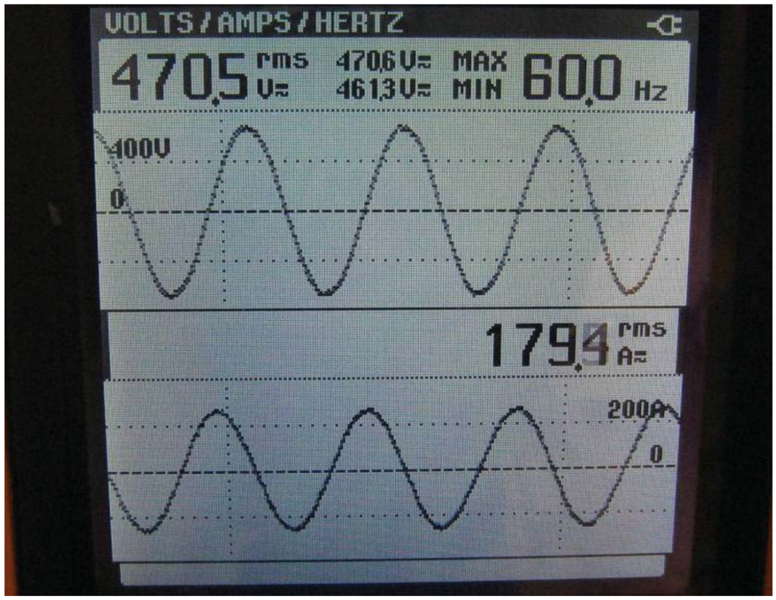


Figure 33. Fluke 43 Screenshot taken during Warm Up Period of Blower Showing the Bus Bar [B] Location Current (Bottom Trace) and Phase-to-Phase Voltage (Φ1-Φ2; Top Trace).

Ambient temperature at the motor control cabinet was noted at 25.5°C. Power drifted for the first several minutes the blower was operated. Table 14 shows the measured data values with variation noted over an approximately two-minute long window. The measurement was repeated six minutes later.

Table 14. Summary of Initial Measurements

Time	Voltage (Vrms)	Amps (Arms)	Power (kW)	Power Factor
9:13 am	468.5 +/- 0.2	193.0 +/- 0.2	143.0 +/- 0.5	0.912 steady
9:19 am			142.5 +/- 0.5	

Total power variation over the measured interval was approximately 1%. The power factor indicated an inductive load.

The peak values of the 3-phase voltages were recorded as:

VΦ1: 388.1 V

VΦ2: -387.0 V

VΦ3: 388.4 V

Values match within 0.4%.

The peak values of the 3-phase currents were recorded as:

IΦ1: 279.4 A

IΦ1: 282.6 A

IΦ1: 281.2 A

Values match within 1.2%.

Additional parameters recorded:

VA: 156k VA (nominal)

VAR: 63.9 kVAR (nominal)

Energy (power integrated over a 10 minute window) measured at 23.78 kWh for a time interval of 0.16663 hours (9.98 minutes). This gives an average power for the interval of 142.711 kW. This is within 0.6% of the instantaneous values recorded.

The Fluke 43 was used to record voltage and current after the power integration as a crosscheck. Values of 468.8 Vrms and 194.8 Arms were recorded.

This data indicated that the loading of the 186 kW blower motor was very stable and that the phases were well-balanced. Ten minute integration periods were used for the remainder of the data collection for total energy measurements. The blower motor is loaded at about 76% of capacity in normal operation.

5.7 COMBINED PARAMETER MEASUREMENT TEST PROCEDURE: VOLTAGE AND CURRENT WAVEFORMS AND THD MEASUREMENT

5.7.1 Rationale

Reduction of voltage distortion and current distortion within the electric power distribution system of a building is desirable because harmonic distortion can cause additional power losses in building wiring and, if severe enough, can cause equipment malfunctions. Reduction of total current also lowers the wiring losses in a building. A claimed benefit of the USES device [2] is the reduction of total current (related to power factor) and harmonic current (related to load distortion) of the voltage and current waveforms.

5.7.2 Purpose

1. Quantify voltage and current distortion properties with and without the USES device.
2. Quantify the total current with and without the USES device.
3. Use the collected data to verify the manufacturer's claim that the USES device reduces total current and harmonic distortion.

5.7.3 Expected Results

With the USES device connected, the voltage and current waveforms should show lower total and harmonic current (including lower THD) based on the manufacturer's claim [2]. The manufacturer does not make a specific claim for the total current or distortion reduction. Because the device adds capacitance to the circuit in shunt with the load, and because the load is inductive, it is expected that there will be some level of total and harmonic reduction. The measured values of the total current and distortion with and without the USES device will be recorded and reported. Figure 34 illustrates this approach.

5.7.4 Results

Voltage and current distortion values were found to vary with time. Values recorded were based on the maximum distortion value observed over an approximately two-minute interval. Values seen were as follows:

Without the USES devices in circuit

Vthd = less than 2%

Ithd = less than 3.5%

With one USES device in circuit

Vthd = less than 2.5%

Ithd = less than 4.2%

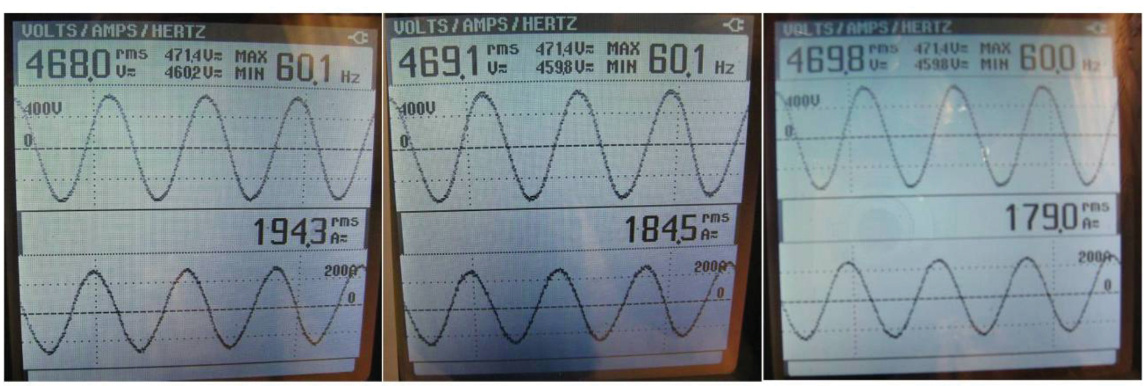
With two USES devices in circuit

Vthd = less than 2%

Ithd = less than 2.8%

Total current was reduced from 193.0 Arms with no USES devices, to 182.3 Arms with 1 USES device, to 175.9 Arms with two USES devices. The voltage at the motor control center also increased from 468.5 Vrms with no USES device, to 470.7 Vrms with one USES device, to 471.4 Vrms with two USES devices. This can be attributed to the increase in power factor from 0.912 with no USES devices, to 0.957 with one USES device, to 0.988 with 2 USES devices.

Based on the measured values, within our measurement error, there was no apparent impact on distortion for voltage or current with the USES devices. A reduction in total current and increase in input voltage was seen commensurate with the improvement in the total power factor of the blower motor load. This reduction in current to the motor control center is expected to result in a reduction in wiring losses in the feeder wiring. These wiring losses are dependent on the feeder wire sizing and length.



(A) (B) (C)

Figure 34. Voltage (Top Trace) and Current (Bottom Trace) Waveforms without the USES Devices (A); with One USES Device (B); and with Two USES Devices (C)

5.8 POWER AND ENERGY MEASUREMENT

5.8.1 Rationale

The ability to reduce the energy consumption of a process without impacting the performance of the process is desirable. Energy reduction without loss-of-process productivity adds directly to an operator's bottom line, lessens the environmental impact of the process, and lowers the power demand seen by the utility. As per the USES Web site, one stated benefit of the USES device is that it lowers the power and energy demand of an inductive load. [2]

5.8.2 Purpose

1. Quantify power consumption at locations *[A]* and *[B]* with and without the USES device.
2. Quantify the power and energy reduction provided by the device.
3. Use the collected data to verify the manufacturer's claims or described benefit that the USES device lowers power (kW) demand and lowers energy (kWh) demand.

5.8.3 Expected Results

With the USES device connected, the measured power and energy should be reduced in comparison to the power and energy measured without the USES device based on the benefits of the USES device provided on the manufacturer's Web site.[2][3] The device data sheet indicates that the power and energy savings will be "load dependent." The measured levels of power and energy will be recorded and reported with and without the USES device connected.

5.8.4 Results

Power measurements for location *[B]* are summarized in Table 15. Figure 35 shows a plot of the average power for each of the six-10-minute intervals for which data were collected.

Table 15. Summary of Power Data for Location *[B]*

Data Set	Energy (kWh)	Avg. Power (kW)	Voltage (Vrms)	Current (Arms)	PF
1 – no USES devices	23.78	142.71	468.5	193.0	0.912
2 – 1 USES device	23.70	142.23	470.7	182.3	0.957
3 – 2 USES devices	23.59	141.53	471.4	175.9	0.988
4 – no USES devices	23.62	141.68	468.6	191.5	
5 – 1 USES device	23.58	141.44	469.6	181.8	0.957
6 – 2 USES devices	23.62	141.71	470.3	175.8	0.988

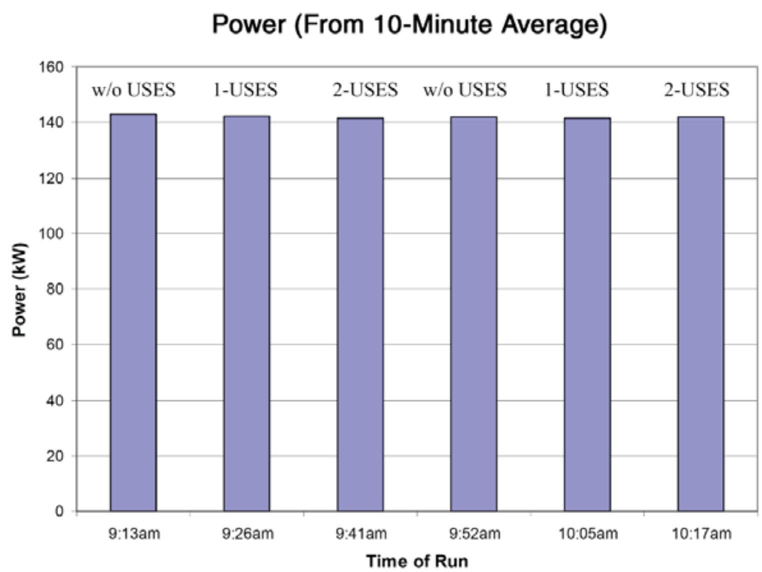


Figure 35. Power Averaged over 10-minute Intervals for 6-Data Runs

The mean value of power for all data sets was calculated as 141.88 kW. The power data is re-plotted in Figure 36 in percent variation from this mean value. The standard deviation of the power measurement was 0.34% for all six data sets. What can be seen from Figure 36 is that the measured blower motor power decreased over the first three data sets and then remained relatively constant over the remaining four data sets. The small (less than 1%) drift in the early data sets could be due to changes in the motor performance as it heats up or due to drift in the current transformer outputs (CTs) when they are exposed to the heating of the bus bar in the motor control center.

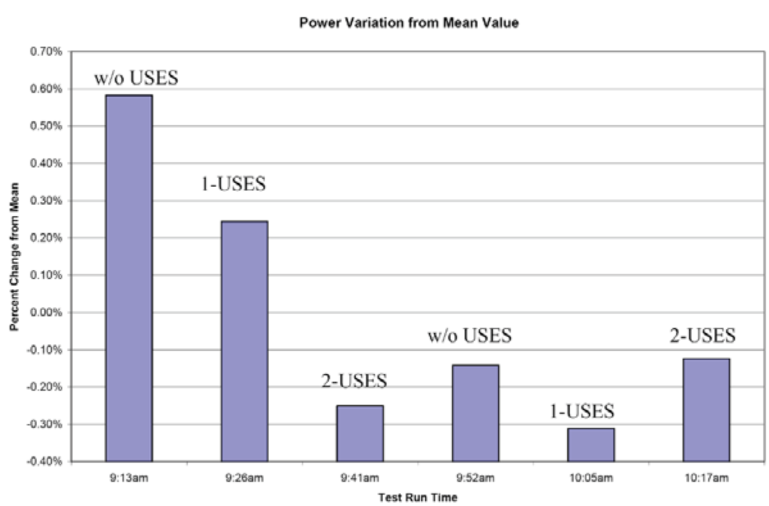


Figure 36. Over Deviation from the Mean Power over 10-Minute Intervals for six-Data Runs

The initial drift in measured power occurred over the first approximately 40 minutes of operation of the blower. If only the data taken for the last 40 minutes is considered, the standard deviation drops to 0.09%.

Considering all data sets examined, the USES devices had no impact on power consumption within the accuracy of the measurement equipment (approximately the 1% level). If only the last four sets of data are considered, the accuracy drops to the approximately 0.3% level.

5.9 POWER FACTOR MEASUREMENT

5.9.1 Rationale

Increasing the power factor of an inductive load is desirable as it directly reduces the current flowing in the power feed circuit. This has the benefit of reducing power losses in wiring upstream from the load. Power factor is composed of two terms taken as a product. The two terms are the displacement power factor and the distortion power factor. One of the benefits listed by the manufacturer of the USES device is an increase in the power factor for inductive loads.[2] Both components of the power factor, displacement and distortion, will be monitored.

Note: A power factor correction (PFC) cabinet is co-located with the motor control center at the 186 kW fluidizer bed blower. It is not known if the capacitor sizing in the PFC cabinet was adjusted to accommodate the added USES device capacitance, nor is it known if the PFC cabinet is normally switched in-circuit. This will need to be addressed during the field testing.

5.9.2 Purpose

1. Quantify the true power factor and displacement power factor at locations *[A]* and *[B]* with and without the USES device
2. Quantify the power factor correction provided by the USES device
3. Use the collected data to verify the manufacturer's claim that the USES device provides power factor correction

5.9.3 Expected Results

The USES device adds capacitance to the line in shunt with the load. Because the device is designed to be used with inductive loads, adding capacitance will change the power factor from lagging toward leading. If the USES device's capacitive reactance is less than the inductive reactance of the motor load, then the power factor will be increased but remain lagging (inductive). If the USES devices's capacitive reactance exceeds the inductive reactance of the inductive load, it is possible that the power factor could be changed from lagging (inductive) to leading (capacitive). With the USES device connected, it is expected that the measured displacement power factor will increase based on the manufacturer's claim [2]. A specified level of power factor correction is not claimed by the manufacturer and obviously depends on the load. The measured level of power factor (true and displacement) will be recorded and reported with and without the USES devices connected.

5.9.4 Results

Data was collected with the power factor correction cabinet collocated with the motor control center disabled. Power factor values recorded for location *[B]* were:

PF = 0.912 with no USES devices

PF = 0.957 with 1 USES device

PF = 0.998 with 2 USES devices

The power factor was lagging for all cases.

5.10 MOTOR TEMPERATURE MEASUREMENT

5.10.1 Rationale

Reducing motor wear and maintenance can provide significant cost savings to a facility. Motor failures require facility down time that is not only costly but can also make the whole facility process unusable while maintenance is being performed. The manufacturer has stated on its Web site that one of the benefits of USES devices is reduced motor wear and maintenance. [2] A factor in motor wear is the operating temperature of the motor. It is expected that motor life would be shortened as the motor operating temperature increases; therefore, temperature reduction is the most likely mechanism for the claimed reduction in motor wear and maintenance.

5.10.2 Purpose

1. Quantify the motor run temperature with and without the USES device
2. Use the collected data to assess the manufacturer's claim that the USES device reduces motor wear and maintenance

5.10.3 Expected Results

With the USES device connected, given that one of the provided benefits of the USES device [2] is to reduce the total and harmonic load current, the measured motor temperature should be lower than that measured when the USES device is not connected. Actual temperatures with and without the USES devices will be recorded and reported. A decrease in operating temperature for the motor does not verify the benefit, but it does provide an indicator of motor stress in operation and a qualitative indicator of the claim's validity.

5.10.4 Results

Motor housing temperature values were recorded after 20 minutes in each state (no USES device; 1 USES device; 2 USES devices). The tests were run in consecutive order with less than three minutes between runs. The temperature data is shown in Figure 37.

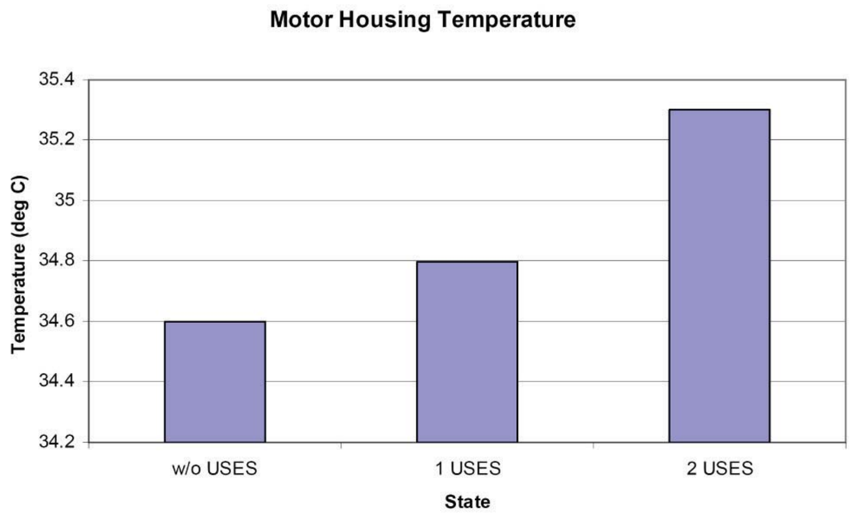


Figure 37. Motor Housing Temperature for the 3-Run States

The data is inconclusive as to the impact of the USES devices. The trend shown is believed to be the warm up of the motor during operation. Given the large thermal mass of the motor it might take hours for thermal equilibrium to be established for a given state of operation. Since it would be difficult to exactly match run conditions over a period of hours (both the facility ambient temperature near the blower and the incinerator operation conditions), no attempt was made to further assess the USES device's impact on motor temperature.

5.11 TEST PROCEDURE 2: COMBINED PARAMETER MEASUREMENT

1. Equipment setup as in Part 1 testing (see Figure 25).
2. With all USES devices disconnected and during operation of the 186 kW (250-hp) fluidizer blower, record at location [A] over the operation cycle: voltage and current waveforms, voltage and current THD data, power, energy, true power factor and displacement power factor. Also record the motor temperature and ambient temperature. Data should be accumulated with timing as established in Procedure 1 - Step 5. Record waveforms and data as per Procedure 1 – Step 7.
3. With only one of the two USES devices connected at the 186 kW bed fluidizer blower connected, repeat Step 2.
4. With both USES devices connected at the 186 kW fluidizer bed blower connection, repeat Step 2.
5. With all USES devices disconnected and during operation of the 186 kW (250-hp) fluidizer blower, record at location [B] over the operation cycle: voltage and current waveforms, voltage and current THD data, power, energy, true power factor and displacement power factor. Also record the motor temperature and ambient temperature. Data should be accumulated with timing as established in Procedure 1 - Step 5. Record waveforms and data as per Procedure 1 – Step 7.
6. With only one of the two USES devices connected at the 186 kW bed fluidizer blower connected, repeat Step 5.
7. With both USES devices connected at the 186 kW fluidizer bed blower connection, repeat Step 5.

5.11.1 Test Setup Requirements

Same as those for Procedure 1 (see Figure 25).

5.11.2 Deviations from Test Plan and Rationale

Data collection at location *[A]* was abandoned due to the outdoor location of the cabinet and that it would have required exposure to medium voltage wiring. This eliminated Steps 2 through 4 of the procedure. The ambient temperature in Step 5 (vicinity of the blower motor) was not recorded since the airspace near the motor had a mix of cool outside air and hot air from an incinerator process. Any additional deviation from the test plan is noted in the detailed summary for a particular measurement.

5.6 Summary of USES Field Evaluation Results

Field testing indicates that the USES devices did not impact motor power consumption within the measurement capabilities of this effort. Voltage and current distortion remained unchanged with or without the USES devices. The USES devices did provide VAR support for the motor load, improving the power factor and decreasing the reactive currents in the feed wires to the motor control center, which would be expected to reduce losses in the in-wiring that comprises the feed circuit to the motor control center. Error budget analysis indicates that the power measurements were accurate within less than 1%. Standard deviation of repeated power measurements indicated that repeatability of measurements was within 0.34% for all data collected.

6
REFERENCES

1. IEEE Std 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality
2. USES Power Enhancement. "The USES® Advantage." 24 March 2008
<http://www.usesmfg.com/advantg.html>.
3. USES Power Enhancement. "Success Stories." 24 March 2008
<http://www.usesmfg.com/stories.html#post>

7
GLOSSARY

ASD	Adjustable Speed Drive
ACEEE	American Council for and Energy Efficient Economy
CEC	California Energy Commission
CT	Current Transformer
CVS	Constant Voltage Source
DR	Demand Response
HID	High-Intensity Discharge
kWh	Kilowatt-hour
MW	Megawatt
OEM	Original Equipment Manufacturer
OV	Over Voltage
PFC	Power Factor Correction
PIER	Public Interest Energy Research
RESD	Retrofit Energy-Savings Devices
THD	Total Harmonic Distortion
UPS	Uninterruptible Power Supply
UV	Under Voltage
VAR	Volt-Ampere Reactive
VSD	Variable Speed Drive

APPENDIX A
EQUIPMENT USED IN THE MINI-EVR^{TM} TESTS

	Device	Picture	Info
1	Voltech PM100 Power Analyzer (x2)		Used for steady-state power and harmonic calculations
2	Nicolet Vision (x3)		16 channel data acquisition up to 100 kHz
3	High Voltage Probe		These probes are used with the Nicolet Vision
4	Fluke 87		Multimeter
5	Pacific Power Source MS3060 (x3)		Programmable Source

	Device	Picture	Info
6	Sag/swell Generator		Used for a variety of different tests including input voltage operating window, sag profile and swell test
7	Resistive Load		This is a terminal of 13 heater elements that can be hooked up in any number of series or parallel combinations for up to 17.5 kW of load at 230 V. Each of the elements is rated at 208 V_{RMS} so they should always be used in groups of two in series. Each element is roughly 8.6 Ω
8	Caterpillar Generator		225-kVA Caterpillar Generator is used for larger UPSs and tests such as surge, swell, and any other tests where it is very important that the source size is much greater than the equipment under test.
9	Current Probe		AEMC SR661 current probe. Scalable range from 10, 100, and 1000 amp ranges
10	Lecroy Waverunner (x2)		Oscilloscope

	Device	Picture	Info
11	California Instruments MX45		Programmable source. It is essential for the surge and notch test because it can offer very high dV/dt. It can be used as a substitute for a sag generator in most tests, if needed.

APPENDIX B
INSTRUMENTATION ERROR BUDGET FOR USES POWER MEASUREMENTS

POWER METER

Power will be measured with a Voltech PM3000A power analyzer. The power measurement error budget for the PM3000A is:

Power Accuracy (45–450 Hz) = +/- [(Areading x V error) x PF] +/- [(Vreading x A error) x PF] +/- (0.04/PF)% Preading +/- 100 µW

Vreading = Voltage

Areading = 1mV/A (clamp on current probe)

Areading = current/CTr

Verror is given as: Verror = +/- 0.05% Vreading +/- 0.05% range +/- 5 mV

Aerror is given as: Aerror = +/- 1% +/- 1mV (or +/- 1% +/- 0.1A)

Aerror is given as: Aerror = +/- 0.05% Ireading +/- 0.05% range +/- 100 µA

Assume the 186 kW motor load is at 75% of full load. This means a current of about 168 A per phase at 480 V. The power factor (PF) is assumed to be 0.9.

Verror = +/- 0.05% x 480 +/- 0.05% x 1000 +/- 5mV = +/- 0.24 +/- 0.50 +/- 0.005 = +/- 0.745V

Aerror = [+/- 1% x 168 +/- 0.1A] = +/- 1.78A

Perror = +/- [(168A x 0.745) x 0.9] +/- [(480 V x 1.78) x 0.9] +/- 62.0 +/- 100 µW

Perror = +/- 125.2 +/- 769.0 +/- 62.0 +/- 100 µW = +/- 956.2 W

Total Power = 186 kW x 0.75 = 139.5 kW

Perror (%) = +/- 0.685

APPENDIX C
USES TEST DATA LOG

DATA SET 1

Glens Falls WWTP USES EVALUATION
10-Nov-08
Location [B] Ambient temp 25.5 to 25.8 deg C

Data Set 1

Values watched over an approx. 2-minute period

Both USES Devices OFF

Time	9:13 AM					
	Value	Variation(+/-)	Units			
Power	143.00	0.5	kW	motor rating is 250HP		
Voltage	468.50	0.2	V	186500 W		
Current	193.00	0.2	A			all data
VA	156.20		kVA	loading	76.08%	
Var	63.90		kVAR			
PF	0.912	stable	(inductive/lagging)			9:41 on

Time	9:19 AM		
	Value	Variation(+/-)	Units
Power	142.52	0.5	kW
Voltage			V
Current			A
VA	156.24	0.05	kVA
Var	63.90	0.3	kVAR
PF			

Power Integration		completed at 9:23 AM	
Time	0.16663	Hours	
Energy	23.78		kWh

	Average Power over interval			*Fluke 43 Crosscheck*		
set 1	**142.7114**	**kW**		*Voltage*	*468.6*	*V*
Vthd	less than 2%		all phases	*Current*	*194.8*	*A*
Ithd	less than 3.5%		all phases	*Current and votlage values look good*		

DATA SET 2

Data Set 2

One USES Devices ON - (left unit, A)

Time	9:26 AM		
	Value	Variation(+/-)	Units
Power	142.28	0.2	kW
Voltage	470.70	0.1	V
Current	182.33	0.2	A
VA	148.58		kVA
Var	43.06		kVAR
PF	0.957	stable	(inductive/lagging)

Time	9:31 AM		
	Value	Variation(+/-)	Units
Power	142.21		kW
Voltage	469.50		V
Current	182.57		A
VA	156.24		kVA
Var	63.90		kVAR
PF			

Power Integration		completed at 9:36 AM	
Time	0.16663	Hours	
Energy	23.7		kWh

	Average Power over interval		
set 2	**142.2313**	**kW**	
Vthd	less than 2.5%		all phases
Ithd	less than 4.2%		all phases

DATA SET 3

Data Set 3

Both USES Devices ON

Time	9:41 AM		
	Value	Variation(+/-)	Units
Power	142.00	0.2	kW
Voltage	471.40	0.1	V
Current	175.89	0.2	A
VA			kVA
Var			kVAR
PF	0.988	stable	(inductive/lagging)

Time	9:46 AM		
	Value	Variation(+/-)	Units
Power	141.75		kW
Voltage	470.40		V
Current	175.86		A
VA	143.22		kVA
Var	21.33		kVAR
PF			

Power Integration		completed at 9:51 AM	
Time	0.16668	Hours	
Energy	23.59		kWh

	Average Power over interval		
set 3	**141.5287**	**kW**	
Vthd	less than 2%		all phases
Ithd	less than 2.8%		all phases

REPEAT TESTS

Repeat of test with both USES units OFF

Time	9:52 AM		
	Value	Variation(+/-)	Units
Power	141.61		kW
Voltage	468.60		V
Current	191.50		A
VA			kVA
Var			kVAR
PF			
Power Integration		completed at 10:02 AM	
Time	0.16671	Hours	
Energy	23.62		kWh
	Average Power over interval		
set 1a	**141.6832**	**kW**	

Repeat of test with one USES unit ON (left, A)

Time	10:05 AM		
	Value	Variation(+/-)	Units
Power	141.54		kW
Voltage	469.60		V
Current	181.80		A
VA			kVA
Var			kVAR
PF	0.957		
Power Integration		completed at 10:15 Am	
Time	0.16671	Hours	
Energy	23.58		kWh
	Average Power over interval		
set 2a	**141.4432**	**kW**	

Repeat of test with both USES units ON

Time	10:17 AM		
	Value	Variation(+/-)	Units
Power	141.51		kW
Voltage	470.30		V
Current	175.76		A
VA			kVA
Var			kVAR
PF	0.988		
Power Integration		completed at 10:27 AM	
Time	0.16668	Hours	
Energy	23.62		kWh
	Average Power over interval		
set 3a	**141.7087**	**kW**	

APPENDIX D
SOLA CVS - SPECIFICATION

Parameter	Condition	Value
Voltage	Continuous at full load (lower input voltage possible at lighter load)	+10% to -20% of nominal
	For temporary surge or sags	+20% to -35% of nominal
Current[1]	at Full Load & 80% of nominal input voltage	I_{in} @ (VA / .87) / (V_{in} * 80%)
Frequency	See the Operating Characteristics pdf for details.	60 Hz
Output		
Line Regulation	V_{in} >80% and <110% of nominal	±1%
Overload Protection	At Nominal Input Voltage	Current limited at 1.65 times rated current
Output Harmonic Distortion	At Full Load within Input Range	3% total RMS content
Noise Attenuation	-Common Mode -Transverse Mode	40 dB 40 dB
Output Harmonic Distortion	3% total RMS content at full load.	
General		
Efficiency	at Full Load	Up to 92%
Storage Temperature	Humidity < 95% non-condensing	-20° to 80°C
Operating Temperature	Humidity < 95% non-condensing	-20° to 50°C
Audible Noise	Full Resistive Noise	32 dBA to 65 dBA
Approvals	60 Hz Models	UL1012; CSA[2]
Warranty		10 + 2 Years

1 - Consult user manual for fuse sizing.
2 - Applies to all models except 23-28-275-6.

APPENDIX E
MINI-EVR™ - SPECIFICATION

Application

Power Rating/Size (kVA)

3, 5, 7.5,10, 15 standard (larger sizes available)

Phase

Single phase

Voltage

120, 208, 220, 240, 380, 400, 440, 480, 600 - Any voltages up to 600v available

Frequency (Hz)

50 or 60 Hz

Cable Entry

Side, bottom or top - hardwired to terminal blocks

Regulation

Standard Regulation

+10%/-25% input voltage/±3% output voltage

Optional Regulation

±10% input voltage/±5% output voltage

Regulation Variation

None - constant for 0 to 100% load and any load power factor

Operating Characteristics

Overload/Inrush Capability

1000% 1 second, 500% 5 seconds, 200% 1 minute (1000% min. fault clearing)

Minimum Load

No minimum load

Tap Switching
No load current interruption or waveform distortion on switching

Load Power Factor

No limitations, compatible with all load types

Zero Crossing Sensitivity
Tap switching independent of load current zero crossing
Harmonic Distortion
No distortion added at any load or power factor

Response Time

One-cycle typical (1.5 cycle max) regardless of load or load power factor

Efficiency

99%

Operating Frequency

±3% nominal

Unit/Load Protection

Failsafe Electronic Bypass

Actuates on hi-temperature, over-current, component failure without loss of load

Surge Suppression
Tested to ANSI/IEEE standard C62.41

Construction

Technology

Electronically-controlled tap switching series transformer design
Switching Semiconductors
SCRs are not required to carry full unit current - non-full power semiconductors
Controls Microprocessor-based controls
Cooling Natural convection, no cooling fans used
Autotransformer Meets ANSI specs

Enclosure

NEMA 12 standard

Environmental Requirements

Audible Sound Level

Meets or exceeds NEMA standards

Ambient Temperature

32 to 104°F (0 to 40°C)

Relative Humidity

0-95% non-condensing

Operating Altitude

0 to 10,000 ft (3000m)

Standard Options

Split Phase

220/110v, 240/120v output

APPENDIX F
TEST EQUIPMENT LISTING FOR USES FIELD EVALUATION

ITEM 1 - VOLTECH INSTRUMENTS UNIVERSAL POWER ANALYZER, MODEL PM3000A; SN AU133/0618; CAL DATE: 5/22/2008

ITEM 2 - AEMC INSTRUMENTS CURRENT PROBE, 1000A/100A/10A; MODEL SR661; SN 02L19414DV

ITEM 3 - AEMC INSTRUMENTS CURRENT PROBE, 1000A/100A/10A; MODEL SR661; SN 107610BEDV

ITEM 4 - AEMC INSTRUMENTS CURRENT PROBE, 1000A/100A/10A; MODEL SR661; SN 107612BEDV

ITEM 5 - FLUKE POWER QUALITY ANALYZER, MODEL 43, SN DM7750020; CAL DATE: 12/28/2007

ITEM 6 - OMEGAETTE TEMPERATURE PROBE, MODEL HH306, SN 020602194; CAL DATE: 7/11/2008

ITEM 7 - FLUKE TRUE RMS MULTIMETER, MODEL 287, SN 96660096; METER IS NEW; CAL DATE NOT SHOWN (USED FOR EVALUATION SET UP SUPPORT)

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Assessment of Retrofit Energy-Saving Devices

Final Report 10-07

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