December 2003 • NREL/SR-560-34966

System Integration of Distributed Power for Complete Building Systems

Phase 1 Report

R. Kramer
NiSource Energy Technologies
Merrillville, Indiana

Subcontractor Report

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

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Prepared under Subcontract No. NAD-0-30605-10

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Abbreviations and Acronyms

40CFR60	Title 40, *Code of Federal Regulations*, Part 60
acfh	actual cubic feet per hour
ANSI	American National Standards Institute
BOCA	Building Officials and Code Administrators International Inc.
CHP	combined heat and power
CO	carbon monoxide
DG	distributed generation
DNPH	dinitrophenylhydrazine
DP	distributed power
H_20	water
IEEE	Institute of Electrical and Electronics Engineers
mL	milliliter
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NET	NiSource Energy Technologies Inc.
NFPA	National Fire Protection Association
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxide
O_2	oxygen
O_3	ozone
THD	total harmonic distortion
UDS	utility distribution system
UL	Underwriters Laboratories
USEPA	United States Environmental Protection Agency
VOCs	volatile organic compounds

Executive Summary

NiSource Energy Technologies Inc. (NET) has completed the base year of a planned 3-year effort to address research and development to significantly advance distributed power development, deployment, and integration. Its long-term goal is to design ways to extend distributed generation (DG) into the physical design and controls of buildings. The NET approach is to evaluate grid-connected and aggregated distributed power systems using technologies with dynamic optimization and control of energy use to identify regulatory, integration, and interconnection issues. In addition, DG, and specifically combined heat and power (CHP), holds promise to greatly improve energy efficiency and reduce environmental emissions. NET worked to meet these goals through advances in the implementation and control of CHP systems in end-user environments and a further understanding of electric interconnection and siting issues.

Important results from the first year were:

1. A survey of the state of the art of interconnection issues associated with DG

   Survey responses were organized into equipment supplier, end user, and utility categories. The report provides a basis for assessing the state of agreement among the parties regarding interconnection. Recommendations were made to improve interactions among the parties.

2. A survey of the local zoning requirements for the NiSource service territory

   This survey provides a basis for assessing the knowledge of local municipalities and makes recommendations for improvement to accelerate the penetration of CHP in the marketplace.

3. The acquisition of data about the operation, reliability, interconnection, and performance of CHP systems and components of two test sites.

   a. A test site in Chesterton, Indiana, provided efficiency, reliability, and operating information for a CHP system in an operating commercial business. Efficiency data were gathered for the system's microturbine, and an initial building model was completed for analysis of CHP efficiency for the entire building. This data will be valuable for designing and implementing future commercial CHP applications.

   b. A test site in Gary, Indiana, provided detailed operating data for two microturbines and a flywheel energy storage device in various grid-connected and isolated configurations. The responses and interactions of multiple inverters, a motor generator, and resistive and inductive loads were considered.

> A statistical profile of the operating characteristics of a variety of operating configurations was developed. Results were presented for the experimental design in the form of response surfaces and other appropriate representations to facilitate interpretation. In addition, a database of noise, environmental, and vibration information was assembled.
>
> One major concern is the response of DG devices to the starting of motors and other inductive loads. This behavior was studied both for grid-connected and standalone modes with various combinations of DG devices. Various issues associated with standalone operation for inductive transients were identified. This effort provided a database of information that will be valuable for designing standalone and grid-connected DG systems. Various operating issues associated with motor starting were identified, and methods to resolve the issues were suggested.

The base year of the project entailed three areas of effort.

Task 1 Results: Interconnection Issues in Small DG Systems

The purpose of this task was to identify and detail interconnection issues. To accomplish this, NET identified technical, institutional, and regulatory issues related to the interconnection of distributed power systems with utility grids and examined what approaches and solutions were taken.

This included:

1. Determining the state of the art in interconnection technology and methods
2. Describing the architecture and pertinent electrical characteristics of the utility distribution system and identifying any characteristics that affected the interconnection
3. Describing the physical interconnection with the utility grid, the equipment providing interconnection, and other software and hardware required for safety, reliability, or power quality
4. Identifying interconnection required tests (e.g., interconnection equipment, type of test, field test, etc.)
5. Determining and documenting the costs and delays incurred because of technical interconnection requirements
6. Determining the effects of utility rates, fees, business practices, and experience as well as regulatory practices on the cost of interconnection.

More than 100 utilities were contacted. After two follow-up inquiries to all the utilities, responses were obtained from 17. In general, there seems to be a lack of understanding of the potential for DG in the industry.

Task 2: Zoning and Permitting of Distributed Power Generators

The purpose of this task was to identify zoning and permitting requirements and assess the associated costs of installing distributed power systems. NET investigated the effects of zoning and permitting requirements identified within the NiSource service area. These requirements included environmental permitting and municipal building, electrical, safety, and mechanical code requirements. It was generally noted that there are few consistent codes for the implementation of DG. Efforts are under way by a variety of groups to produce and coordinate standards, but there is generally confusion locally as to what the requirements are for operation and interconnection of DG systems.

Task 3: System Integration and Performance

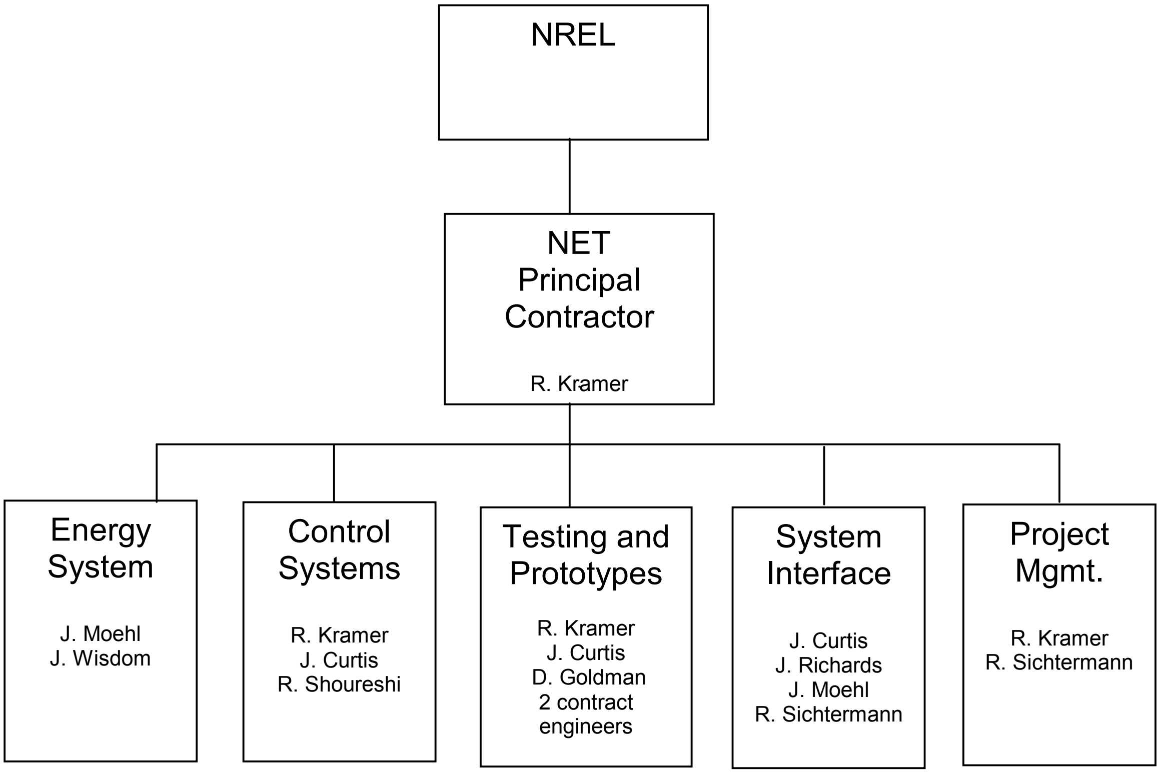
The purpose of this task was to gather data through comprehensive field-testing to assess the validity of computer models. NET undertook extensive field-testing to assess the validity of models relative to actual operating practices. Key elements of this testing were instrumentation, experiment design, and the interactions between the control system and monitors at the user site.

NET benchmarked the performance of two DG systems for reliability, emissions, efficiency, power quality, heat rate (if applicable), conformance to Institute of Electrical and Electronics Engineers standards, and control system and power electronics performance. NET also monitored the performance of the power electronics interfacing with the utility grid. Specifically, NET examined the effect of DG on the operation of the grid and the effect of the grid on the operation of DG.

The following issues were considered. Microturbine performance was measured based on factors that influence its operation, including gas pressure, temperature, power factor, and output level. Various factors of operation were considered to illustrate the numerous interactions among the measured factors of the experimental design. The interactions of multiple microturbines with one another, with an energy storage device (flywheel), and with the grid were considered and measured. Power quality and transient response of single and multiple turbines in combination with the grid and a flywheel were considered and made part of the experimental design.

Generally, the microturbines performed according to the manufacturer's specifications. Various interactions between operating parameters were identified and will be of value in the design of systems for use in the field. In grid-isolated operation, issues associated with inductive transients were identified. This suggests special care should be given during the design of systems that will operate in a dual mode with motors or other inductive loads, especially for transients. Issues with harmonic content were also noted under various operating conditions.

The organizational structure for the project base year is diagramed below.



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1 Introduction

Interest in the use of distributed generation (DG) and storage has increased substantially over the past 5 to 10 years because of its potential to provide increased reliability and lower-cost power. This is particularly true for customer-sited generation. The advent of competition and customer choice in the electric power industry has, in part, been the stimulus for this increased interest. Also contributing to this trend has been the development of small modular generation technologies such as photovoltaics, microturbines, and fuel cells.

Industry estimates are that distributed resources will account for up to 30% of new generation by 2010. The potential environmental benefits of distributed power (DP) exploiting, for example, renewable resources, combined heat and power (CHP), and hybrid systems are substantial.

A Department of Energy goal and vision for the 21st century is full-value DP captured in an electricity market in which customers can sell power, employ load management, and provide operations support services (ancillary services) as easily as the utility in an automated and adaptive electric power system. As the cornerstone of competition in electric power markets, DP will also serve as a key ingredient in the reliability, power quality, security, and environmental friendliness of the electric power system. By supporting customer choice, DP may be the long-term foundation of competition in the electric power industry.

Although the application of DG and storage can bring many benefits, the technologies and operational concepts to properly integrate it with the power system must be developed to realize these benefits and avoid negative effects on system reliability and safety. The current power distribution system was not designed to accommodate active generation and storage at the distribution level or to allow such systems to supply energy to other distribution customers.

The technical issues of allowing this type of operation are significant. For example, control architectures to allow safe and reliable DP operation, and particularly to exploit the potential for DP to provide grid support, will require system protection redesign. This will require large amounts of information fed to advanced, possibly neural, networks and intelligent local controllers to act quickly to reconfigure and operate local distribution areas for local- and transmission-level benefits. New system architectures and the enabling hardware and software will need to be developed.

Electricity regulation, zoning and permitting processes, and business practices developed under the framework of an industry based on central-station generation and ownership of generation facilities by a regulated monopoly can be barriers to the orderly development of market opportunities for DP in a restructured electric power industry. These barriers need to be identified and addressed through the active and mutual participation of all parties (i.e., industry and government). These parties must develop solutions and provide leadership and educational approaches to reduce infrastructure barriers to the full deployment of DP resources.

This subcontract with NiSource Energy Technologies Inc. (NET) addresses research and development to significantly advance DP development, deployment, and integration. The NET long-term goal is to design ways to extend DG into the physical design and controls of buildings. Its research and development approach is to evaluate grid-connected and aggregated DP systems using technologies with dynamic optimization and control of energy use to identify regulatory, integration, and interconnection issues.

Task One relates to interconnection issues for CHP systems. A survey of all interconnection standards publicly available was completed, and details of individual interconnection issues were compiled in a variety of tables. Comparisons among the various requirements were made.

Task Two relates to a survey and study of local regulation and zoning requirements issues for CHP systems. Building commissioners and zoning boards were contacted to determine their use and acceptance of CHP systems. Tables were compiled for analysis and comparison.

Task Three considers operating performance issues for two CHP test sites. The first is located at a customer site in Chesterton, Indiana. The second is located at a test site in Gary, Indiana. Test data were gathered for both systems. For the first site, data on reliability and system operating characteristics were compiled for a CHP system operating in a retail environment. For the second system, a factorial design of experiment was performed for sensitivities to input temperature, gas pressure, inductive load, and power output level. In addition, transient tests were done for step changes in resistive load and power factor. Issues related to the interaction of multiple turbines and energy storage devices were considered.

2 Task 1 Results: Interconnection Issues in Small Distributed Generation Systems

A major challenge facing widespread implementation of DG interconnection is technological capability. The level of development attained is directly proportional to the initiative, effort, and cooperation that the involved entities—utilities, manufacturers, and governmental bodies—are willing to put forth.

In an attempt to assess the state of the art in interconnection technology, NET contacted more than 100 major investor-owned utilities across the nation. The degree of support for DG interconnection varies widely among electric utilities based on the nature and complexity of the requirements set forth in the reviewed standards. With a few exceptions, there appears to be a general consensus among utilities regarding the necessity of a disconnect switch between the generator and the utility. The standards of all participating utilities rely to some degree on pre-existing technical standards such as those developed by the American National Standards Institute (ANSI), the Institute of Electrical and Electronics Engineers (IEEE), the National Electrical Safety Code (NESC), the National Fire Protection Association (NFPA), and Underwriters Laboratories (UL). Protective relaying requirements among the utilities vary in nature and complexity. Some are very flexible—giving very little in the way of specific recommendations—while others appear to be very well-defined and sometimes rigid. The majority of these utilities do require a dedicated power transformer for the purpose of isolating the generator from other utility customers. Among the utilities, a general consensus is evident regarding the issue of power quality. Most standards rely heavily on the requirements presented in IEEE 519-1992.

In addition, nearly every utility requires some form of field-testing before allowing a generator to operate in parallel with its system. A review of the interconnection standards reveals a varying degree of stringency among the testing requirements.

To further assess the state of the art in interconnection technology, NET analyzed how two manufacturers approached the same technical issues. There appears to be reasonable agreement that a fusible disconnect switch or circuit breaker, or both, should exist between the generator and the utility. Standards references can directly support the legitimacy of a utility-generator interconnection document and are used to that extent. Basic protective devices are normally included as part of the generation package. Under most circumstances, an intervening transformer is required between the generator and the utility—whether it is internal to the generator package or placed externally in the system. While operating parallel to the distribution grid, the generator will attempt to mimic the electrical characteristics of the grid by providing high-quality power.

Generally, the utility administers the interconnection process. The potential effects of time and cost issues on a DG project are dramatically influenced by utility requirements.

Regulatory activities take place primarily on a state-by-state basis in the United States. On the heels of initiation of nationwide electric utility restructuring, many of these regulatory bodies are making recommendations regarding the technical, operational, and financial issues relating to DG-grid interconnection.

With regards to the advent of small-scale, customer-owned generating plants (microturbines, fuel cells, etc.) and their potential effect on the electric utility industry (particularly at the power distribution level), the sometimes-volatile debate over the idea of grid interconnection has been renewed—only on a smaller scale than ever before.

2.1 Technical Issues Related to Grid-Connected Distributed Generation Systems

The first and most obvious challenge to widespread DG interconnection is technological viability. If the technological hurdles to DG interconnection are not cleared, the potential benefits of integration with the utility electrical distribution system may never be fully realized. DG has the potential to alleviate many problems with distribution and transmission system power and ancillary service flows and shortages. Significant penetrations of DG on the electric system could provide cost-effective alternatives to more conventional approaches to power shortage and power quality problems.

2.1.1 The State of the Art of Interconnection Technology and Methods

The level of development interconnection technology attains is directly proportional to the initiative, effort, and cooperation that the involved entities—utilities, manufacturers, and governmental bodies—put forth. To gain insight into this issue, NET performed a data search that yielded a large volume of information regarding interconnection practices and procedures.

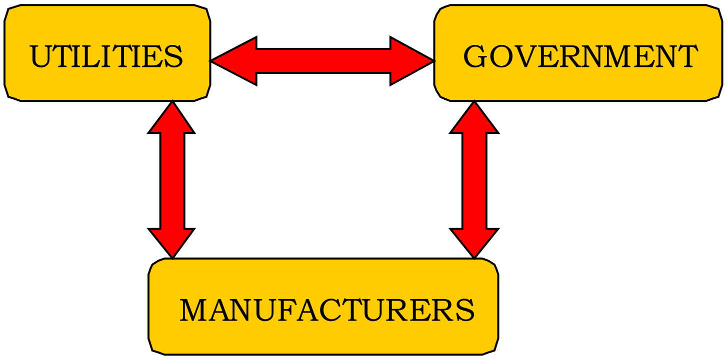

Figure 1. Necessary interaction among involved entities

2.1.1.1 Survey of Utility Requirements on Key Technical Issues

To assess the state of the art in interconnection technology, NET contacted more than 100 major investor-owned utilities across the nation.[1] From each utility, NET requested documentation of established technical interconnection requirements for a customer-generator wishing to operate in parallel with the utility's electrical distribution system. A small percentage of the contacted utilities responded and supplied the appropriate standard.

The documents were read and analyzed for prevailing technical issues. These issues were generator classification, disconnect switch requirements, applicable codes and standards, protective relaying specifications, isolation transformer requirements, and power quality requirements.

2.1.1.1.1 Generator Classification

Utilities take many approaches to classifying generators in interconnection requests. Among the classification schemes are size, mode of generation, and power flow characteristics (i.e., one-way or two-way). This section presents the classification methods of each surveyed utility.[2]

Utility 1

The three main influences on Utility 1's requirements are size of the parallel generator, characteristics of the parallel generator, and nature of the associated distribution system.

Generators are divided into four classes according to size. Class I covers single- and three-phase generators of 50 kW or less. Class II covers three-phase generators from 51 kW to 300 kW. Class III covers three-phase generators from 301 kW to 5,000 kW, and Class IV covers three-phase generators more than 5,000 kW.

Generators are further divided into three classes at each level according to the interface characteristics of the generator. Interconnection requirements vary some, depending on whether the generator is considered a synchronous unit, an induction unit, or a static inverter unit.

Utility 2

Applicability of the requirements of Utility 2 is based primarily on the nature of the generator. All synchronous and asynchronous generation falls into one category, and non-islanding, UL-approved inverters fall into the other category. Size plays a lesser role in Utility 2's classification procedures.

Utility 3

For Utility 3, DG interties are classified as either one-way power flow or two-way power flow. In one-way power flow, electrical load exceeds generator capacity, and, therefore, power flows only from the utility to the customer. In two-way power flow, electrical load is less than generator capacity, and power flows in either direction between the utility and the customer. Further requirements are based on the type of utility system with which the DG is being connected.

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[1] Utility names and URLs were found at http://www.utilityconnection.com/page2b.html.

[2] Utilities and manufacturers will remain anonymous for the purposes of this report.

Utility 4
Utility 4 has two classes: single-phase units less than 25 kVA and single-phase units more than 25 kVA plus all three-phase units. Generators that fall into the former class undergo a far simpler process than those that fall into the latter class.

Utility 5
The classification of generators for Utility 5 is based on two characteristics: output capacity of the unit and type of generator employed.

- Class IA covers all single-phase units
- Class IB covers three-phase units less than 50 kW
- Class II covers three-phase units from 51 kW to 500 kW
- Class III covers three-phase units from 501 kW to 5,000 kW
- Class IV covers three-phase units with output exceeding 5,000 kW.

Requirements also vary according to whether the generator interfaces with the grid using an induction generator, a line commutated inverter, a synchronous generator, or a force commutated inverter.

Utility 6
Utility 6 classifies DG units strictly by generator type. Two sets of rules exist: one for rotating generation (steam and combustion turbines, internal combustion engines, induction or synchronous wind turbines, etc.) and another for inverter-derived generation (fuel cells, photovoltaics, batteries, etc.).

Utility 7
Utility 7 classifies generator installations by size and uses the following guidelines. Extremely Small Generator covers generation of 100 kVA maximum up to 600 V. Small Generator covers generation from Extremely Small Generator up to 1,000 kVA maximum up to 600 V and 500 kVA maximum above 600 V. Medium Generator covers generation from Small Generator up to 12,500 kVA regardless of voltage, and Large Generator covers generation from Medium Generator up to approximately 50,000 kVA.

As with most other utilities, specific requirements will be based to some degree on the type of generator, the location of the generator on the utility system, and the manner of operation.

Utility 8
Utility 8 has classified parallel-operating sources into three categories based on the degree of power output. The first class includes units of less than 200 kVA, the second class includes units between 200 kVA and 5,000 kVA, and the last class includes generators more than 5,000 kVA. The type of generator plays a lesser role in the determination of specific interconnection requirements.

Utility 9
Utility 9 uses three generator classifications. These classifications are based on size and type of generator. The first group includes residential photovoltaic systems rated at 10 kW or less. The second group includes DG units rated 300 kVA or less that do not fall into the first group, and the third group includes DG units rated more than 300 kVA.

Utility 10
The standard produced by Utility 10 is quite narrow in its application. It categorizes all DG units as static power converter-type units less than or equal to 100 kW or static power converter-type units greater than 100 kW.

Utility 11
Utility 11 bases its classification on generator technology (three-phase synchronous systems, induction systems, inverter systems, etc.) as well as on size, for which there are two classes (small and large, with an 11-kVA threshold).

Utility 12
One class of generators exists for Utility 12: those with generation not exceeding 40 kW and operating at 240 V or less. Slight variations in requirements also exist, depending on the nature of the generating equipment (induction or synchronous generator, line-commutating or self-commutating inverter, etc.).

Utility 13
Generation facilities are classified into four groups of one-way or two-way power flow with synchronous or signal-dependent generation. Synchronous generation is defined in this standard as generation capable of operating independent of the grid. Signal-dependent generation is defined as generation dependent on a signal from the grid. As described earlier, one-way power flow occurs when the generator output never exceeds the customer’s electrical load; two-way power flow occurs when the generator output exceeds the customer’s electrical load at times.

Utility 14
Utility 14 uses a combination of the power flow and size classification methods to categorize nonutility generators for interconnection.

One-way power flow is the classification for generators not intended to inject power into the utility’s system. Two-way power flow is the classification for generators wishing to export power to the utility distribution system (UDS).

Generators in each of these categories are further divided into three groups by power output. Extremely Small covers those generating less than 100 kVA. Large covers those generating more than 3 MVA or those that pose a threat of islanding a portion of the UDS. Small covers generators not classified as Large or Extremely Small.

Utility 15
No specific method of generator classification exists for this utility. In general, its requirements are based on a combination of type and size of generator, location of the generator on the UDS, and the manner in which the generator will operate (i.e., one-way or two-way power flow).

Utility 16
Utility 16 has no specific categories for generator classification. Like most other utilities, its requirements will be influenced by size, type, and location.

Utility 17
Utility 17 primarily classifies generators according to size. Large includes generation in excess of 5,000 kW and those setups that carry the possibility of islanding a portion of the UDS. Medium includes generation from 1,000 kW to 5,000 kW. Small includes generation less than 1,000 kW but greater than 100 kW, and Extremely Small includes three-phase generation less than 100 kW and nearly all single-phase units.

2.1.1.1.2 Manual Disconnect Switch
The disconnect switch is a mechanical device used to isolate a circuit or equipment from a source of power. In general, all utilities require a disconnect device as part of the interconnection setup.

The main disconnect issues addressed by the utility standards are visible break capabilities, load break capabilities, utility accessibility and lockability, and disconnect switch labeling. In Table 1, each utility’s requirements are summarized.

Table 1. Manual Disconnect Requirements of Surveyed Utilities

Utility	Visible Break	Load Break Capability	Utility Accessible	Utility Lockable	Clear Labeling of Disconnect
1	√[a]	√	√	√	√
2	NS	√	√	√[b]	NS
3	√	NS	√	√	√
4	√	NS	√	√	NS
5	√	√	√	√	NS
6	√	√	√	√[c]	NS
7	√	NS	√	√	NS
8	NS	NS	√	√	NS
9	√	√	√	√[b]	√
10	√	NS	√	√[b]	√
11	√	NS	√	√[b]	NS
12	NS	NS	√	√	NS
13[d]	NS	NS	√	NS	NS
14	√	NS	√	√	NS
15	√	NS	√	√	NS
16	√	√	√	√	NS
17	√	√	√	√[b]	√

√ = Required by standard
NS = Not specified in standard

Notes:

[a] Utility 1's definition of "visibly open" requires that the switch blades, jaws, and air gap between them be clearly visible in open position. It insists that the view of these components not be obscured by the arc shield or switch case. It appears that a switch designed specifically for the application is required. It is uncertain whether such switches are readily available.
[b] Utility lockable in open position only.
[c] Utility lockable in open and closed positions.
[d] Minimum requirements for Utility 13 call only for an intertie circuit breaker device on the generator side.

2.1.1.1.3 Applicable Codes and Standards

Nearly all utility interconnection standards require installations to meet minimum state and local codes and requirements in addition to the codes and standards in its documents.

Table 2 compares the major standard references in the standards of utilities in this survey.

Table 2. National Codes and Standards Referenced

Utility	ANSI/IEEE	NEC	NESC	NFPA	UL
1	519	√	NR	NR	√
2	C37.90	240, 690	NR	NR	√
3	519, C37.90, ANSI 84.1	√	√	NR	NR
4	100, 386, 519, 929, 1547, C37.108, 37.13, 37.2, 37.41, 37.90, 37.90.1, 37.90.2, 37.95, 62.41, 62.45, 62.92.1, 84.1	√	√	√	1741-2000 98-1994 363-2000 489-9
5	80	√	√	√	√
6	519, 929, C37.90, ANSI 432.2, 41.1	√	NR	NR	1741
7	80, 242, 446, 519, 1001, 1021, 1109, C37.90, 37.95	√	√	√	NR
8	√	NR	√	NR	NR
9	367, 487, 519, 929, C37.90, 37.90A, 37.90.1, 37.90.2, 37.98, 37.2, 39.1, 39.5, 57.13, 84.1, 62.41	√	√	NR	1741
10	141, 519, C37.2, 57.110, 84.1	√	√	NR	NR
11	519, 929, 1547, C37.90.1, 62.41, 62.45	100	NR	NR	1741
12	929	705	√	NR	1741
13	519	NR	NR	NR	NR
14	242, 446, 1001, 1021, C37.90, 37.95	√	√	√	NR
15	84, 519, 929, C37	701, 702, 705	NR	NR	NR
16	519, 929, C37.90, 62.41	√	√	NR	1449
17	80, 242, 446, 519, 1001, 1021, C2, 37, 37.90, 37.90.1, 37.90.2, 37.95	√	√	70	NR

Notes to Table 2:

√ – Referenced in standard (without specific document number)
NR – Not referenced specifically in standard

Definition of codes/standards referenced in Table 2:

ANSI/IEEE	
519-1992	IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems
386-1995	IEEE Standard for Separable Insulated Connector Systems for Power Distribution Systems Above 600 V
929-2000	IEEE Recommended Practice for Utility Interface of Photovoltaic Systems
1547	Standard for Distributed Resources Interconnected With Electric Power Systems
80-2000	IEEE Guide for Safety in AC Substation Grounding
242-1996	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
446-1995	IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications
1109-1990	IEEE Guide for the Interconnection of User-Owned Substations to Electric Utilities
367-1996	IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage From a Power Fault
487-2000	IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Locations
141-1993	IEEE Recommended Practice for Electric Power Distribution for Industrial Plants
C37.90-1989	IEEE Standard for Relays and Relay Systems Associated With Electric Power Apparatus
C37.90.1-1989	IEEE Standard Surge Withstand Capability Tests for Protective Relays and Relay Systems
C37.90.2-1995	IEEE Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference From Transceivers
C2	National Electrical Safety Code
C37.108-1989	IEEE Guide for the Protection of Network Transformers
C37.13-1990	IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures
C37.41-1994	IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories
C37.95-1989	IEEE Guide for Protective Relaying of Utility-Consumer Interconnections
C62.41-1991	IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits
C62.45-1992	IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits
C62.92.1-1987	IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part I - Introduction
C37.98-1987	IEEE Standard for Seismic Testing of Relays
C57.13-1993	IEEE Standard Requirements for Instrument Transformers
C57.110-1998	IEEE Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load
NEC	
Article 100	Definitions
Article 240	Overcurrent Protection
Article 690	Solar Photovoltaic Systems
Article 701	Legally Required Standby System
Article 702	Optional Standby Systems
Article 705	Interconnected Electric Power Production Sources
NESC	
NFPA	
70	National Electrical Code
UL	
98	Enclosed and Dead-Front Switches
363	Knife Switches
489	Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures
1449	Transient Voltage Surge Suppressors
1741	Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems

2.1.1.1.4 Protective Devices

Protective relaying devices initiate the removal of equipment from service automatically and quickly when an electric fault or disturbance occurs. Proper protective relaying is essential to a safe generator-utility interconnection.

The protective relaying requirements of each utility are summarized in this section. In most cases, these are solely for the protection of the UDS facilities and do not take protection of the generator into consideration.

Utility 1

Table 3. Protective Relaying Requirements for Utility 1

	Induction Generator/ Line Commutated Inverter	Synchronous Generator/ Force Commutated Inverter
Class I <50 kW	Undervoltage contactor	Undervoltage contactor Synchronizing
Class II 51–300 kW	Over/undervoltage Over/underfrequency	Over/undervoltage Over/underfrequency Synchronizing
Class III[a] 301–5,000 kW	Over/undervoltage Over/underfrequency	Over/undervoltage Over/underfrequency Synchronizing
Class IV[a] >5,000 kW	Not anticipated	Over/undervoltage Over/underfrequency Synchronizing Ground time overcurrent Ground instantaneous overcurrent Voltage-controlled time overcurrent Loss of excitation Overexcitation Negative sequence time overcurrent

[a] Class III and Class IV generators require utility-grade protective devices.
Undervoltage relay setting: 80% of nominal voltage level with 1-second maximum time delay
Overvoltage relay setting: 120% of nominal voltage level with 1-second maximum time delay
Overfrequency relay setting: 62 Hz with 1-second maximum time delay
Underfrequency relay setting: 58 Hz with 1-second maximum time delay

Utility 2

Utility 2 requires utility-grade over and undervoltage relays, over and underfrequency relays, and unbalanced fault detection. No distinction is made concerning generator size. Additional equipment may be necessary after the site-specific study.

Utility 3

General requirements for Utility 3 include provisions for:

- Loss of a single phase of supply (in accordance with trip settings in Table 4)
- Distribution system faults
- Equipment failures
- Abnormal voltage (see Table 4)
- Abnormal frequency (59.3–60.5 Hz, 10-cycle trip time)
- Lightning and switching surges
- Excessive harmonic voltages
- Excessive negative sequence voltages
- Separation from supply
- Synchronizing generation
- Re-synchronizing the DG after electric restoration of the supply.

Tables 4 and 5 list the additional, case-specific requirements for Utility 3.

Table 4. Over/Undervoltage Trip Settings of Utility 3

Voltage	Maximum Trip Time
V<50%	10 cycles
50%<88%	120 cycles
110%<120%	60 cycles
V>120%	6 cycles

Table 5. Specific Protection Requirements of Utility 3

Secondary Distribution System – Residential (Single-Phase only)	Secondary Distribution System – Nonresidential (Single- or Three-Phase)	Primary Distribution System – One-Way Power Flow (Three-Phase)	Primary Distribution System – Two-Way Power Flow (Three-Phase)
Anti-islanding protection Prevention of connection to de-energized system	Anti-islanding protection Prevention of connection to de-energized system	Reverse power Fault pressure Phase overcurrent – high/low side Ground overcurrent – high/low side Neutral overcurrent Transformer differential Timer IPP breaker Intertie breaker Neutral resistor	Fault pressure Phase overcurrent – high/low side Ground overcurrent – high/low side Neutral overcurrent Transformer differential Timer IPP breaker Intertie breaker Neutral resistor

Note for DG operated in parallel with the primary distribution system: All protective functions are required as dedicated intertie protection, even if they duplicate certain relays applied to the generator.

Additional Note: Any DG facility with output more than 1,000 kW requires utility-class protective equipment per ANSI/IEEE C37.90.

Utility 4

Table 6. Utility 4 Relaying Requirements

Basic Isolation Protection – Sell-Back Operation	Basic Isolation Protection – Non-Sell-Back Operation	Supplemental Isolation/Fault Protection
Undervoltage relays (adjustable 70%–90%, with time delay)	Reverse power relay (1.5-W import requirement)	Remote trip channel
Overvoltage relays (adjustable 105%–120%, with time delay)	Trip delay timer (2 seconds)	Zero sequence overvoltage relay
Underfrequency relay (57–59.3 Hz with 10-cycle trip setting)		Primary neutral overcurrent relay
Overfrequency relay (60.5 Hz with 10-cycle trip setting)		Voltage restrained time overcurrent relay

Note: Utility-grade relays are required for single-phase units more than 25 kVA and for three-phase units exceeding 100 kVA.

Utility 5

Table 7. Protection Requirements for Utility 5

Class I		Class II	
Induction Generators and Line Commutated Inverters	**Synchronous Generators and Force Commutated Inverters**	**Induction Generators and Line Commutated Inverters**	**Synchronous Generators and Force Commutated Inverters**
Undervoltage	Phase/ground-fault protection	Phase/ground-fault protection	Phase/ground-fault protection
	Overvoltage	Overvoltage	Overvoltage
	Undervoltage	Undervoltage	Undervoltage
	Overfrequency	Overfrequency	Overfrequency
	Underfrequency	Underfrequency	Underfrequency
		Negative sequence overcurrent protection	Negative sequence overcurrent protection

Class III		Class IV	
Induction Generators and Line Commutated Inverters	**Synchronous Generators and Force Commutated Inverters**	**Induction Generators and Line Commutated Inverters**	**Synchronous Generators and Force Commutated Inverters**
Phase/ground-fault protection	Phase/ground-fault protection	Phase/ground-fault protection	Phase/ground-fault protection
Out of synch scheme	Out of synch scheme	Out of synch scheme	Out of synch scheme
Overvoltage	Overvoltage	Overvoltage	Overvoltage
Undervoltage	Undervoltage	Undervoltage	Undervoltage
Overfrequency	Overfrequency	Overfrequency	Overfrequency
Underfrequency	Underfrequency	Underfrequency	Underfrequency
Negative sequence overcurrent protection	Negative sequence overcurrent protection	Negative sequence overcurrent protection	Negative sequence overcurrent protection

Utility 6

Table 8. Protection Specifications for Utility 6

Rotating Generation		Inverter-Derived Generation	
Isolation	**Fault**	**Isolation**	**Fault**
Undervoltage (set at 90% of nominal voltage) with 2-second time delay	Out-of-step relaying	Undervoltage (IEEE 929 for <10 kW; case by case for all others)	Overcurrent
Overvoltage (set at 110% of nominal voltage) with 2-second time delay	Synchronism check (10°–60° angular range with 0.5–5 second time-delay range)	Overvoltage (IEEE 929 for <10 kW; case by case for all others)	Synchronization (5% voltage differential, 0.2 Hz frequency differential, and 10° phase window)
Overfrequency (60.5 Hz)	Nondirectional phase overcurrent	Overfrequency (IEEE 929 for <10 kW; case by case for others)	
Underfrequency (set at 57.5 Hz) with 5-second time delay	Nondirectional ground overcurrent	Underfrequency (IEEE 929 for <10 kW; case by case for others)	
	Nondirectional neutral overcurrent	Utility recovery (5 minutes required)	
	Voltage-controlled time overcurrent	DC isolation (for DC current >0.5% of rated inverter output)	
	System backup impedance (plus external timer with 1–2 second time delay)	Islanding protection (10-second time limit)	

Note: Utility-grade fault and isolation protection required in conformance with ANSI/IEEE C37.90.

Utility 7

The following relay specifications apply. In general, utility-grade relays are required unless otherwise noted.

- Overcurrent relays – industrial-grade for applications <600 V; utility-grade for all other applications
- Overvoltage relays – operating at no more than 110% of the nominal voltage level with a 1-second maximum time delay
- Undervoltage/negative sequence relays – shall detect 5% negative sequence voltage or less, operating at no less than 80% of the nominal voltage level for balanced undervoltage conditions and at no less than 90% of the nominal voltage level for undervoltage on one phase only. Maximum time delay of 1 second. Reset level to be at no less than 95% of the nominal voltage level.

- Overfrequency relays – should trip at no more than 63 Hz, with a maximum time delay of 1.5 seconds
- Underfrequency relays – should trip at no less than 54 Hz, with a maximum time delay of 1.5 seconds
- Reverse power relays – should trip breaker for power flow no greater than 4% of the maximum power generating capacity of the unit, with a maximum time delay of 1 second
- Zero sequence inverse time overvoltage detection relay scheme
- Ground fault detection relay scheme
- Voltage-supervised time overcurrent protective scheme
- Negative sequence overcurrent relay

Utility 8

Table 9. Protective Relaying Specifications for Utility 8

Generation Less Than 200 kVA	Generation More Than 200 kVA
Line voltage relay to prevent islanding	Phase overcurrent trip device
	Residual overcurrent/overvoltage
	Under/overvoltage relays
	Under/overfrequency relays
	Phase sequence/undervoltage relay

Note: In general, generators less than 1,000 kVA do not require utility-grade relays.

Utility 9

Table 10. Protective Relaying for Utility 9

Single-Phase Induction Generator		**Three-Phase Induction Generator**		**Three-Phase Synchronous Generator**	
Isolation Protection	**Fault Protection**	**Isolation Protection**	**Fault Protection**	**Isolation Protection**	**Fault Protection**
Overfrequency Underfrequency Overvoltage Undervoltage	Undervoltage	Overfrequency Underfrequency Overvoltage Undervoltage	Undervoltage Ground time-overcurrent Zero sequence voltage Negative sequence	Overfrequency Underfrequency Overvoltage Undervoltage	Phase time-overcurrent with voltage restraint Ground time-overcurrent Synchronizing Zero-sequence voltage Negative sequence

Note: Utility-grade relays are required for units more than 300 kVA and, in some instances, for units less than 300 kVA.

Utility 10

The following specifications apply only to units employing static power converter technology with capacity less than 100 kW.

- Anti-islanding protection
  - Under/overfrequency
  - Under/overvoltage
- Interconnection protection
  - Phase sequence
  - Synchronizing
- Over current/fault protection
  - Instantaneous/time overcurrent
  - Molded case circuit breaker

Utility 11

Utility 11 puts forth a general set of protective requirements. All setups require overvoltage, undervoltage, overfrequency, and underfrequency protection as prescribed in Table 11.

Table 11. Voltage and Frequency Settings for Utility 11

Relay	Range	Period
Fast undervoltage	<60 V	10 cycles
Undervoltage	60–106 V	120 cycles
Overvoltage	132–165 V	120 cycles
Fast overvoltage	>165 V	6 cycles
Underfrequency	<59.3 Hz	10 cycles
Overfrequency	>60.5 Hz	10 cycles

Synchronous generators also require synchronization relays. For setups not intended to export power to the utility, a reverse power relay and underpower protection relay is required. Finally, utility system fault detection may be necessary in certain cases.

Utility 12

Overcurrent protection in the form of a circuit breaker or fuse is required for all installations. Induction generators and line commutated inverters require a device that will disconnect the generator if the voltage is less than 85% of the nominal voltage level for more than 2 seconds. Synchronous generators and self-commutating inverters are required to install a device that will disconnect the generator if the voltage is less than 85% for more than 2 seconds or more than 110% for more than 0.1 second. Disconnection should also occur if the frequency is less than 59.5 Hz or more than 60.5 Hz.

Systems that meet the requirements of IEEE 929-2000 and UL 1741 automatically satisfy all the above requirements of Utility 12.

Utility 13

The following device requirements may be applicable to any generation site:

- Phase distance and timer – settings vary
- Transformer primary phase and ground overcurrent – phase overcurrent set at 200% of transformer-rated current; ground overcurrent set at 100% of transformer-rated current
- Overvoltage – set at 110% of nominal voltage level, with a 5–10 second time delay
- Undervoltage – set at 80% of nominal voltage level, with a 5–10 second time delay
- Transformer differential and transformer neutral differential – set for 10%–30% differential current
- Sudden pressure – manufacturer-specified settings

- Transformer secondary phase and ground overcurrent – settings similar to those for transformer primary phase and ground overcurrent relays
- Stuck breaker and timer – set at 200% transformer rated current with time delay
- Overfrequency – generally set at 61 Hz with a 5-second time delay
- Underfrequency – generally set at 59 Hz with a 5-second time delay
- Phase directional overcurrent and power directional – set to control power flow into the utility's system.

Utility 14

Relay specifications and settings are not provided in Utility 14's standard. The protection package is to be developed by the customer and approved by the utility. The document states that utility-grade relays are required for installations more than 100 kVA.

Utility 15

Table 12 lists Utility 15's minimum protective relaying requirements.

Table 12. Utility 15 Relaying Requirements

Synchronous Generator	Induction Generator
Automatic synchronizing	Undervoltage
Undervoltage	Overvoltage
Overvoltage	Neutral overcurrent
Neutral overcurrent	Underfrequency
Underfrequency	Overfrequency
Overfrequency	

Utility 16

Table 13. Utility 16 Relaying Requirements

Synchronous Generators	Induction Generators	Synchronous Inverters
Undervoltage	Undervoltage	Undervoltage
Instantaneous overcurrent	Overvoltage	Overvoltage
Phase time-delayed overcurrent	Overfrequency	Overfrequency
Ground overcurrent	Underfrequency	Underfrequency
Overvoltage		
Overfrequency		
Underfrequency		

Utility 17

Table 14. Utility 17 Relaying Requirements

Minimum Requirements	Other Requirements (As Determined by Facilities Study)
Over/underfrequency	Impedance
Overcurrent	Out of step
Ground overvoltage	Transfer trip
Reverse power, where applicable	Directional overcurrent
Synchronizing/reclosing	

Note: Utility-grade relays are required for installations exceeding 100 kVA.

2.1.1.1.5 Isolation Transformer

A dedicated power transformer is often called for by the utility to isolate a power-producing customer from other utility customers. For example, if multiple customers—one of which possessed an interconnected power source of sufficient size—were fed off the same utility transformer, the possibility of forming an unintentional island would exist. In other words, should the utility power drop out, the independent power source could conceivably attempt to back feed power to every other customer fed off the secondary side of the utility transformer—thereby forming an unintentional island. This is not a situation utilities find desirable.

Table 15 displays the surveyed utilities' policies on the necessity of an isolation transformer.

Table 15. Isolation Transformer Requirements Among Surveyed Utilities

Utility	Comments
1	Required for units >10 kW unless fed off a dedicated utility transformer
2	Required for interconnected three-phase generators
3	Dedicated power transformer required
4	Required at discretion of utility
5	Dedicated power transformer required
6	Required at discretion of utility
7	Required at discretion of utility
8	Dedicated power transformer required for units <200 kW
9	Required at discretion of utility
10	Customer-owned isolation transformer required
11	Not required by utility
12	Not required by utility
13	Dedicated power transformer usually required by utility
14	Required at discretion of utility
15	Dedicated transformer usually required; small units may be exempt
16	Dedicated power transformer required
17	Dedicated power transformer required at discretion of utility

Utility 10's standard applies only to units smaller than 100 kW interfaced using a static power converter.

2.1.1.1.6 Power Quality

Most of the utilities that have developed a comprehensive interconnection standard have certain expectations of the quality of power produced by the interconnected power source. A few of the relevant issues pertaining to power quality are voltage limits, voltage flicker, frequency control, harmonics, fault current level, and power factor. Figure 2 show a generic voltage profile, and Table 16 presents details of what each utility requires in this area.

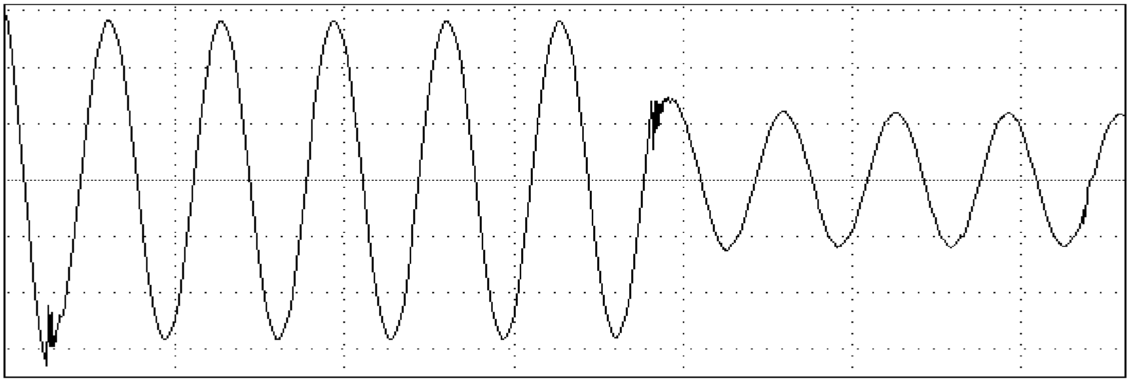


Figure 2. Generic voltage profile

Table 16. Power Quality Specifications Among Surveyed Utilities

Utility	Comments
1	Must satisfy IEEE 519-1992 at minimum. Allowable power factor is 90% lagging but not leading. Maximum allowable current imbalance is 10%. Must limit harmonic content, power fluctuations. Voltage flicker not to exceed utility standard.
2	Standard includes no specific information regarding power quality requirements.
3	Includes very general section on power quality requirements that addresses abnormal voltages, frequencies, and harmonics per ANSI/IEEE 519-1992 and sets a specific limit of 3% for voltage unbalance at the point of common coupling.
4	Customer must conform to power quality requirements of IEEE 1547 for the limits of DC injection, voltage flicker, harmonics (ANSI/IEEE 519-1992 also referenced), immunity protection, and surge capability. Minimum power factor is 0.9.
5	Standard contains only a general reference to the idea of power quality.
6	Standard states that equipment is to conform to ANSI/IEEE 519-1992.
7	Voltage is to be within 6% of nominal level; 2% maximum voltage flicker; “soft” load transfer, if necessary; 60 Hz system frequency restoration contribution; power factor 0.95 leading–0.95 lagging; harmonic distortion per IEEE 519-1992.
8	Standard contains only general references to the concept of power quality, including abnormal voltage, abnormal frequency, and voltage flicker.
9	Harmonic limits and voltage fluctuations per IEEE 519-1992; power factor 0.9 leading–0.9 lagging.
10	Power quality standard addresses concerns in the areas of voltage (onsite generation should be operated at +5/-10% of nominal voltage at the point of common coupling), power factor (varies with customer rate class), harmonic voltage limits, and harmonic current limits (harmonic limits to be in adherence to ANSI/IEEE 519-1992).

Utility	Comments
11	Power quality-related items addressed in this standard are normal voltage operating range (106–132 V on 120-V base), voltage flicker (limits as defined in ANSI/IEEE 519-1992), frequency (58.0/59.3–60.5 Hz), harmonics (in compliance with ANSI/IEEE 519-1992), DC injection, and power factor.
12	Contains generic reference to standard waveform, harmonic distortion, and voltage limits; installation must meet applicable standards in all of these areas.
13	Maximum 5% voltage waveform distortion. 1% limit on phase unbalance. Total voltage harmonic distortion not to exceed 5% (3% limit for single harmonic) per IEEE 519-1992. Power factor of generator must be from 0.85 lagging to unity.
14	Voltage to be within 6% of nominal level. 2% maximum voltage flicker. Operating frequency not to deviate more than 0.5 Hz from 60-Hz base. Power factor 0.85 leading–0.85 lagging. Harmonic content based on IEEE 519-1992.
15	Contains general reference to non-sinusoidal waveform and voltage fluctuation per IEEE 519-1992, 929-2000, and 84. Generator to be capable of producing 0.85 power factor.
16	Standard addresses voltage limits but not specifically. Power factor to be 0.90 lagging–0.95 leading at normal voltages. Harmonic content to satisfy requirements of IEEE 519-1992.
17	Issues addressed include voltage limits and voltage flicker, frequency control (0.5 Hz maximum deviation on a 60-Hz base), power factor of 90% lagging to 90% leading, harmonic distortion limits per IEEE 519-1992, fault current levels.

2.1.1.2 Conclusions of Utility Survey

- Widely varying support exists for DG interconnection among electric utilities. The degree of support is based on the nature and complexity of the requirements set forth in the standards.
- General consensus exists among utilities regarding the necessity of a disconnect switch between the generator and the utility and the characteristics, placement, and operability of the switch. A few exceptions exist.
- All participating utility standards rely to some degree on pre-existing technical standards such as ANSI, IEEE, the National Electrical Code (NEC), NESC, NFPA, and UL. The most referenced standards are ANSI/IEEE 519-1992, 929-2000, and C37.90; NEC; and NESC. Some utilities go to great lengths to reference any standard that might possibly be applicable (such as Utility 4 and Utility 9).

- Protective relaying requirements among the utilities vary in nature and complexity. Some are very flexible, giving very little in the way of specific recommendations, and others appear to be very well-defined and sometimes rigid. For example, a number of utilities insist that the more expensive utility-grade relays be used at the point of connection to the utility—even if the same relaying function already exists within the generator installation. All are trying to accomplish goals such as utility system protection and employee safety.
- The majority of these utilities require a dedicated power transformer to isolate the generator from other utility customers.
- Generation power factor specifications are an important ingredient of any comprehensive interconnection standard. Among the utilities, a general consensus is evident regarding the issue of power quality. Most standards heavily rely on the requirements presented in IEEE 519-1992.

2.1.1.3 Recommendations of Utility Survey

- Generator classifications are based primarily on direction of power flow (one-way or two-way). This is followed by power output capability and nature of generator (synchronous, induction, etc.).
- The disconnect switch requirement should be included in any interconnection standard. This switch should exhibit a visible gap between contacts when in open position (visible with case door open), have full load break capability, be accessible to and lockable (in open position) by the utility, and be clearly labeled.
- A standard that coordinates well with existing national standards is desirable. It is important that any DG unit applying to operate in parallel with the grid be in compliance with any directly applicable national standards—particularly those of ANSI/IEEE, NEC, and NESC. Occasional references to specific standards can be helpful when necessary and directly applicable to the issue.
- Reasonable protective relaying requirements are essential to a safe interconnection. However, overkill and redundancy are not necessary to accomplish the basic tasks of isolation and fault protection. At minimum, the standard should include a listing of possible situations that should be cared for through sound protective relaying. Among these would be distribution system faults, abnormal system voltage or frequency, equipment failure, harmonic voltages, etc. The installation would then be subject to field-testing and verification of system and settings prior to actual interconnection.
- Depending on the size of the generating unit, it is reasonable to require an isolation transformer to confine any undesirable electrical characteristics to the generator. For generators larger than a certain size threshold, a dedicated utility power transformer is in order. This would prevent the power producer from being fed off a secondary shared with other utility customers.

- Power quality requirements need to address the areas of voltage limits, voltage flicker, harmonic distortion, power factor, abnormal frequency, and fault current levels.

  Reference to IEEE 519-1992 and the current draft of IEEE 1547 for specific requirements would be helpful in forming a baseline.

2.1.1.4 Survey of Manufacturer Specifications and Recommendations on Key Issues

To further assess the state of the art in interconnection technology, NET looked at how two manufacturers approached the same technical issues.

2.1.1.4.1 Disconnect Switch

Manufacturer 1
Technical specifications for Manufacturer 1 require that a UL-listed circuit breaker or fused disconnect with visible air gap be installed between the ~30-kW generation unit and the user's electric subpanel. Maximum distance between these two points is 25 feet. Disconnect ratings and characteristics must meet all applicable local codes.

Manufacturer 2
This manufacturer's setup calls for two disconnect switches. A disconnect switch or circuit breaker assembly for the customer's side comes mounted within the generator case; an easily accessible external utility disconnect switch is then needed to isolate the power system from the utility or load.

2.1.1.4.2 Applicable Codes and Standards

Manufacturer 1
Mention is made of certain specific standards, and general statements recognize that each unit is subject to applicable local codes and regulations. Some of the standards referenced are:

- UL 2200
- NFPA 70
- NEC
- National Electrical Manufacturers Association (NEMA) 250-1997
- IEEE 519
- American Gas Association

Manufacturer 2
It is made clear that installation of such a unit should meet all applicable codes and regulations. In addition, the generation system has been evaluated for conformance to industry codes and standards. A nationally recognized testing laboratory for use in the United States and Europe lists it. Some of the bodies mentioned within the installation manual are:

- UL
- NEMA
- NFPA.

2.1.1.4.3 Protective Devices

Manufacturer 1
This particular generator (~30 kW) has the following protective relaying functions built in:

- Undervoltage – adjustable settings
- Fast undervoltage – adjustable settings
- Overvoltage – adjustable settings
- Fast overvoltage – adjustable settings
- Over/underfrequency – adjustable settings
- Rate of change of frequency – maximum of 1 Hz per second (fixed settings, not adjustable).

Reverse power flow protection may also be programmed into the operation of the generator to prevent export of power to the utility.

Manufacturer 2
The main inverter has the capability of detecting and reacting to abnormal power line conditions that could have a negative effect on power quality. These conditions include:

- Overvoltage
- Undervoltage
- Over/underfrequency.

2.1.1.4.4 Isolation Transformer

Manufacturer 1
Requires a voltage transformer for the generator under any of the following conditions:

- Circuit connects voltages other than the 400–480 VAC output of the generator
- Connection circuits with wiring schemes other than a four-wire wye with ground (preferred method) or a three-wire wye with ground
- Connection to a system where the impedance is high enough to cause overvoltage at the noted output current of the system. In this case, a tapped or auto-intervening transformer is required to lower the nominal voltage if this cannot be done with the installed transformer.

Manufacturer 2
An external transformer is not required if an internal 120/208-V autotransformer is installed. The customer voltage requirements determine if an external transformer is required.

2.1.1.4.5 Power Quality

Manufacturer 1

This generator's electrical output is three-phase, 400–480 VAC and 45–65 Hz. Both voltage and frequency are determined by the grid and mimicked by the generator. Output current will be in phase with grid voltage, with unity power factor. The generator is also capable of DC output up to 700 V. The output conforms to IEEE 519-1992, according to the manufacturer.

Manufacturer 2

The generator's electrical output is three-phase, 275 VAC line to line and 50/60 Hz.

2.1.1.5 Conclusions and Recommendations

- There appears to be reasonable agreement that a fusible disconnect switch or circuit breaker, or both, should exist between the generator and the utility. This affords protection to the utility as well as the generator.
- Standard references can be useful in directly supporting the legitimacy of a utility-generator interconnection document.
- Basic protective devices such as over/undervoltage and over/underfrequency are normally included as part of the generation package. Some packages include additional features such as reverse power flow protection and rate of change of frequency protection.
- Under most circumstances, an intervening transformer is required between the generator and the utility—whether it is internal to the generator package or placed externally in the system.
- While operating parallel to the distribution grid, the generator will attempt to "copy" the electrical characteristics of the grid. This normally provides high-quality power. It is important that a generation source be in conformance with IEEE 519-1992 regarding harmonic distortion.

2.1.2 Architecture and Pertinent Electrical Characteristics of the Utility Distribution System

The basic architecture of the UDS comprises the components and systems described in this section.

2.1.2.1 Power Substation

The power substation serves as an interface between the high voltage transmission system of 345, 138, or 69 kV and the electric UDS of 15 kV or less. The basic function of the power substation is to convert circuit voltage from very high levels to more reasonable levels that can be safely distributed to surrounding communities.

2.1.2.1.1 Characteristics

The power substation consists of large voltage transformers, distribution buswork, reclosers, relaying, and other equipment. The transformers step down the voltage to distribution levels as necessary. Usually, multiple distribution circuits are tapped off of the buswork, which is fed from the secondary side of the transformers. Circuit breakers and reclosers with associated relaying are applied to each outgoing electric distribution circuit.

2.1.2.1.2 Effect on Interconnection

What is the potential relationship between the power substation and the interconnection of DP sources throughout the system? Much of the potential effect is dependent on the distributed generator penetration on the outgoing distribution circuits. Low DG penetration has relatively little or no effect on such substations, but high DG penetration could have a positive effect on power substations by relieving individual distribution circuits of stress because of overload. When strategically placed throughout the service territory, it could also curtail the need for enormously expensive transformer and equipment upgrades at the substation.

2.1.2.2 Distribution Power Lines

These lines distribute power from the secondary side of the substation transformer to commercial, industrial, and residential customers for end use.

2.1.2.2.1 Characteristics

Distribution circuits, emanating from the substation, can be several miles long and are usually made of solid or stranded copper wire, stranded aluminum alloy wire, or steel-reinforced aluminum wire primary conductors. They transmit power at approximately 2–9 kV line voltage and are sized according to the electrical load they support. A typical circuit is designed to support up to several megavolt-amperes in electrical load.

2.1.2.2.2 Effect on Interconnection

The correlation between DG interconnection and power distribution lines is not great until elevated DG penetration levels are reached on an individual circuit. The main effect, which would require research, is two-way power flow on the distribution circuit. In a situation in which DG penetration is high and the utility buys surplus power back from the generator (which may become more common in the near future), there will be times when power flows “backward” through the system (i.e., from the customer to the utility). This is a marked change from the traditional electric distribution infrastructure to which the industry is so accustomed.

2.1.2.3 Primary Voltage Regulation

Distribution circuits span longer distances in rural areas than they do in urban areas. Excessive primary line voltage drops often accompany these longer distances. This creates the need for voltage regulation equipment, which steps the line voltage up to where it should be.

2.1.2.3.1 Characteristics

A general overview reveals that voltage regulation equipment (which can be installed as a bank or with each phase on separate poles) normally includes an adjustable-tap transformer, bypass switch, and monitoring and controls. The regulator setup reads incoming line voltage and increases the voltage when necessary. The adjustable-tap transformer is flexible and can adapt to incoming line voltages.

2.1.2.3.2 Effect on Interconnection

Carefully thought-out implementation of DG technologies would positively affect this aspect of the distribution system. The addition of DG units has the potential to support utility line voltage, particularly in cases in which the circuit traverses a great distance—a situation in which primary line voltage regulators are apt to be installed. In some cases, perhaps, these regulators could be eliminated from the system.

2.1.2.4 Fused Capacitor Banks

A typical alternating-current electric circuit, such as those used to distribute electric power, attempts to keep voltage and current synchronized. As voltage increases, current increases similarly. When current and voltage are not synchronized, energy inefficiencies result. These inefficiencies require additional power and result in higher generation costs. Inductive loads such as transformers and motors cause current to lag behind voltage. If a circuit has too many inductive loads, capacitors are added to help compensate for the lagging current. This is known as power factor correction.

2.1.2.4.1 Characteristics

A typical switched capacitor bank has one or more capacitors tied to each of the three-phase wires and an electronically controlled switch that turns them on or off as the circuit needs them.

2.1.2.4.2 Effect on Interconnection

The interaction between DG and utility capacitor equipment is dependent on the generator technology and the quality of the power it produces. It is possible for such a unit to produce power that is rich in volt-amperes-reactive, thereby increasing the overall power factor of the utility circuit. Similarly, such a unit could put out power in which VARs are consumed, thereby having a negative effect on the utility circuit's power factor.

2.1.2.5 Fused Distribution Transformer

The distribution transformer steps down voltage from primary levels of several kilovolts to usable levels of 120–480 V at the residential, commercial, or industrial customer's premises.

2.1.2.5.1 Characteristics

The distribution transformer is viewed by the utility system as an inductive load, which causes the system current to lag behind the system voltage. This results in a reduced system power factor. Depending on the wiring configuration of the utility transformer, the customer's service can be three- or four-wire, wye or delta (at a variety of voltage levels).

2.1.2.5.2 Effect on Interconnection

The interconnection of a generator with the grid through a transformer secondary shared with other utility customers is not viewed favorably by most utilities. It is thought to be more sound when the customer-generator is connected via a dedicated utility distribution transformer. This provides a buffer between the DG unit and other utility customers and helps protect against unintentional islanding of the generation facility.

2.1.2.6 Metering

The next portion of the UDS is revenue metering. This is usually the last line of defense between the utility and the customer-generator.

2.1.2.6.1 Characteristics

The electric meter has traditionally been used as a one-way device to measure energy use for billing purposes.

2.1.2.6.2 Effect on Interconnection

A major issue concerning DG-grid interconnection is metering and billing. DG applications that focus on load or peak shaving would not cause a problem. However, when a unit produces more power than the customer consumes, what happens to that surplus power? Without a reverse power-relaying scheme, that power will flow backward through the electric meter and onto the power grid.

Two metering options exist. One is net metering, which requires the installation of a bi-directional meter that runs forward and backward in the direction the power is flowing at any instant. The other option is the installation of two separate meters. In this case, one meter registers incoming power flow, and the other accounts for power flow from the customer to the utility system. In most instances, power pushed back onto the grid is not acceptable to the utility and is not compensated for.

2.1.2.7 Safety

When dealing with interconnection issues, a primary concern of utilities is employee safety. In fact, the majority of utility requirements in this area appear to be safety-driven. As a result, this factor has a significant effect on the nature of the interconnection and needs to be adequately addressed before any such project is implemented in the field.

2.1.3 The Physical Interconnection With the Utility Grid, the Equipment Providing Interconnection, and Software and Hardware Required for Safety, Reliability, and Power Quality

The physical interconnection with the grid is more than just a “plug-in” between the grid and the generator; it can involve a complex system of components working together to ensure a safe, sound connection of two separately derived power sources. This section contains a breakdown of a few of the myriad possible components involved in such a scenario. Each component is briefly defined, and some explanation is given of its role in the physical interconnection with the grid.

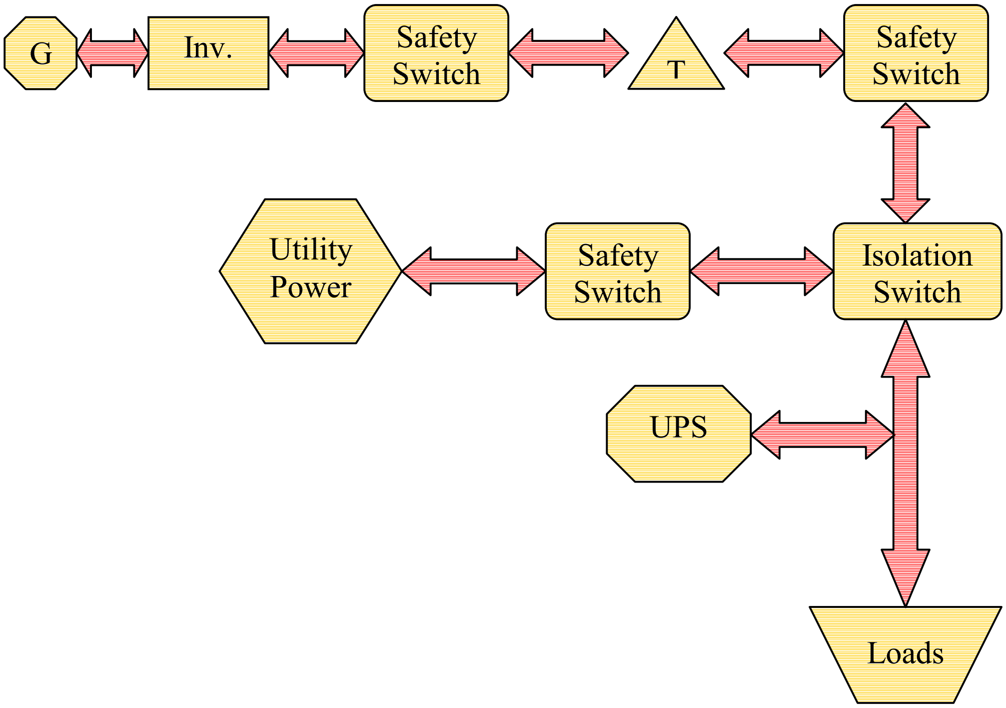


Figure 3. Example of a physical interconnection with utility grid power

2.1.3.1 Power Conditioner, DC to AC

This item is better known as the DC-to-AC inverter. Through a series of microprocessor-based operations, the inverter converts low-voltage direct current power—such as that produced by photovoltaic, battery, and fuel cell systems—into alternating current power suitable for connection with utility-grade power systems. It is a key element of the grid connection setup.

2.1.3.2 Isolation Transformer

The isolation transformer, whether installed to meet utility requirements or solely for voltage transformation of the generator output, is another item that is often between the DG unit and the grid. Typically, this piece of equipment is tied directly to the output of the generator (and possibly inverter), sometimes passing through a manual disconnect switch on the way.

2.1.3.3 Uninterruptible Power Supply Systems

Continuous uninterruptible power supply systems are often used to help critical equipment ride through momentary absences of grid power using instantaneous switchover methods. They also can be used in conjunction with grid-connected alternative power sources to ride through the early stages of an extended utility power outage—the moments needed for certain backup power generation systems to pick up the electrical load.

2.1.3.4 Disconnect Switch
As stressed in earlier portions of this report, the safety disconnect switch is a vital component of the physical interconnection with the grid. The strategically placed fusible disconnect affords protection and control not only to the utility but also to the customer-generator. It provides a means for electrical disconnection during emergency situations. The simple pull of a lever initiates a mechanical reaction that clearly and forcefully creates an open point in the power circuit for which it is installed. The disconnect switch is indispensable to the safe grid-connected generation system.

2.1.3.5 Protective Relays
Protective relays are also essential to safe generator-utility interconnection. Protective relaying accounts for abnormal electrical conditions (abnormal voltages, abnormal frequencies, and unwanted reverse power flow), whether they occur on the utility side or the generator side, and initiates some corrective action prior to the onset of a more dangerous situation.

2.1.3.6 Electrical Distribution Panels
Electrical distribution panels, which contain current-rated circuit breaker protection, distribute the power created by the generating source to the "protected loads" at the customer's facility.

2.1.4 Interconnection Required Tests
Table 17 presents a general overview of the testing required by each surveyed utility. Nearly every utility anticipates some form of testing before allowing a generator to operate in parallel with its system. An in-depth review of the interconnection standards reveals a varying degree of stringency among the testing requirements.

It is imperative that the generation unit's protective relaying package function in a way that ensures safe and sound operation. This can be accomplished through thorough testing, including options for pre-installation and post-installation testing. Commissioning testing takes place prior to connection and start-up of the unit, and periodic functional testing takes place at regular intervals throughout the life of the generator. In most cases, a utility representative must be present for the testing procedure—and sometimes must actually perform the testing procedure. Otherwise, an approved, qualified testing agency is required to perform this.

The main objective of the testing is to verify that the specific protective functions in the generator package will respond as they should to abnormal conditions.

Table 17. Utility-Required Interconnection Testing Procedures

Utility	Interconnection Required Testing
1	Calibration and functional testing are required at installation. Such testing shall be repeated periodically—at no more than 4-year intervals.
2	Functional testing is required prior to initial interconnection. Operating and functionality tests may be conducted at unspecified intervals as deemed necessary.
3	Functional testing of protective equipment is required initially. The utility may test the protective scheme at any given time thereafter.
4	An automatic shutdown test is the only required test for single-phase installations less than 25 kVA. All others require initial commissioning testing per IEEE 1547. Functional testing of protective scheme by utility is required.
5	Pre-installation testing is required. Post-installation testing will be required at the discretion of the utility.
6	Commissioning testing of isolation and fault protection systems is required. Periodic and functional testing of the protective systems is required at intervals specified by the utility.
7	Initial pre-qualifying testing is required. Re-qualification testing is required at intervals of 4 years or less.
8	Functional testing for protective devices is required at intervals as frequent as those used by the utility for its protective devices.
9	Initial and periodic functional testing of fault and isolation protection systems is required; periodic testing is to occur at least every 2 years.
10	There are no specified testing procedures.
11	Included in the standard are type testing, production testing, commissioning testing prior to initial interconnection, and periodic testing at intervals of no more than 4 years.
12	The utility reserves the right to require testing on protective schemes that are not considered an integral part of the manufactured power source system.

Utility	Interconnection Required Testing
13	The utility requires initial and periodic verification of generator performance.
14	Pre-parallel inspection and testing by utility is required. Routine, periodic testing is required at unspecified intervals.
15	Initial relay calibration and functional testing of protective system are required. Periodic testing shall be performed on a biennial, annual, and monthly basis depending on the component to be tested.
16	Commissioning testing prior to interconnection is required. Maintenance testing of protective relaying is required no less frequently than once every 60 months.
17	Pre-parallel operational testing of the protection is required. Maintenance testing is required at the discretion of the utility.

2.2 Institutional Issues Related to Grid-Connected Distributed Generation Systems

The problems related to interconnection at a particular location often are connected to the level of acceptance of DG as a viable energy source by the utility. If there is an awareness and acceptance of DG technology and a consideration of the benefits it can provide to the system and customers, there are generally fewer interconnection-related issues. Table 18 illustrates the potential time and cost issues associated with various utility requirements.

Table 18. Potential Costs and Delays

Factor	Possible Costs	Possible Delays
Utility Rates and Fees	High-rate areas. DG owner may want to implement DG technologies for load-shaving applications. Charges related to lower demand could be applicable. A prospective DG customer wanting to install facilities to carry its entire electrical load might be subjected to charges because of the decrease in utility power use. The possibility of other fees also exists.	Various delays can arise contingent on the perceived need for system review and testing.
Business Practices and Utility Experience	The costs associated with these two factors are a direct result of the grid-connection requirements, technical and otherwise, summed up in the various utility-generator grid-connection standards. Myriad possible costs associated with these standards exist. Project costs could increase significantly depending on a variety of factors, including the attitude toward DG in general.	Time delay could result from cost issues, and additional costs could result from time delays.

2.3 Regulatory Issues Related to Grid-Connected Distributed Generation Systems

Regulatory activities for distribution systems generally take place on a state-by-state basis in the United States. Should the transmission grid be affected, there is also the possibility of consideration by the Federal Energy Regulatory Commission. State governmental bodies can serve as mediators between the electric utility and the prospective DG customer and provide a much-needed "check and balance" function in the overall interconnection scenario. Table 19 lists the status of DG regulatory activity.

The prevailing regulatory issues include:

- Development of interconnection standards
  Several state bodies have already developed comprehensive guidelines to which utility interconnection standards are to be subject and should be based on. Many others have made recommendations and are working toward the development of similar comprehensive guidelines.

- Design of fair and reasonable tariffs
  Utility rate structures should not prohibit or discourage the safe interconnection of distributed energy resources with the electric distribution grid.

- Benefits and costs of DG to the grid
  To ensure proper price signals are given to the marketplace, it is important that the real benefits and costs of DG interconnection be understood prior to any extensive regulatory action.

- Ownership, control, and operation of DG systems
  Various approaches have been proposed based on scale and function.

- Technical processes for connecting to the grid
  Uniform technical guidelines within a state help promote implementation of DG systems. These technical guidelines should be laid out in such a way as to promote reasonable, streamlined methods for safely installing and operating these systems.

- Planning processes necessary for grid-parallel DG operation
  Grid-parallel DG installations require some degree of system planning by the utility.

- Applicability of net metering
  The applicability of net metering should be uniform for specific applications within the state through some regulatory process.

- Identification of barriers to the implementation of DG
  It is important to separate the real technical and economic issues from opinion and localized considerations.

- Determination of the effect of utility regulatory practices on the cost of interconnection
  Different regulatory approaches can result in different costs.

Additional results can be found in the appendix.

Table 19. Status of DG Regulatory Activity

State	DG Regulatory Activity	State	DG Regulatory Activity
Alabama	None	Montana	None
Alaska	None	Nebraska	None
Arizona	Initiated	Nevada	Initiated
Arkansas	None	New Hampshire	Initiated
California	Completed	New Jersey	Initiated
Colorado	None	New Mexico	Initiated
Connecticut	None	New York	Completed
Delaware	Completed	North Carolina	None
Florida	Initiated	North Dakota	None
Georgia	Initiated	Ohio	Initiated
Hawaii	None	Oklahoma	None
Idaho	None	Oregon	None
Illinois	Initiated	Pennsylvania	None
Indiana	None	Rhode Island	None
Iowa	None	South Carolina	None
Kansas	None	South Dakota	None
Kentucky	None	Tennessee	None
Louisiana	None	Texas	Completed
Maine	None	Utah	Initiated
Maryland	None	Vermont	Initiated
Massachusetts	Initiated	Virginia	Initiated
Michigan	Initiated	Washington	None
Minnesota	None	West Virginia	Initiated
Mississippi	None	Wisconsin	Initiated
Missouri	None	Wyoming	None

3 Task 2 Results: Zoning and Permitting of Distributed Power Generators

3.1 Building Codes

Building codes are generally adopted on a state-by-state basis. Usually, a state will adopt one of the national codes such as the International Building Code or the Unified Building Code or one of the other four or five national codes. Then the state will adopt amendments to that code to bring it into compliance with state laws. In some cases, a state legislature may not adopt a building code for the entire state. Some states adopt a building code for only government buildings; they leave it to each municipality to adopt building codes for other specific buildings. The National Electric Code is the only national code that is used in all jurisdictions throughout the United States. This code, in its latest form, does not directly address DG. All references are to emergency and standby generating systems. These approximate only a portion of DG technologies' capabilities.

The scope of this investigation is limited to the nine states in which NiSource provides natural gas distribution service. These states are listed below. The scope of this investigation is also limited to state building codes and does not investigate municipalities.

NET conducted discussions with building officials in the nine states of the NiSource service territory. The following sections summarize telephone conversations with the building code enforcement officials. State building codes are summarized in Table 20.

Table 20. State Building Codes

State	Adopted State Building Code	DG Amendments
Indiana	Unified Building Code	No
Kentucky	BOCA	No
Maine	None	No
Maryland	International Building Code	No
Massachusetts	BOCA	No
New Hampshire	None	No
Ohio	BOCA	Yes
Pennsylvania	Title 34, Pennsylvania's Fire & Panic Code	No
Virginia	BOCA	No

3.1.1 Indiana

The Indiana building code is the Unified Building Code with Indiana amendments. There has not been any discussion about DG in the code enforcement community in this state. At present, any DG installation has to comply with all the requirements of the state building code.

3.1.2 Kentucky

The Kentucky building code is the Building Officials and Code Administrators International Inc. (BOCA) National Building Code with Kentucky amendments. There has not been any discussion about DG at the state level. All DG installations in Kentucky must comply with all the requirements of the state building code.

3.1.3 Maine

Maine has no state-mandated building code. Each municipality adopts its own code. This has lead to about 40 or 50 codes or versions.

3.1.4 Maryland

The Maryland building code is the International Building Code with Maryland amendments. There has been no discussion about DG. All DG installations in Maryland must conform to the Maryland building code.

3.1.5 Massachusetts

Massachusetts' building code is based on BOCA but is approximately 50% unique to Massachusetts. There has been no discussion about DG. All DG installations in Massachusetts must comply with Massachusetts' building code.

3.1.6 New Hampshire

New Hampshire has no state-mandated building code. It is up to the individual municipalities to adopt a building code. All New Hampshire government buildings must comply with BOCA. Some municipalities have taken a no-building-code stance. In these municipalities, there are no building codes.

3.1.7 Ohio

Ohio's building code is the BOCA building code with Ohio amendments. There have been discussions about DG in Ohio, specifically about microturbines. At present, the code in Ohio states that the buildings or structures in which the microturbines are installed are exempt from the building codes. The feeling of Ohio code enforcement people is that the code was written for peaking-type plants that would install the turbines in separate buildings.

3.1.8 Pennsylvania

Pennsylvania has had the same building code since 1927. The code is Title 34, Pennsylvania's Fire and Panic Code. There have been no discussions about DG.

3.1.9 Virginia

The Virginia state building code is the BOCA code with Virginia amendments. There has been no discussion about DG in the Virginia Building Code Enforcement Department.

In summary, there has been very little discussion about DG among building code officials in the NiSource natural gas service area. At present, most jurisdictions rely on building codes to ensure public safety when DG systems are installed. In these jurisdictions, there are no code provisions to ensure safety; therefore, it will be up to each official to try to maintain a safe installation. Without set standards, the scope of the installation cannot be determined prior to the installation. This makes for uncertainty and inconsistency of safety and installation costs.

3.2 Environmental Permitting Considerations

This section considers only the permitting of microturbine installations. Environmental rules pertain to the type and quantity of emissions. The exact emissions of small DG other than microturbines are not considered until there is more detail concerning the specific types to be used. Fuel cell emissions are not well enough known to determine exact requirements.

The scope of this section is to summarize the broad air permitting requirements for the installation of end-user DG microturbines on a state-by-state basis in the NiSource Inc. service territory. This is not an exhaustive review of local, county, and regional requirements that may deviate from state or federal regulations. In the event microturbines are proposed to be installed in specific locations, a detailed, site-specific permit analysis must be conducted to ensure compliance with all laws, regulations, and ordinances. In addition, the review includes the following limitations.

3.2.1 Greenfield Sites

The installation of microturbines at existing air emitting sources could trigger additional requirements, including a "netting analysis" in which the emissions of the proposed microturbines must be aggregated with the existing source emissions. The aggregated emissions then determine if and what type of permit is needed. Because this determination is site-specific, the scope of this report cannot address such situations and is limited strictly to greenfield sites. In the event microturbines are proposed to be sited with an existing source, a case-by-case determination would have to be made.

3.2.2 State Requirements

In general, air permit requirements are dictated in state and federal regulations. In some instances, local codes may contain additional requirements. The scope of this report is limited to a review of state and federal requirements.

3.2.3 Distribution and Transmission Service Territories

The review is limited to the service territory states listed.

3.2.4 Assumed Emissions Profile

The emissions profile is assumed identical to the Mostardi-Platt emissions testing at the Northern Indiana Public Service Company Aetna Complex in Gary, Indiana, on Nov. 11, 1999. The maximum emissions profile is summarized in Table 21 and reflects the maximum emissions tested or the maximum published emissions in the United States Environmental Protection Agency (USEPA) AP-42 compilation.

3.2.5 Assumed Turbine Installation

Information on permit applicability is based on a Capstone Model 330 recuperator microturbine firing natural gas at a maximum rate of 0.43 MMBtu/hr and a fuel heating value of 1,020 Btu/cu ft.

State and federal regulations were the primary source of permit applicability information. In addition, many states publish air permit guidelines. These guidelines were used as an aid to determine if any applicable requirements existed. Finally, states were contacted via telephone as a “clean-up” effort in the event that applicable requirements were not apparent in the published regulations or guidance. Table 22 lists the regulation, guidance, and contact information on a state-by-state basis.

Table 21. Maximum Emissions Profile for Microturbines

	Single Unit	**200 kW (8 units)**	
Pollutant	**Maximum (lb/hr)**	**Maximum (lb/hr)**	**Maximum (tons/yr)**
NO_x[1]	0.126	1.01	4.42
CO	0.02	0.16	0.70
VOC	0.009	0.072	0.32
PM/PM_{10}	0.006	0.048	0.38
SO_2	0.0005	0.004	0.02
Formaldehyde	0.0002	0.0016	0.007

[1] NO_x emissions are based on the tested results at a partial load of 20 kW (highest tested value). Testing at full load was 0.011 lb/hr, and the NO_x guarantee on the unit (at maximum load) is 0.0146 lb/hr.

Table 22. State Air Permit Contact Information

State	Rule/Guidance Web Site	Telephone Contact
Kentucky[1]	http://www.lrc.state.ky.us/kar/TITLE401.HTM	(502) 573-3382
Indiana[1]	http://www.IN.gov/idem/rules/	(317) 233-0178
Ohio[1]	http://www.epa.state.oh.us/dapc/fops/addinfo.html	Must call specific region. See Web site.
Virginia[1]	http://www.deq.state.va.us/regulations/air80.html	(804) 698-4023
Pennsylvania[1]	http://www.dep.state.pa.us/dep/deputate/airwaste/aq/permits/permits.html	(717) 787-4325
Maryland[1]	http://www.mde.state.md.us/arma/Programs/Aqpermit/aqpermit.html	(410) 631-3225
Massachusetts[1]	http://www.state.ma.us/dep/bwp/daqc/files/regs/7a.htm#022	(617) 338-2255
New Hampshire[1]	http://www.des.state.nh.us/ard/whatsrce.htm	(800) 498-6868
Maine[1]	http://www.state.me.us/dep/air/faq.htm	(207) 287-2437
West Virginia[2]	http://www.dep.state.wv.us/oaq/permit/nsr/nsr.html	(304) 926-3727
Delaware[2]	http://www.dnrec.state.de.us/air/aqm_page/regs.htm	(302) 739-4764
New Jersey[2]	http://www.state.nj.us/dep/aqm/2708985.html	(877) 927-6337
New York[2]	http://www.dec.state.ny.us/website/dcs/air/air02.html	Must call specific region. See Web site.
Louisiana[2]	http://www.deq.state.la.us/planning/regs/title33/33v03.pdf	(225) 765-0219
Mississippi[2]	http://www.deq.state.ms.us/newweb/homepages.nsf	(601) 961-5192
Tennessee[2]	http://www.state.tn.us/sos/rules/1200/1200-03/1200-03-09.pdf	(615) 532-8657

[1] Natural gas transmission and distribution territory
[2] Natural gas transmission territory

3.3 Summary of Environmental Considerations

3.3.1 Federal

There are no known federal air permit regulations applicable to the installation of microturbines with a maximum firing rate less than 10 MMBtu/hr in a combined installation at a greenfield site of less than 200 kW with the emissions profile shown in Table 21.

3.3.2 State

1. State requirements vary somewhat. Table 23 summarizes air permit exemption levels in our distribution and transmission territories on a state-by-state basis. The microturbine heat inputs and emissions profile will fall under an exemption status in most states. Table 24 summarizes permit requirements based on the review conducted.

Table 23. Exemption Levels on a State-by-State Basis

State	Exemption Levels (Emissions Less Than the Following Amounts)						Single HAP	Total HAP	Special Exemptions
	NO_x	CO	VOC	PM_{10}	SO_2	Pb			
Kentucky[1]	5 tpy	5 tpy	5 tpy	5 tpy	5 tpy		2 tpy	5 tpy	
Indiana[1]	10 tpy	25 tpy	10 tpy	5 tpy	10 tpy				
Ohio[1]	10 lb per 24 hours	10 lb per 24 hours	10 lb per 24 hours	10 lb per 24 hours	10 lb per 24 hours		1 tpy		Natural gas combustion less than 10 MMBtu/hr
Virginia[1]	40 tpy	100 tpy	25 tpy	15 tpy	40 tpy	0.6 tpy			Gaseous fuel combustion less than 50 MMBtu/hr
Pennsylvania[1]									Natural gas combustion less than 10 MMBtu/hr
Maryland[1]									Natural gas combustion less than 1 MMBtu/hr
Massachusetts[1]									Combined combustion turbine installation less than 3 MMBtu/hr
New Hampshire[1]									Natural gas combustion less than 10 MMBtu/hr
Maine[1]									Natural gas combustion less than 10 MMBtu/hr
West Virginia[2]	10 tpy	10 tpy	10 tpy	10 tpy	10 tpy			5 tpy	No other requirements
Delaware[2]	0.2 lb/day	0.2 lb/day	0.2 lb/day	0.2 lb/day	0.2 lb/day	0.2 lb/day			
New Jersey[2]									Gaseous fuel combustion less than 1 MMBtu/hr
New York[2]									Natural gas combustion less than 10 MMBtu/hr
Louisiana[2]	5 tpy	5 tpy	5 tpy	5 tpy	5 tpy				Generally must obtain exemption letter
Mississippi[2]	10 tpy	10 tpy	10 tpy	10 tpy	10 tpy		1 tpy	2.5 tpy	
Tennessee[2]									Gaseous fuel combustion less than 10 MMBtu/hr

[1] Natural gas transmission and distribution territory.

[2] Natural gas transmission territory.

Table 24. Air Permit Requirements

State	30 kW Exempt[3]	200 kW Exempt[4]	Requirements
Kentucky[1]	Yes	Yes	
Indiana[1]	Yes	Yes	
Ohio[1]	Yes	Likely[5]	
Virginia[1]	Yes	Yes	
Pennsylvania[1]	Yes	Yes	
Maryland[1]	Yes	No	More than two microturbines at a site will require a state permit.
Massachusetts[1]	Yes	No	More than six microturbines at a site will require a state permit.
New Hampshire[1]	Yes	Yes	
Maine[1]	Yes	Yes	
West Virginia[2]	Yes	Yes	Assumes no other local requirements apply.
Delaware[2]	No	No	State permitting required.
New Jersey[2]	Yes	No	More than two microturbines at a site will require a state permit
New York[2]	Yes	Yes	
Louisiana[2]	Yes	Yes	Generally must obtain an exemption letter.
Mississippi[2]	Yes	Yes	
Tennessee[2]	Yes	Yes	

[1] Natural gas transmission and distribution territory
[2] Natural gas transmission territory
[3] Assumes maximum heat input of 0.43 MMBtu/hr
[4] Assumes maximum heat input of 3.44 MMBtu/hr
[5] Ohio exempts natural gas combustion units less than 10 MMBtu/hr. However, NO_x emissions potentially exceed the 10-lb-per-24-hour exemption level and create a conflict in the regulations. A region-specific determination would have to be made by the controlling Ohio agency.

2. State permitting could potentially be required for Maryland and Massachusetts in the distribution territory. Delaware will and New Jersey could also potentially require state permits in the event distribution is expanded into these states. In addition, Louisiana strongly encourages an exemption letter be obtained prior to the start of installation.
3. Table 25 lists the permit fees and time required from application submittal to installation for those states that may require permitting for microturbines.

Table 25. Permit Fees and Timelines

State	Permit Fee	Required Time From Submittal to Installation
Maryland	$500	Valid permit upon submittal of fee and forms
Massachusetts	$300	90 to 120 days
Delaware	$300	60 days
New Jersey	$250	Valid permit upon agency receipt of fee and forms

Note: Increments on a state-by-state basis

4. One last consideration is that the installation of microturbines in ozone non-attainment areas may be more difficult. In general, requirements and project scrutiny become more onerous. For example, in Indiana, if a microturbine is sited at an existing source, aggregation of emissions with the source is required and actually may require NO_x offsets. Siting in these areas requires a site-specific permit applicability determination.

Figure 4 provides a comparison of service territories versus ozone non-attainment areas. Microturbine installation at a greenfield site classified as exempt likely will not be a problem in ozone non-attainment areas but should be further reviewed.

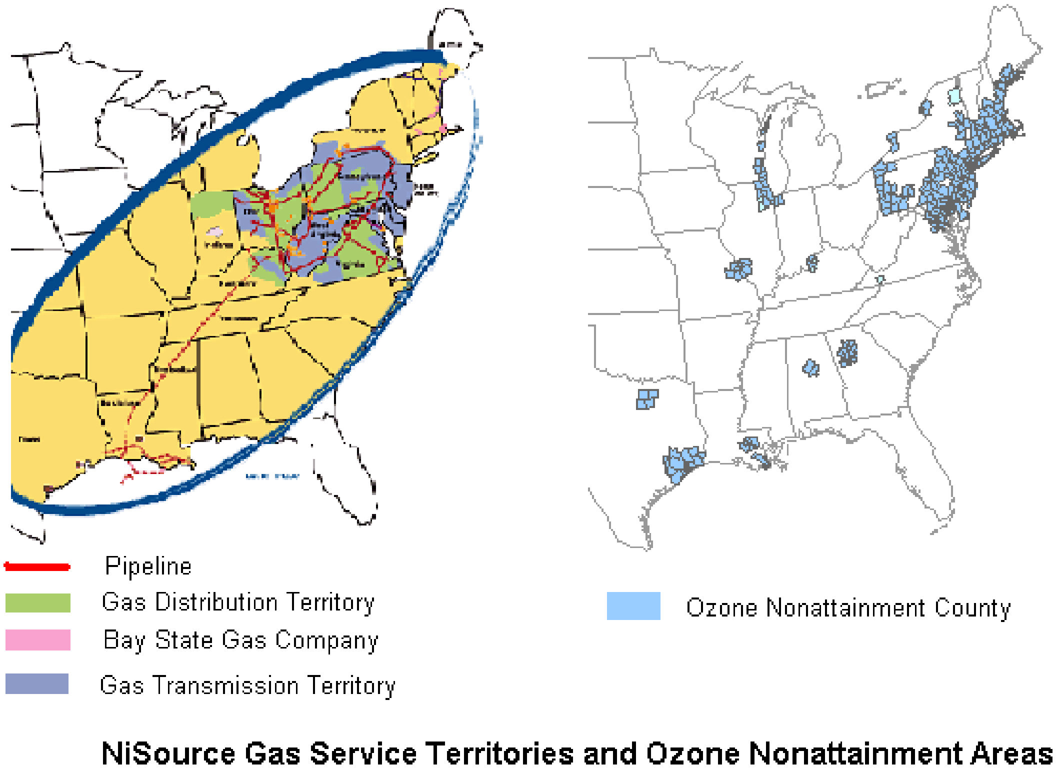


Figure 4. NiSource gas service and ozone nonattainment areas

3.4 Recommendations

1. Once site locations have been chosen, a comprehensive permit applicability review must be conducted on a site-specific basis to ensure compliance with applicable laws, regulations, and ordinances.
2. Because of the limited review in this study and in the event installation needs to be fast-tracked, exemption letter requests could be sent to select states to obtain an agency determination of exemption prior to final siting.
3. Once a "short list" of potential microturbine installation sites has been determined, a detailed air permit applicability review should be conducted to avoid undue delays.
4. DG microturbines installed in non-attainment areas could result in additional requirements.

4 Task 3 Results: System Integration and Performance

Task 3 was concerned with the operating characteristics of DG systems in various situations. In this task, DG systems at two locations were tested to determine various operating and performance characteristics.

4.1 Test Systems

4.1.1 Test System 1

The first location was a commercial site in Chesterton, Indiana. This location has part of its electric load supplied by a CHP system that incorporates a microturbine on the roof of the building. This system operates in a base load manner 24 hours a day, 7 days a week. It is grid-synchronized and has the capability to isolate from the grid with a bumpless transition in the case of loss of power from the grid. In isolated mode, essential loads such as computers and cash registers as well as most lighting and essential building systems continue to operate.

One consideration for this system was its performance over time. A parameter of interest is the efficiency of the electric production. Because the concern was with the potential change in efficiency over time, a basic efficiency calculation was performed. It had a limited number of parameters such that the experiment could be readily characterized and repeated. Efficiency was defined as the energy value input to the turbine in terms of the watts of heat produced by the combustion of the natural gas versus the total electric watts produced by the turbine package after the inverter. These quantities were readily available in real time and involved minimal chances for systematic error.

Figure 5 is the test system at the Chesterton commercial site, which incorporates a microturbine on the roof of the building.

Figure 5. Chesterton, Indiana, system

Figure 6 is the data for a typical test period.

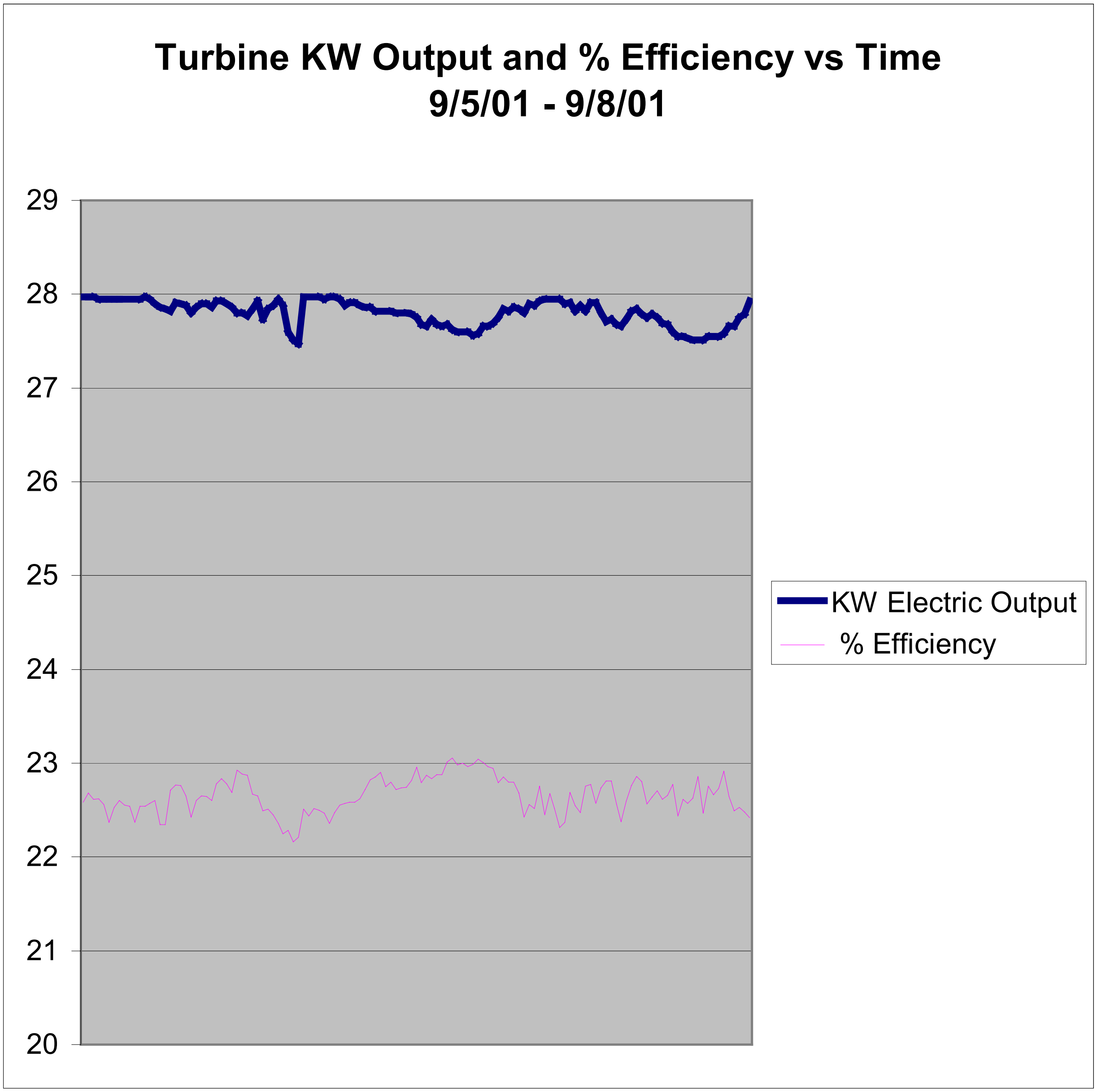


Figure 6. Typical output data from the Chesterton system

In addition to the tests previously described, a preliminary building energy model was developed. When finalized, this model will allow for dynamic (including transient) modeling of building energy use in a CHP mode. Efforts are proceeding with model development and benchmarking.

4.1.2 Test System 2

The second test system was at an industrial site in Gary, Indiana. This site was chosen because of its proximity to existing test facilities and its location near a large industrial substation. The proximity to large industrial loads was important because such loads routinely cause harmonics and other disturbances on the local electric grid. This test was designed to consider the performance of the microturbine in a challenging, real-life environment.

To maximize the value of the experimental effort, a full two-level factorial experiment design was employed for the tests. The techniques used were typical for design of experiment test procedures. Initially, the calculations were performed by hand, but after gaining confidence with the experiment details, a commercial data analysis program was used for the bulk of the data analysis.

4.2 System Test Design

The tests, test equipment, procedures, and data are presented in the following sections.

The test equipment for testing systems 1 and 2 was the same. The equipment was as follows:

Test Equipment

- Microturbine input
  - Microturbine distributed generator
  - Natural gas flow meter – Roots Meter model 15M175 with Roots magnetic coupled EL transmitter model R-3 (three pulses per impeller revolution)
  - Induction load–transformer – 45 kVa and pump 14 hp 460 V–3ph–60 Hz
  - Type “E” thermocouples
  - Artificial load boxes providing heat (resistance heat)
  - RF Technologies Inc. Pressure Transducer mo. PTXI-60 psi

- Microturbine output
  - Metrosonics PA-9

Data Collection Equipment

- Microturbine input
  - Labtech Control software (version 10.1); data logged in Microsoft Excel

- Microturbine output
  - Metrosoft MSPA-9W exported to Microsoft Excel

Data Collection Parameters

- Microturbine input
  - Combustion air temperature (°F)
  - Fuel gas temperature (°F)
  - Ambient temperature (°F)
  - Fuel gas pressure (psig)
  - Fuel gas actual flow rate (acfh)

- Microturbine output
    - Current THD
    - Voltage THD
    - Total power factor
    - Kilowatts
    - Volts
    - Amps

4.3 Test Approach for System 1 and System 2

The purpose of this test is to compare the energy input and the electrical energy output (efficiency) of the microturbine distributed generator when the following input and output parameters are varied:

- Natural gas supply pressure (5 psig and 10 psig)
- Combustion air temperature (85°F and 95°F)
- Inductive load (on and off)
- Power source output (15 kW and 23 kW).

Data were collected according to the factorial design, as previously indicated. Efficiency was calculated from the potential chemical energy input compared with electrical energy output. Potential chemical energy input was determined from fuel gas calculations based on the fuel gas pressure, fuel gas temperature, fuel gas flow rate, and fuel gas heating value of 1,022.5 Btu/ft^3.

The microturbine distributed generator efficiency was tested with the natural gas supply pressure at either 5 psig or 10 psig, with a combustion air inlet temperature of 80°F or 90°F, with the microturbine output set at either 15 kW or 23 kW, and with the inductive load either energized or not energized. The inductive load consisted of a transformer and a 14-hp water pump wired in parallel. The inductive load was added to lower the power factor on the circuit. A power factor of 0.6 was measured prior to starting either microturbine. All combinations of these parameters were tested, and the resulting data were logged using Labtech Control (version 10.1) for the inputs and Metrosoft MSPA-9W for the outputs. For each run, the parameters were set, the system was allowed to come to equilibrium, and a 5-minute data collection run was conducted. The data collected by the Labtech Control software was logged at a rate of once a second. The data collected by the Metrosonics equipment indicated the minimum, maximum, and average of each parameter and were logged once every minute during each 5-minute run.

The input kilowatts were calculated from the logged input data using the following algorithms:

1) $\underline{\text{SCFH} = \text{acfh}}\ \text{X}\ \dfrac{\text{gas pressure (psia)}}{14.7}\ \text{X}\ \dfrac{530}{\text{Temperature (°C)}}$

2) INPUT kW = SCFH X 1022.5 BTU/ft^3 X = 0.2931 kW/BTUH

3) System efficiency = input kW/output kW

4.4 Approach for Testing System 1 and System 2 Combined

Test Equipment

- Microturbine input
  - Microturbine distributed generators
  - Natural gas flow meters – Roots meter model 15M175 with Roots magnetic coupled EL transmitters model R-3 (three pulses per impeller revolution)
  - Induction load consisting of two transformers – 45 kVa, identical, and two pumps, one 14 hp 460 V-3 ph-60 Hz and the other 9 hp 460 V-3ph-60 Hz
  - Type "E" thermocouples
  - Artificial load boxes providing heat to control combustion air temperature (resistance heat)
  - RF Technologies Inc. pressure transducers mo. PTXI-60 psi

- Microturbine output
  - Metrosonics PA-9

Data Collection Equipment

- Microturbine input
  - Labtech Control Software (version 10.1); data logged in Microsoft Excel

- Microturbine output
  - Metrosoft MSPA-9W exported to Microsoft Excel

Data Collection Parameters

- Microturbine input
  - Combustion air temperature (°F) for each microturbine
  - Fuel gas temperature (°F)
  - Ambient temperature (°F)
  - Fuel gas pressure (psig)
  - Fuel gas actual flow rate (acfh) for each microturbine

- Microturbine output for each microturbine
  - Current THD
  - Voltage THD
  - Total power factor
  - Kilowatts
  - Volts
  - Amps

The test procedure for the combined tests is the same as that used for tests 1 and 2.

4.5 Test Results for Testing System 2

4.5.1 Test 1

In this test, a single microturbine was attached to the grid through a transformer, and inductive loads were connected as indicated in the experimental design. The temperature of the intake air was adjusted as indicated. A four-factor experimental design was employed. Figure 7 illustrates the physical design of the equipment.

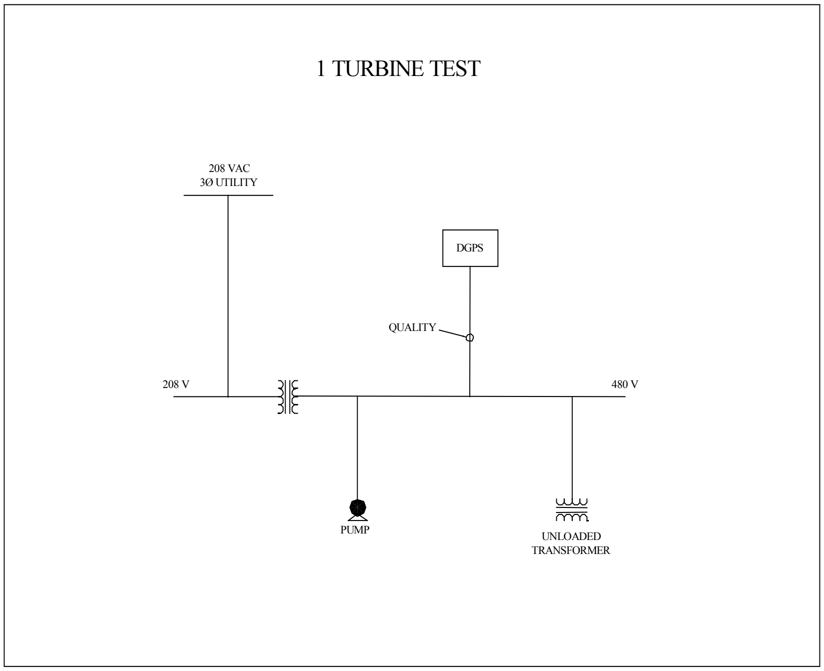


Figure 7. Equipment for a single microturbine test

The diagram shows that the turbine was connected to the grid through a corner grounded delta-wye transformer. A 14-hp pump was run continuously to simulate a typical load, and an unloaded 45-kVA transformer was connected or disconnected to change the power factor. Gas pressure, inductive load, intake temperature, and turbine output were chosen as factors for the experimental design to determine sensitivities. Turbine efficiency—calculated as the ratio of watts of thermal energy input from the combustion of the natural gas fuel to the watts of electricity produced—was the first response. The second response was the total current harmonic distortion (THD). The THD was measured at the location indicated as “Quality” on the previous diagram with a Metrasonics 703 power quality instrument. The values reported for THD are the average of the current THD values for all three phases.

Table 26 describes the experimental design for Test 1.

Table 26. Experimental Design for Factorial Analysis Conducted in Test 1

Order Std	Run	Factor 1 Gas Pressure	Factor 2 Transformer (Inductor)	Factor 4 Turbine Output	Response 1 Efficiency (Fraction)	Response 2 THD (current)
11	1	5.00	on	80.00	24.00	0.1901
13	2	5.00	off	90.00	24.00	0.1866
9	3	5.00	off	80.00	24.00	0.1871
1	4	5.00	off	80.00	16.00	0.1824
6	5	10.00	off	90.00	16.00	0.1825
4	6	10.00	on	80.00	16.00	0.1803
8	7	10.00	on	90.00	16.00	0.1779
10	8	10.00	off	80.00	24.00	0.1892
5	9	5.00	off	90.00	16.00	0.1753
16	10	10.00	on	90.00	24.00	0.1863
2	11	10.00	off	80.00	16.00	0.1815
14	12	10.00	off	90.00	24.00	0.1869
12	13	10.00	on	80.00	24.00	0.1897
7	14	5.00	on	90.00	16.00	0.1753
3	15	5.00	on	80.00	16.00	0.1783
15	16	5.00	on	90.00	24.00	0.1823

A half normal plot was assembled from the data to aid in choosing the parameters of the model (see Figure 8).

For two-level factorial designs, this plot is used to choose significant effects. A plot of the ordered values of a sample versus the expected ordered values from the true population is approximated by a straight line. Hence, if the effects represent a sample from a normal population, they would form approximately a straight line on a normal probability plot of the effects. The important effects show up as outliers on the normal probability plot.

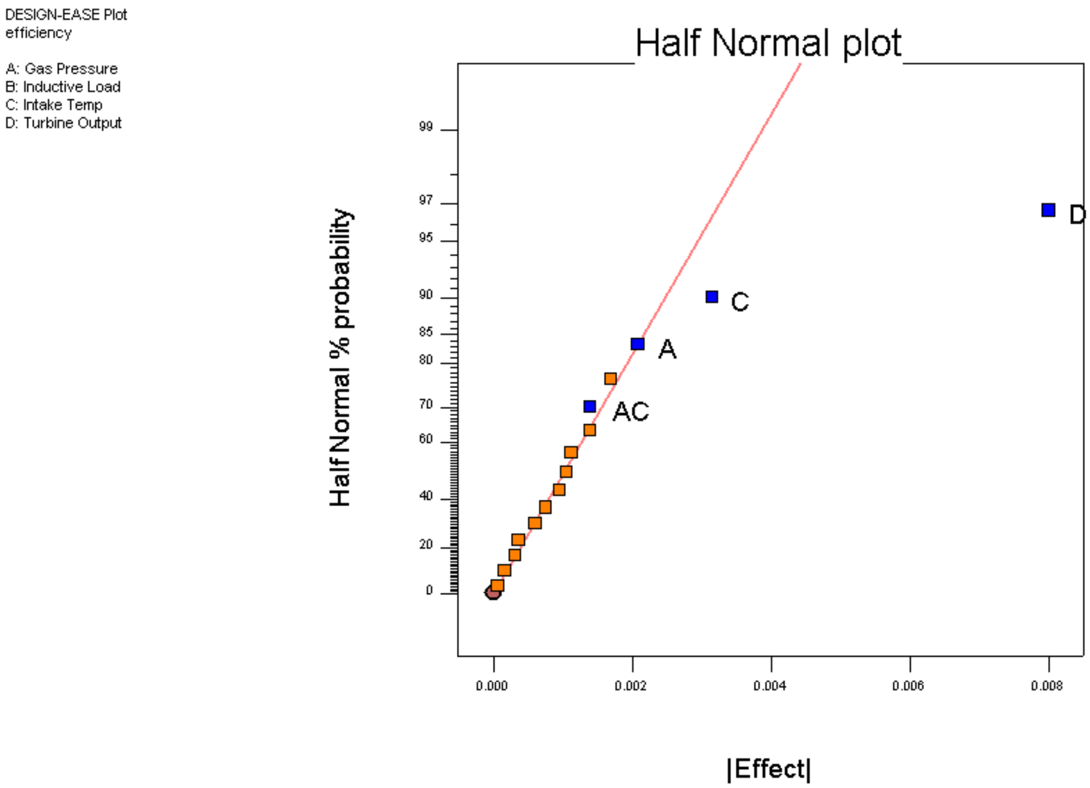


Figure 8. Half-normal plot of test data for single turbine, Test 1

Data plotted on this graph were used to choose parameters for the model. The model parameters were A, C, D, and AC. This resulted in the following model:

> Efficiency = +0.22296 – (4.38000E-003 * Gas Pressure) - (7.42500E-004 * Intake Temp) + (1.01094E-003 * Turbine Output) + (5.65000E-005 * Gas Pressure * Intake Temp).

The statistical results for the model are given in Table 27.

Table 27. Modeled Results From Factorial Analysis for Test 1

Efficiency

Degrees of Freedom for Evaluation

Model	4
Residuals	11
Lack of Fit	11
Pure Error	0
Corr Total	15

				Power at 5 % alpha level for effect of		
Term	**Std Err***	**VIF**	**Ri-Squared**	**1/2 Std Dev**	**1 Std Dev**	**2 Std Dev**
A	0.25	1	0	15.00%	44.60%	95.30%
B	0.25	1	0	15.00%	44.60%	95.30%
C	0.25	1	0	15.00%	44.60%	95.30%
D	0.25	1	0	15.00%	44.60%	95.30%

*Basis Std Dev = 1.0

The power for a signal-to-noise ratio of two standard deviations is 95.3% in this test. Hence, only one replicate was run.

Residual analysis was next considered to confirm the assumptions of the analysis of variance. The normal probability plot should be a straight line. Studentized residuals versus predicted should show a random scatter. As shown in Figure 910, predicted versus actual should show points scattered randomly along a 45-degree line. Outlier T versus run number should be within the bounds indicated. The Box Cox plot is used to see if a data transformation is appropriate.

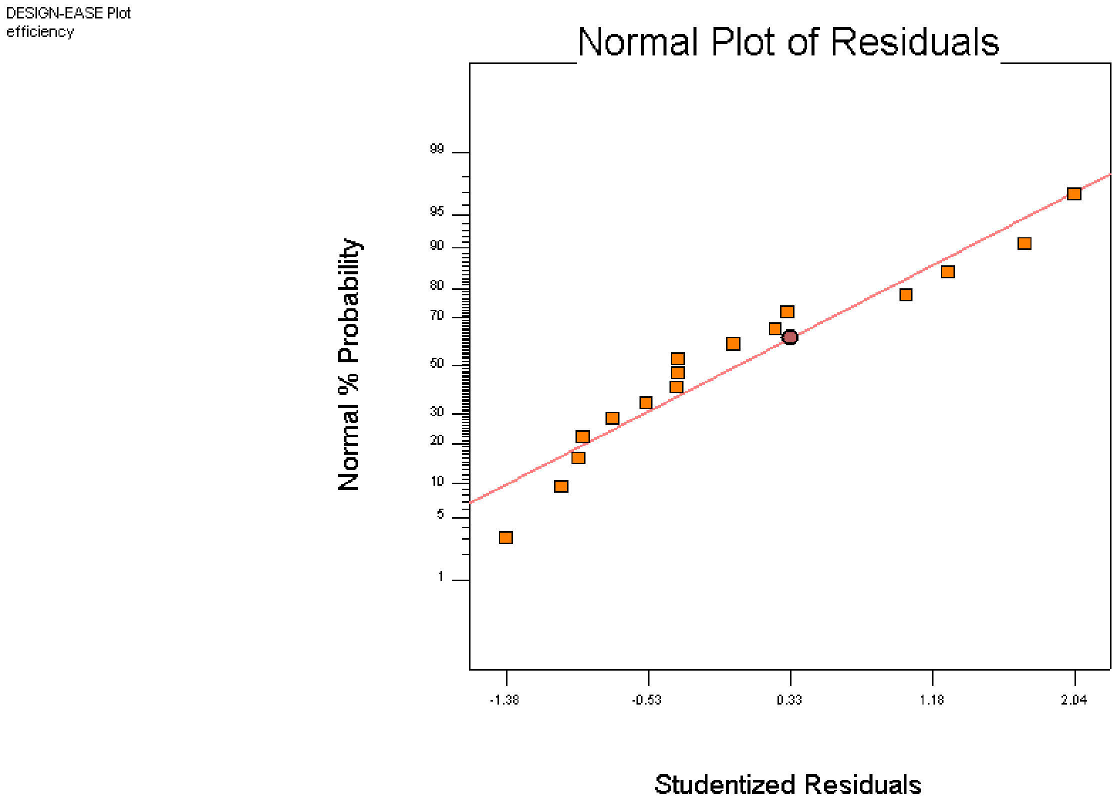


Figure 9. Normal probability plot of normal residuals

A normal probability plot indicates whether the residuals follow a normal distribution and, hence, a straight line. A small amount of scatter about the line is expected.

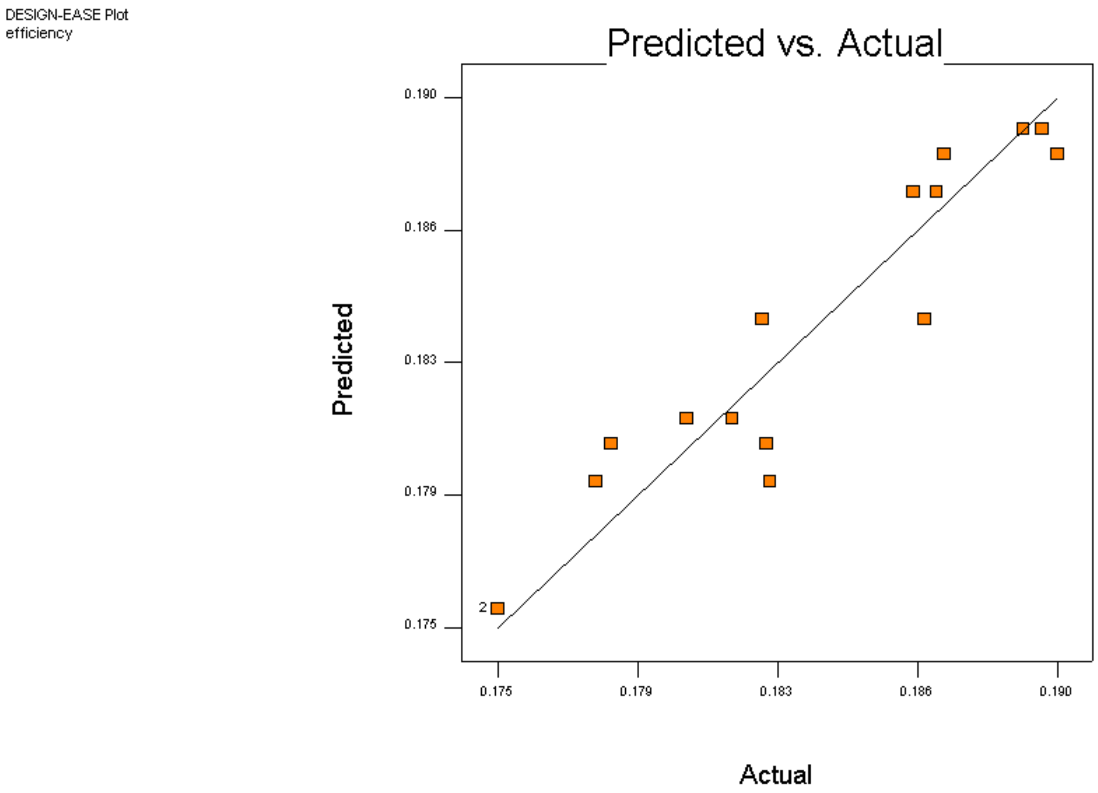


Figure 10. Actual versus predicted residuals

The plot in Figure 11 illustrates the residuals versus the ascending predicted response values. It tests the assumption of constant variance. The plot should be a random scatter (constant range of residuals across the graph.)

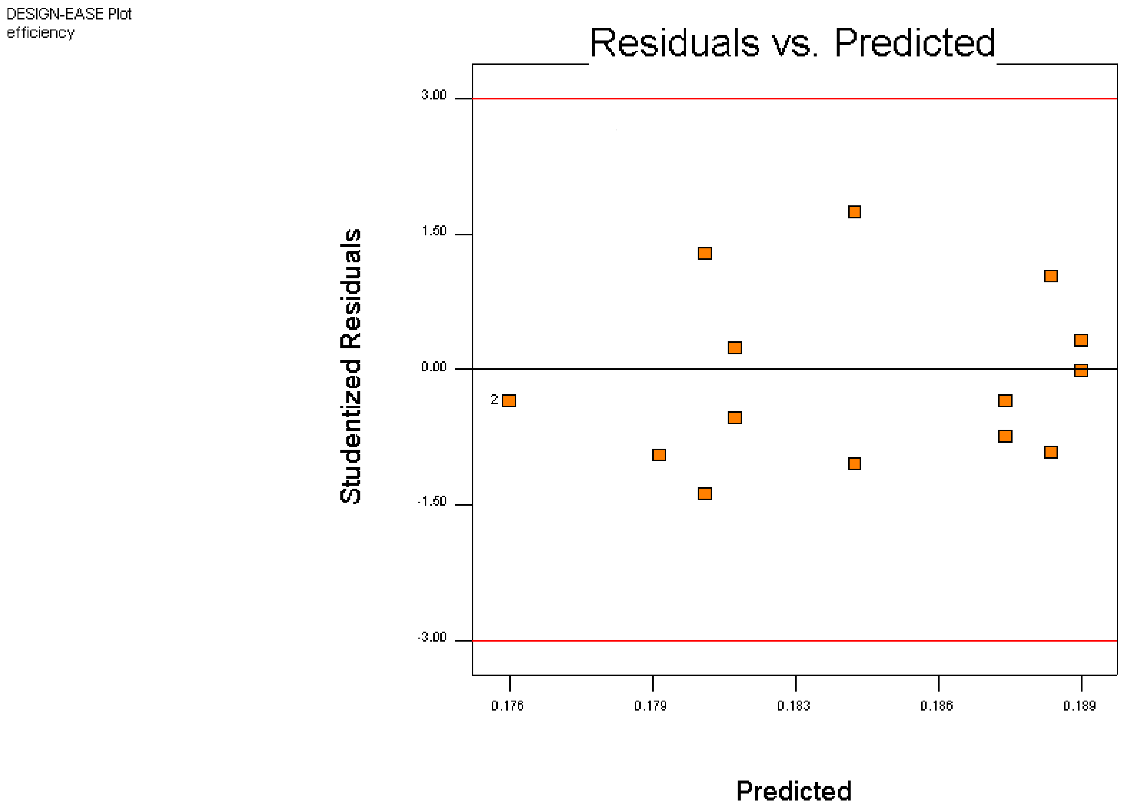


Figure 11. Data testing constant variance and random scatter

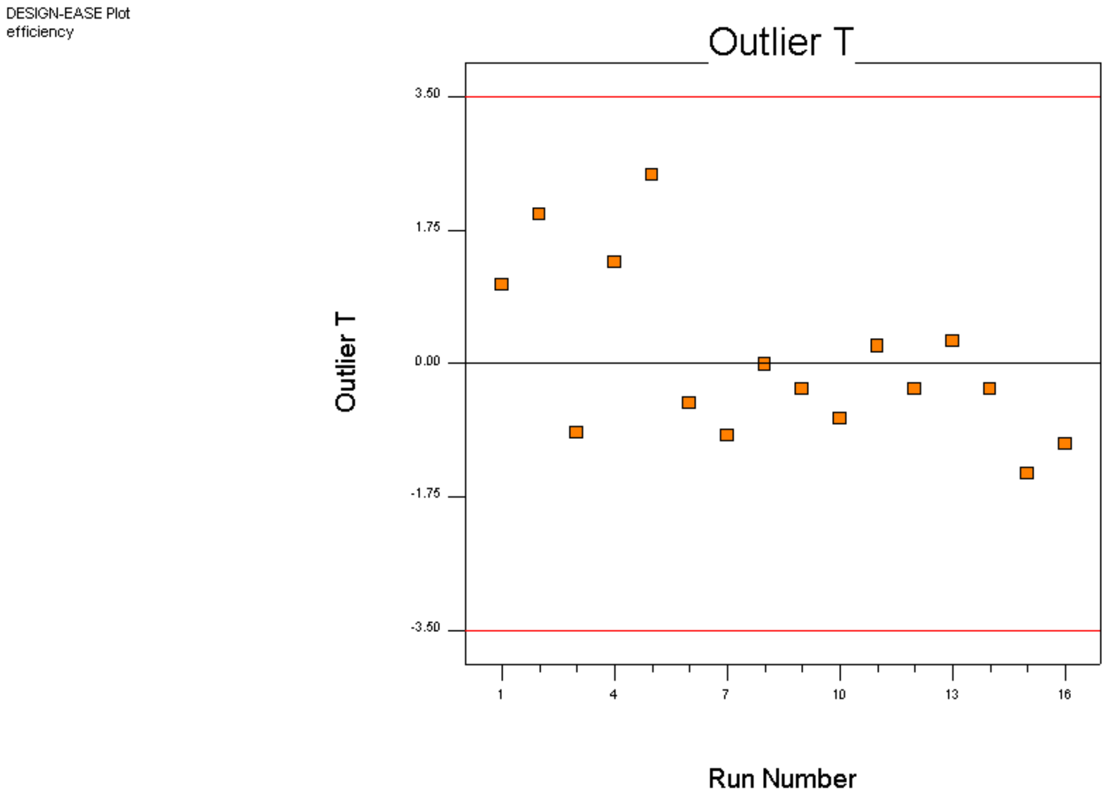


Figure 12. Plot of data control limits

This graph is an indication of how many standard deviations the actual value deviates from the value predicted after deleting the point in question.

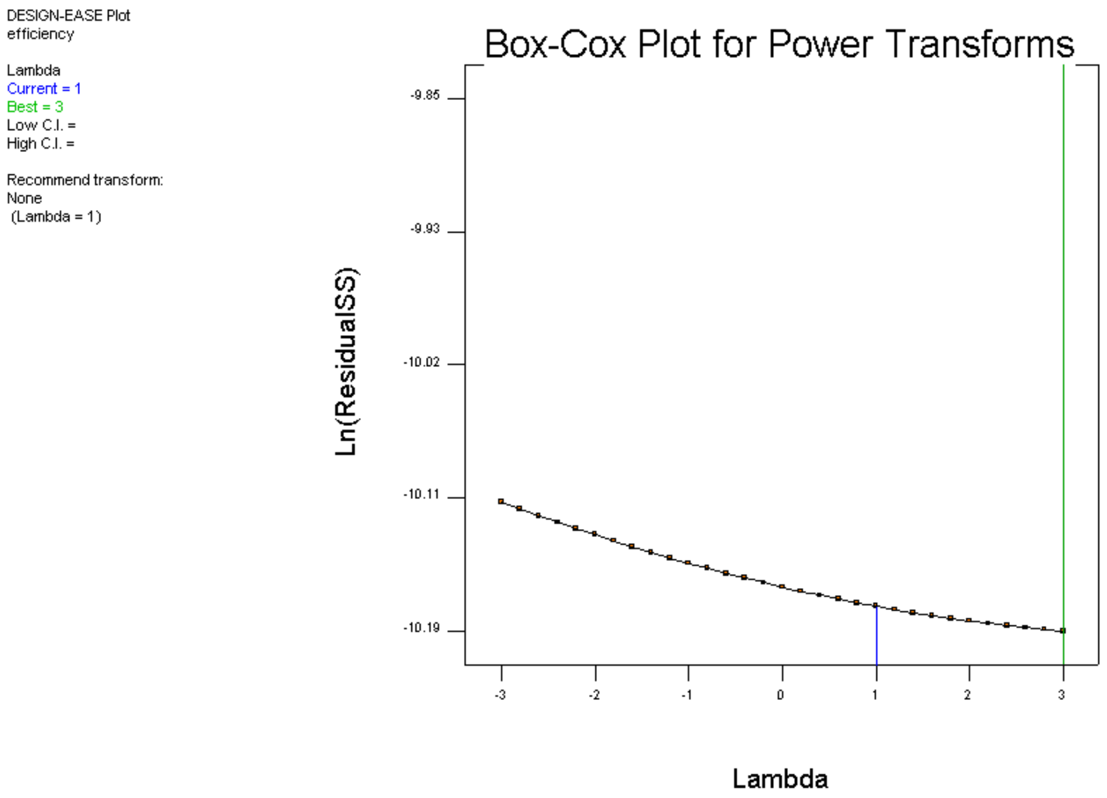


Figure 13. Box Cox plot for power transforms, Test 1

This figure provides information about the potential selection of a power law transformation. If a recommended transformation is listed, it is based on the best lambda value, which is found at the minimum point of the curve generated by the natural log of the sum of squares of the residuals. If the 95% confidence interval around this lambda includes 1, then a specific transformation isn't recommended.

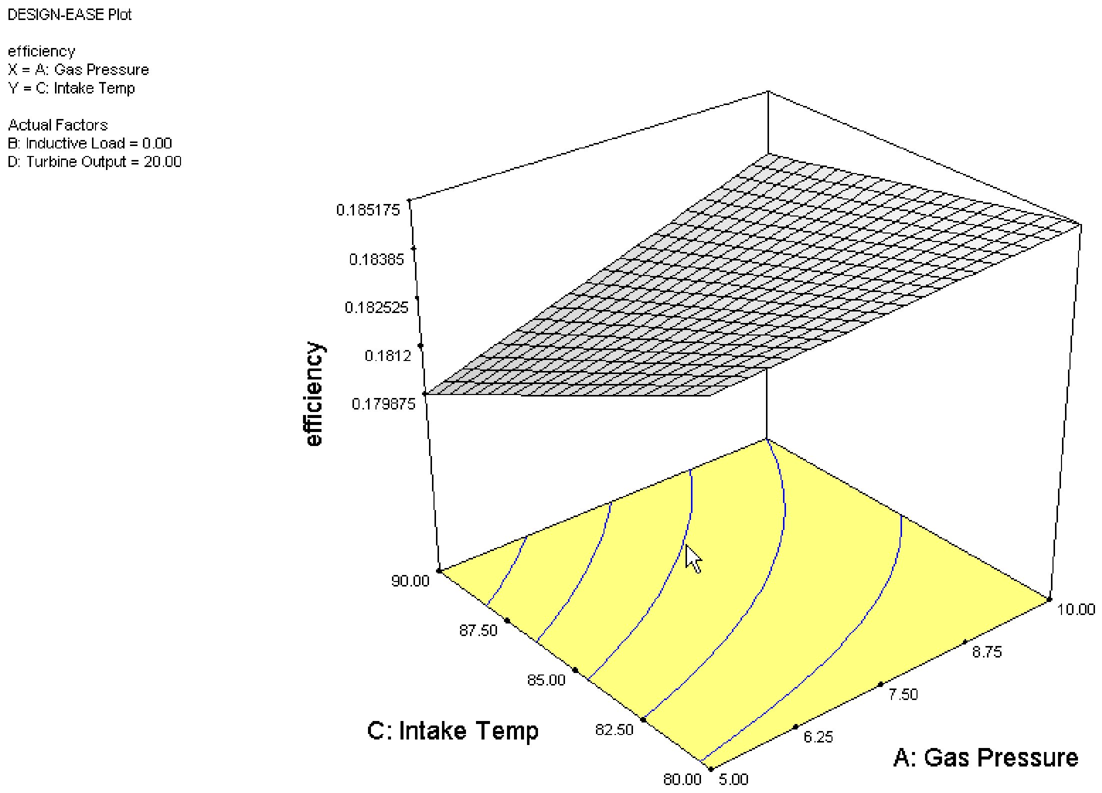


Figure 14. Effect of intake temperature on operating efficiency – System 1, Test 1

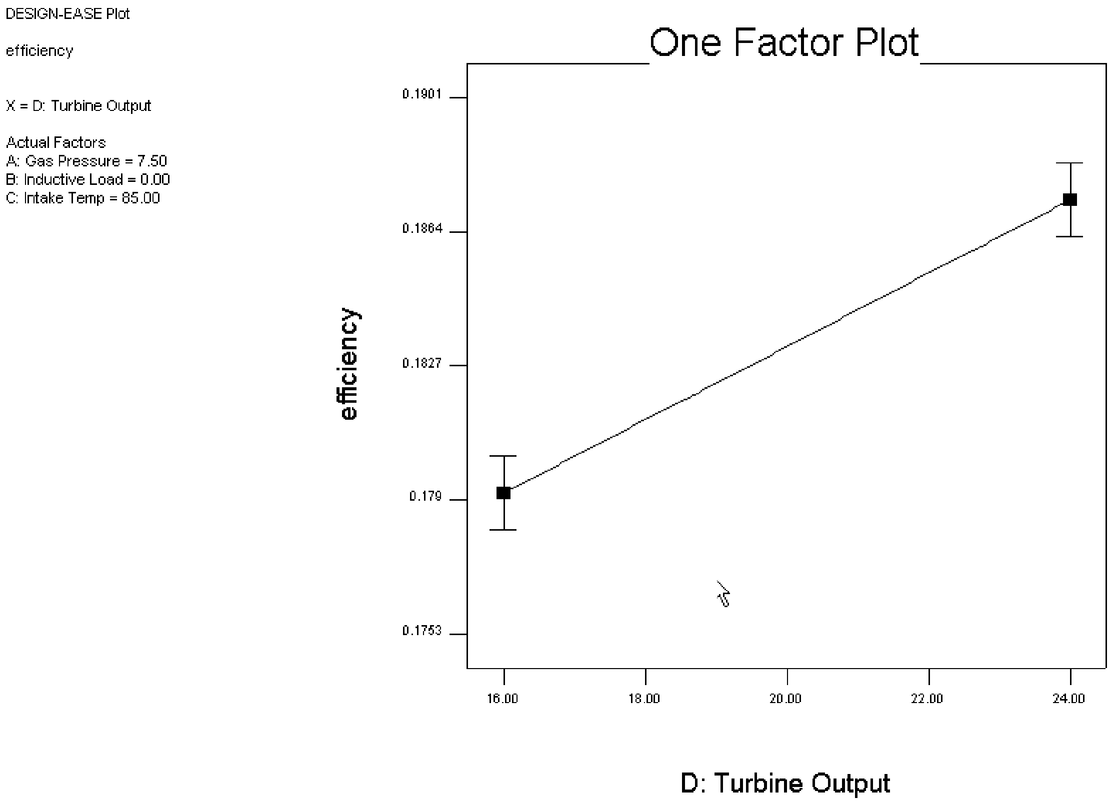


Figure 15. Range of efficiency relative to power output – System 1, Test 1

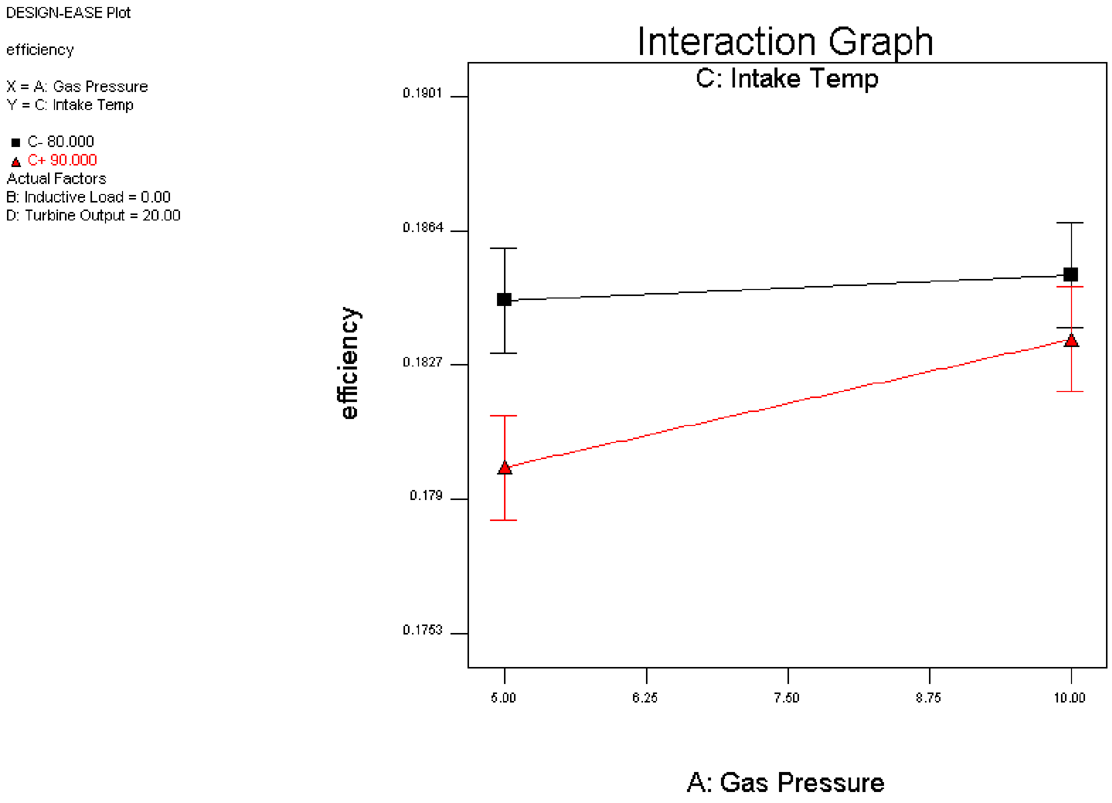


Figure 16. Effect of gas pressure on operating efficiency

As can be seen from figures 14, 15, and 16, efficiency is dependent on temperature, output level, and gas pressure. There is also a minor interaction between gas pressure and intake temperature. For this microturbine, changing the local power factor had negligible influence on efficiency.

The results were also evaluated for total harmonic distortion (THD). These data are presented in figures 17–22. The analysis continues the factorial assessment to identify the parameters most significant for microturbine operation.

The following set of graphs relate to the second response, which is current THD.

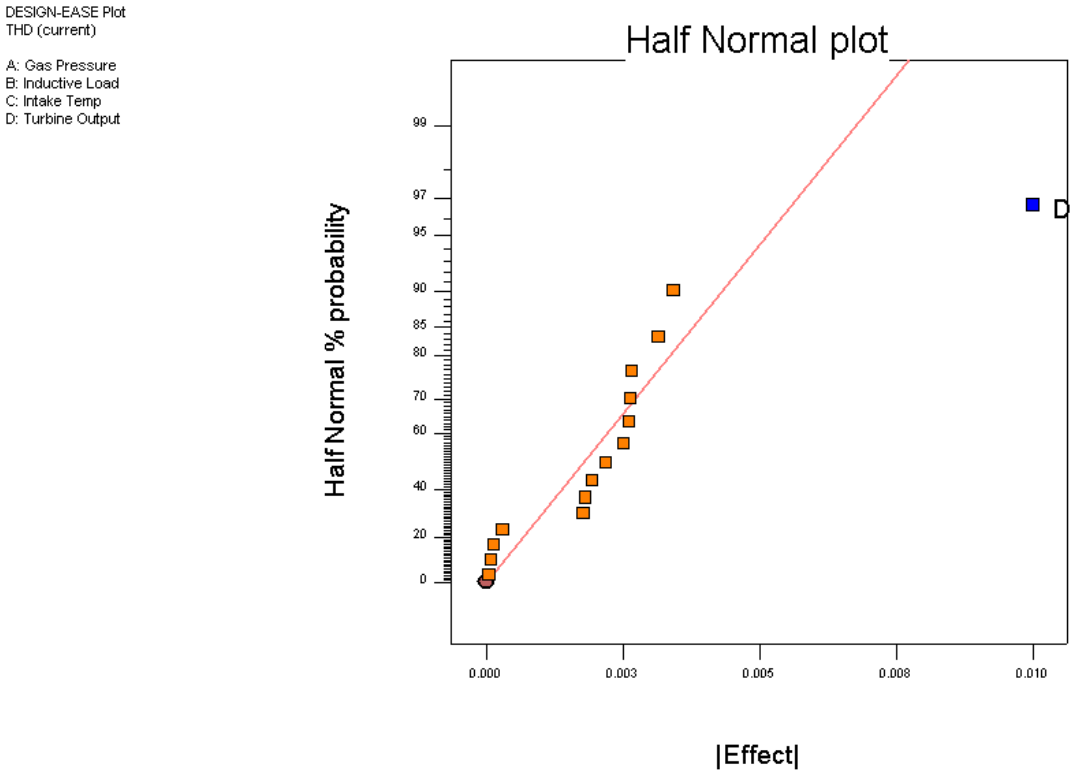


Figure 17. Half normal plot of System 2 test data showing THD outlier

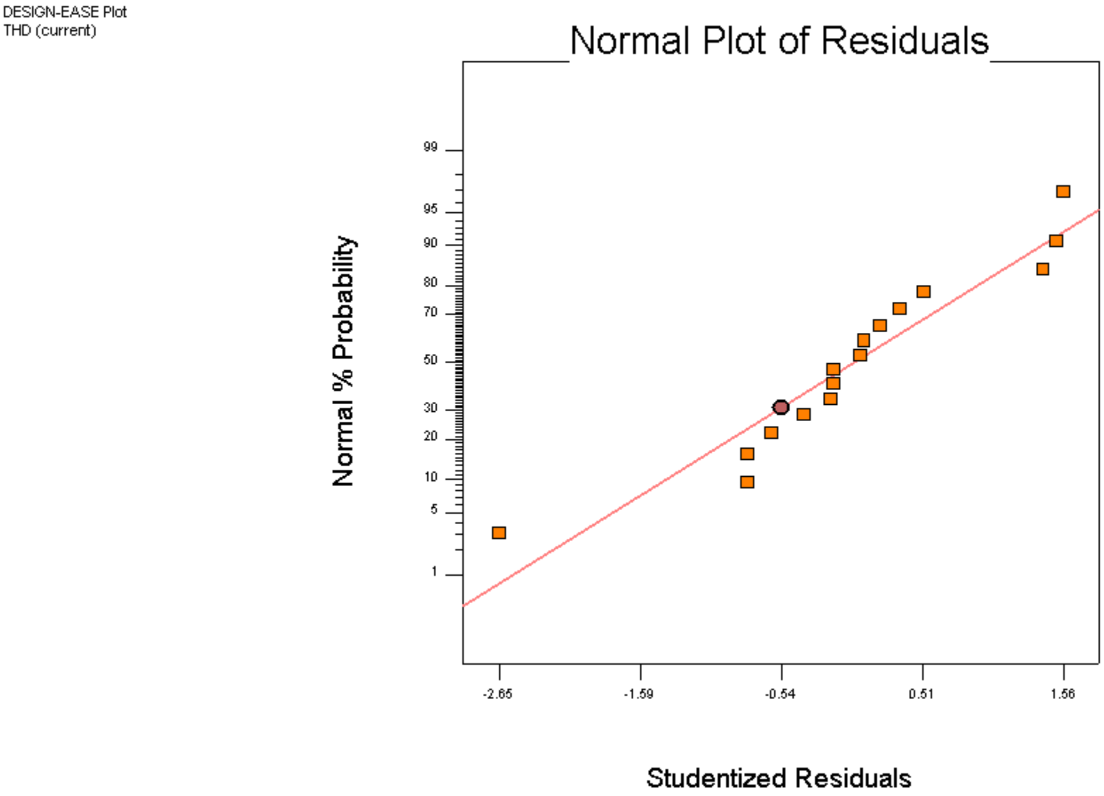


Figure 18. Normal probability plot of THD

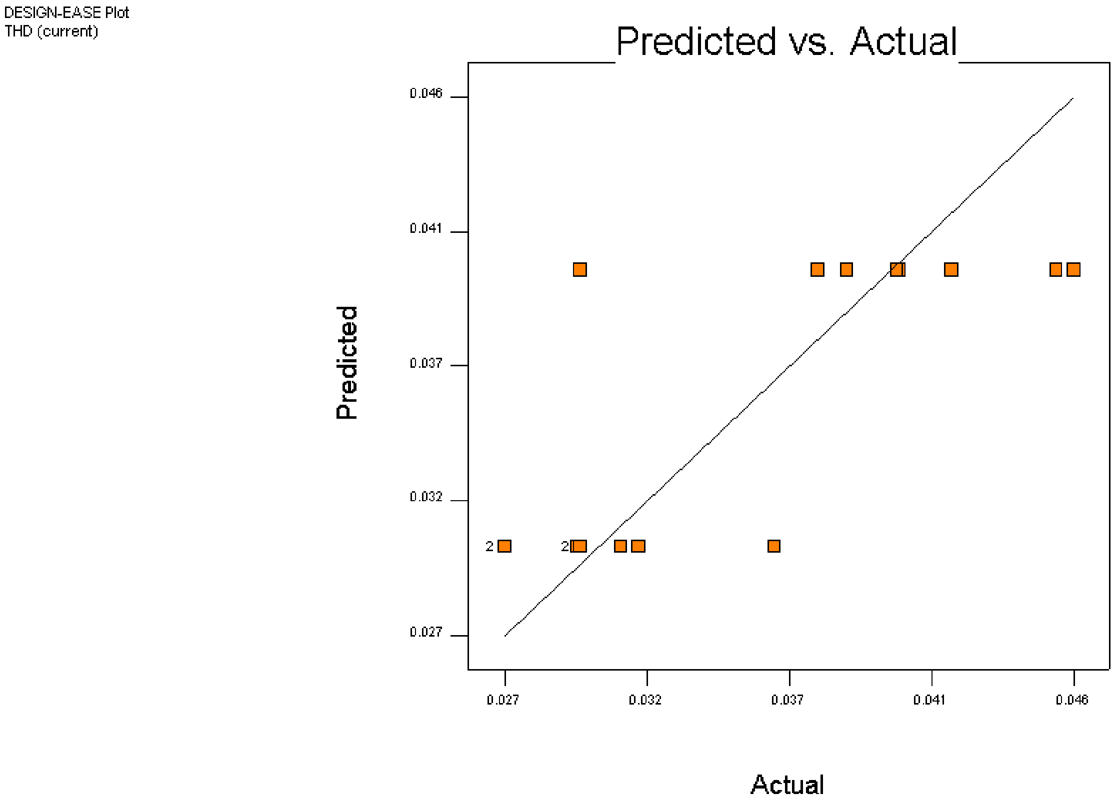


Figure 19. Actual versus predicted THD analysis

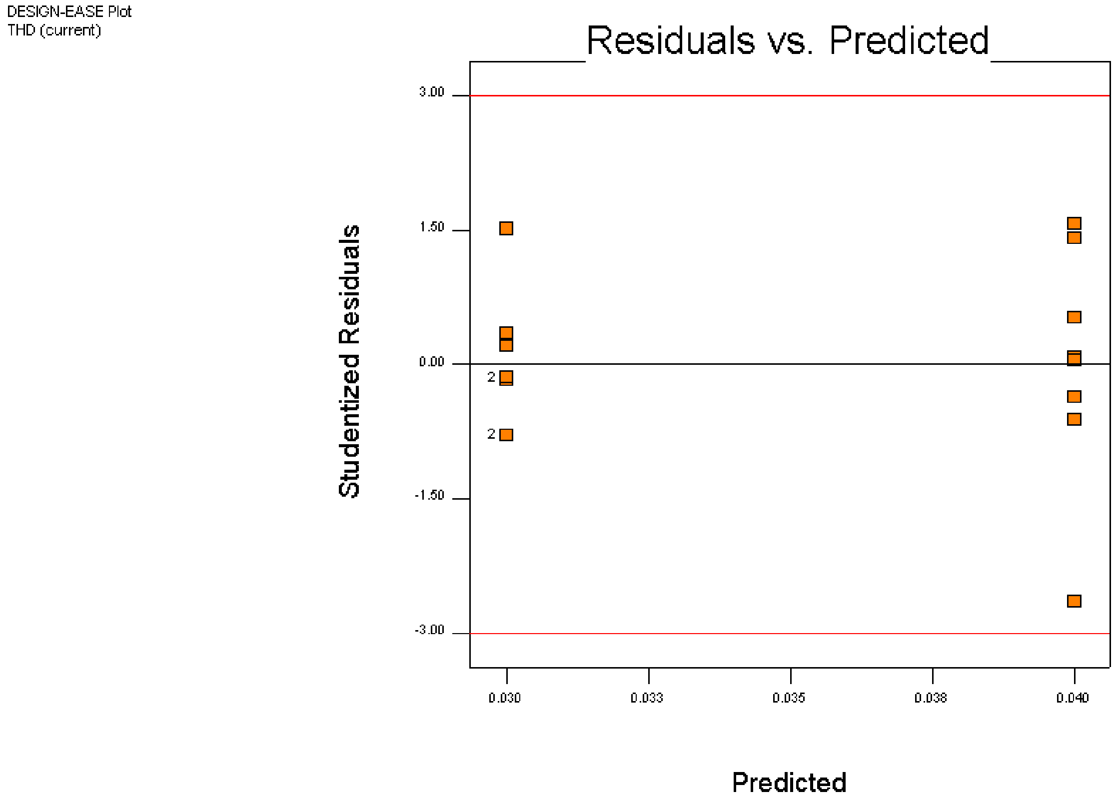


Figure 20. Data testing constraint variance and random THD scatter

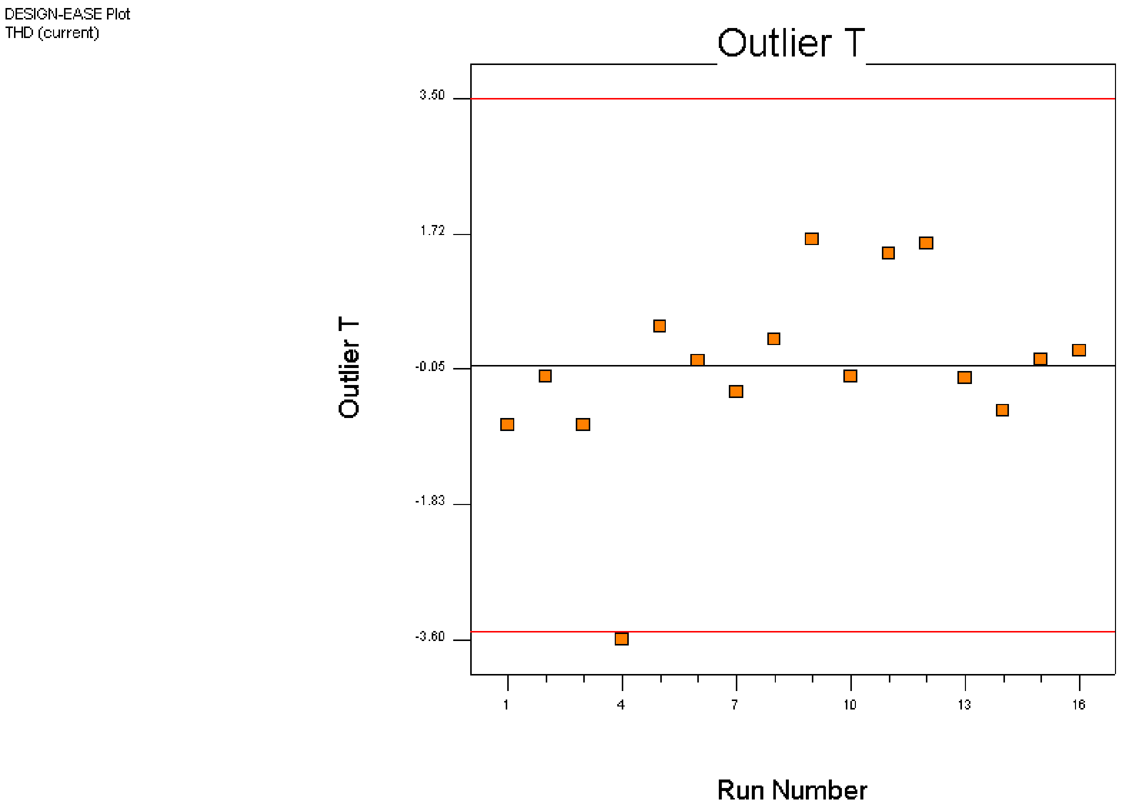


Figure 21. Plot of data control limits for THD

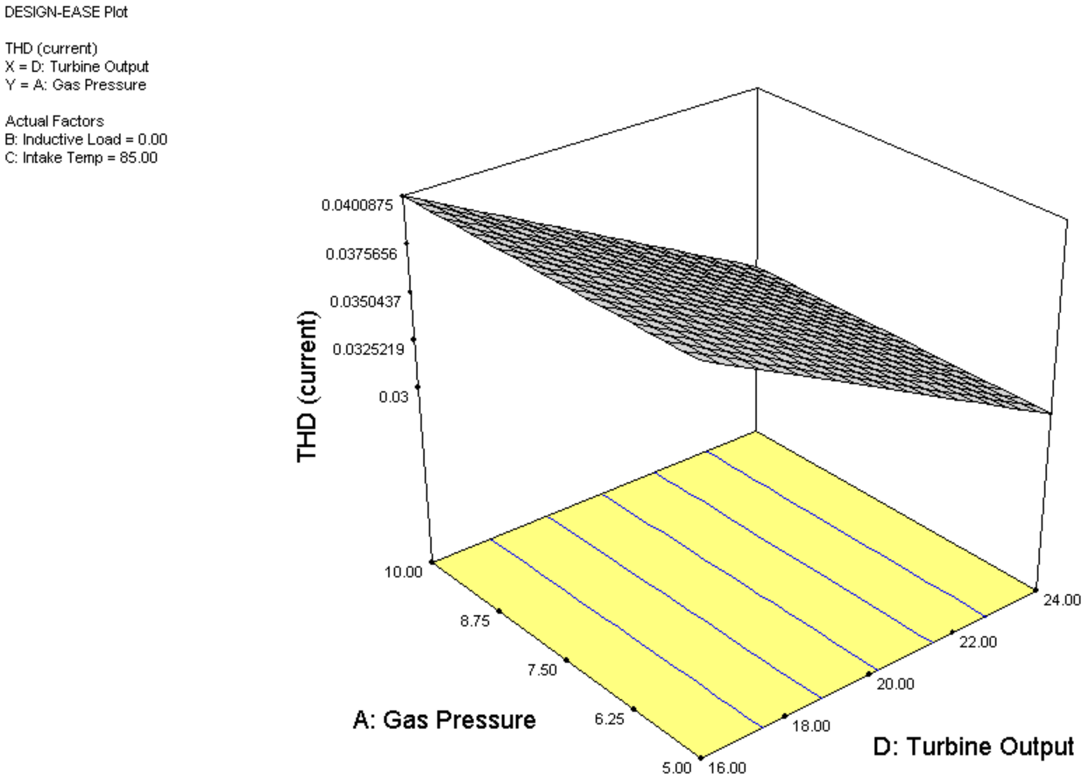


Figure 22. Effect of THD on operating efficiency for System 1

The data indicate that THD is highest at low gas pressure and low turbine output.

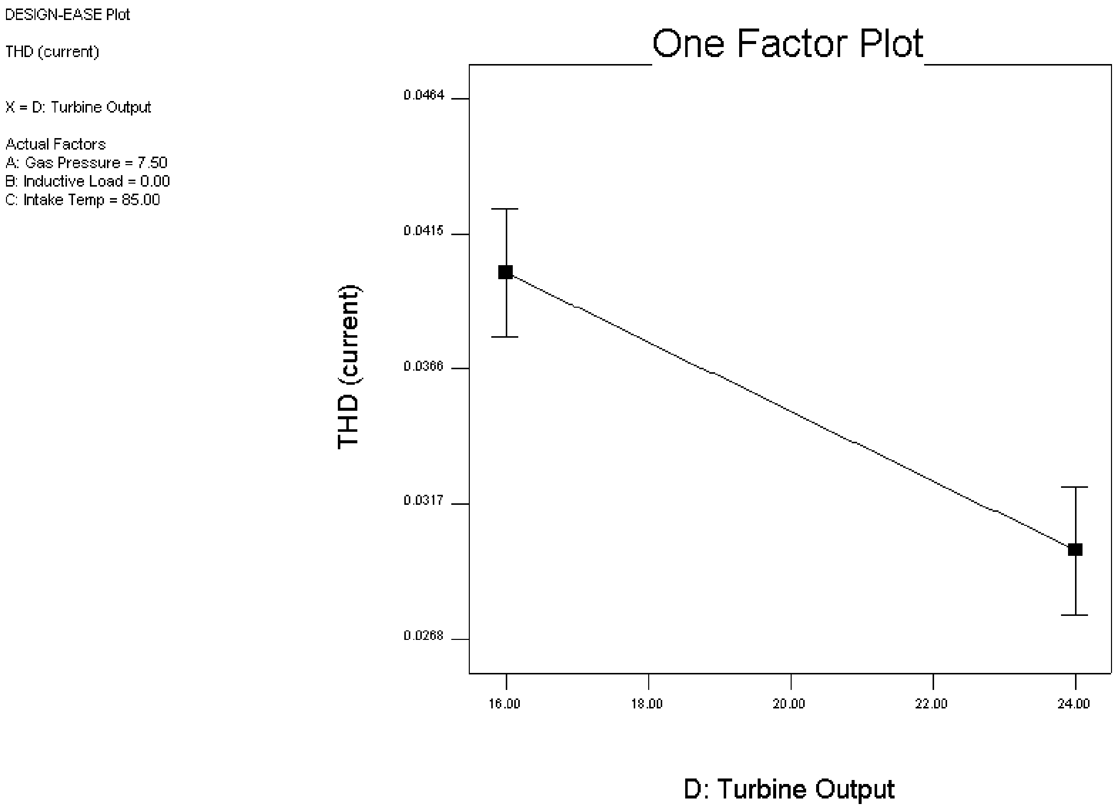


Figure 23. One-factor plot of THD versus output

As shown in figures 23 and 24, the current THD depends only slightly on the output level of the turbine. The voltage THD showed no effects.

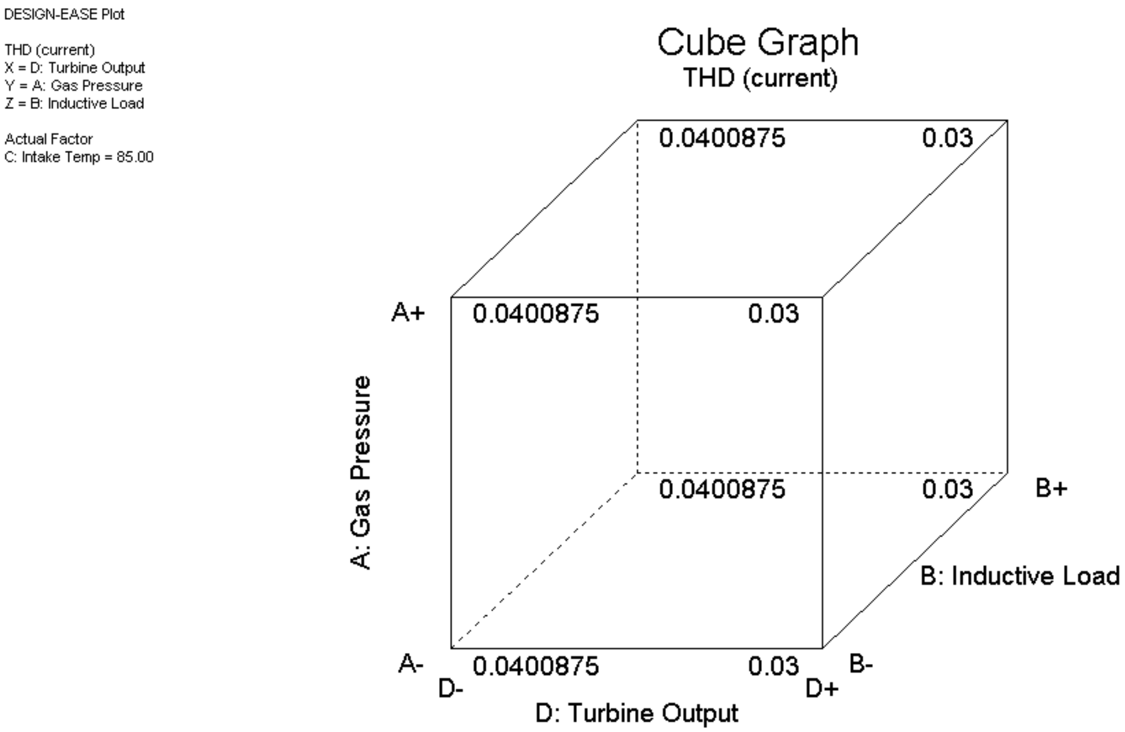
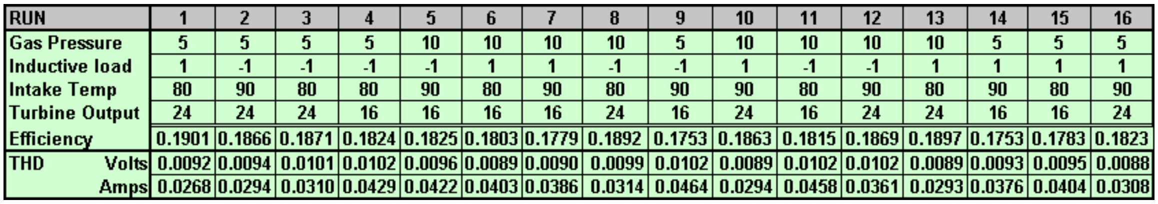


Figure 24. Cube Plot of THD

Data Summary
Test 1

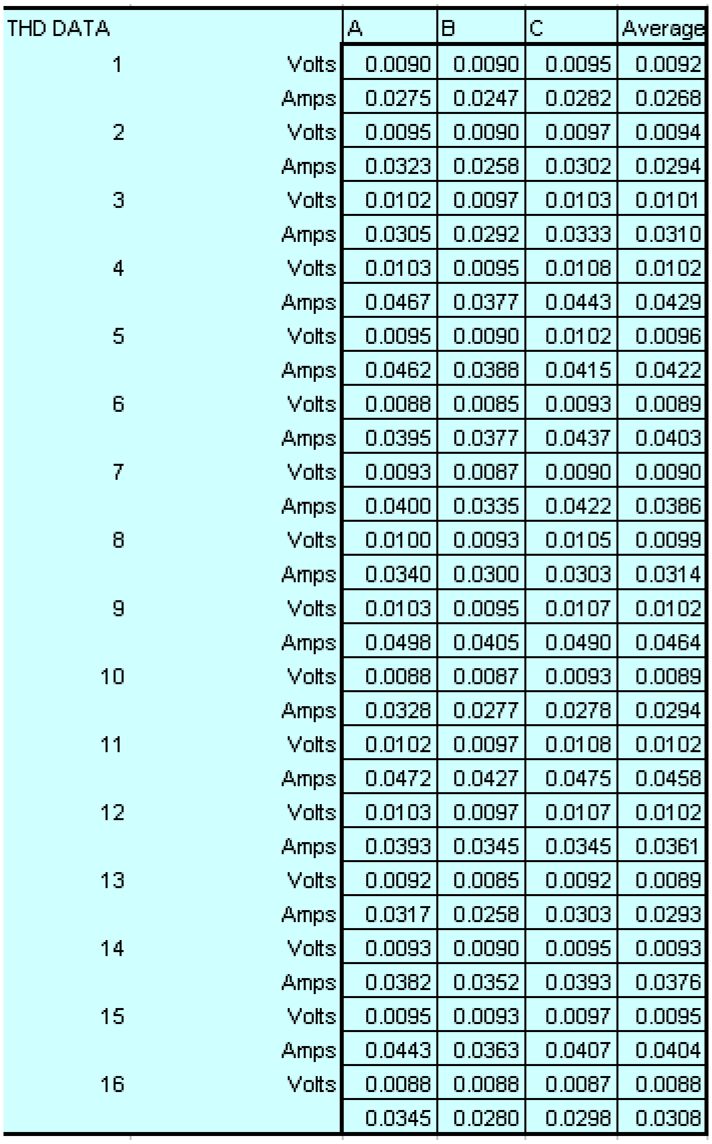
The following are the processed data for the tests performed in Test 1.

Table 28. Test 1 Data Set



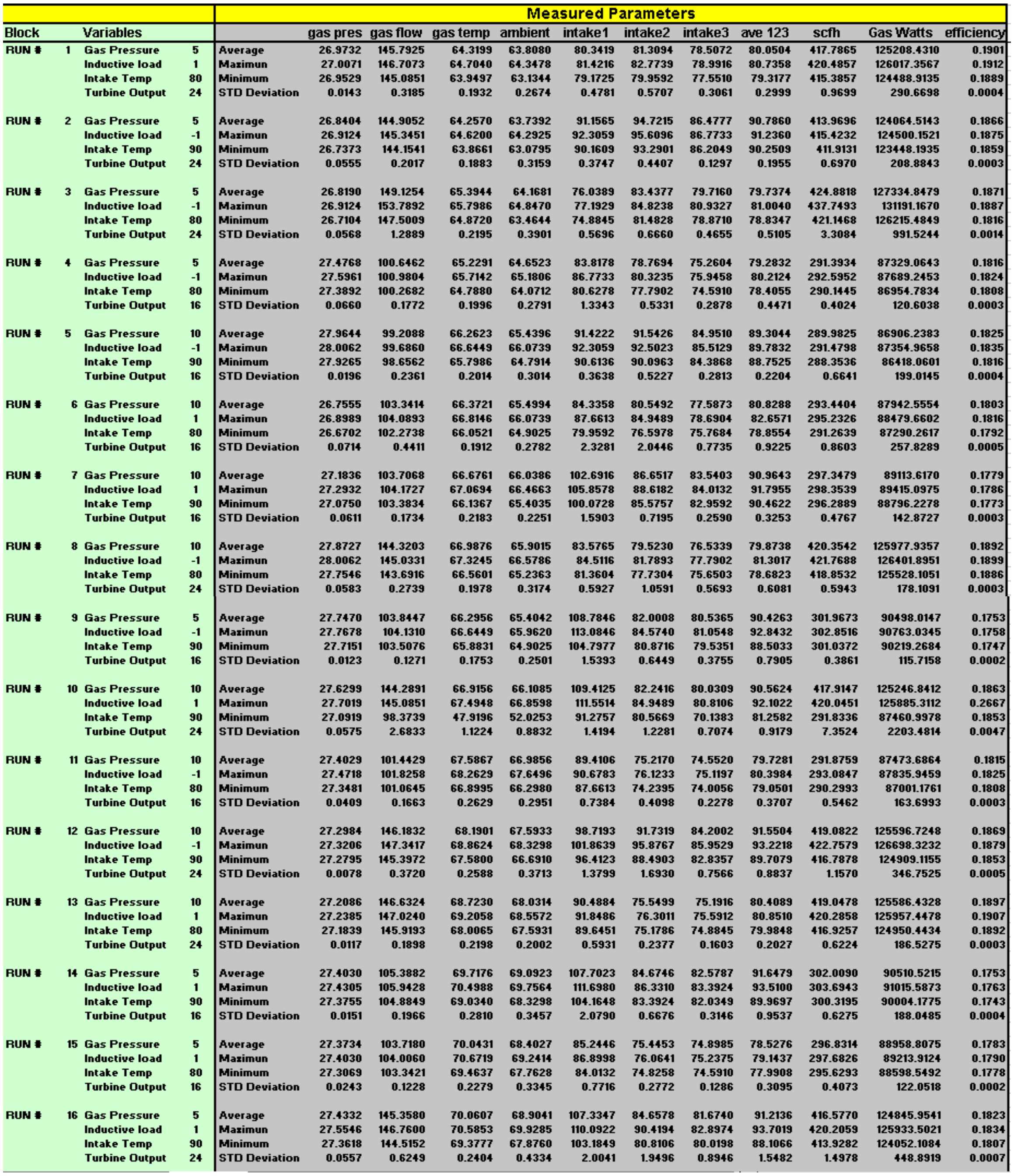
RUN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gas Pressure	5	5	5	5	10	10	10	10	5	10	10	10	10	5	5	5
Inductive load	1	-1	-1	-1	-1	1	1	-1	-1	1	-1	-1	1	1	1	1
Intake Temp	80	90	80	80	90	80	90	80	90	90	80	90	80	90	80	90
Turbine Output	24	24	24	16	16	16	16	24	16	24	16	24	24	16	16	24
Efficiency	0.1901	0.1866	0.1871	0.1824	0.1825	0.1803	0.1779	0.1892	0.1753	0.1863	0.1815	0.1869	0.1897	0.1753	0.1783	0.1823
THD Volts	0.0092	0.0094	0.0101	0.0102	0.0096	0.0089	0.0090	0.0099	0.0102	0.0089	0.0102	0.0102	0.0089	0.0093	0.0095	0.0088
Amps	0.0268	0.0294	0.0310	0.0429	0.0422	0.0403	0.0386	0.0314	0.0464	0.0294	0.0458	0.0361	0.0293	0.0376	0.0404	0.0308

Table 29. Backup THD Data for Table 28



THD DATA		A	B	C	Average
1	Volts	0.0090	0.0090	0.0095	0.0092
	Amps	0.0275	0.0247	0.0282	0.0268
2	Volts	0.0095	0.0090	0.0097	0.0094
	Amps	0.0323	0.0258	0.0302	0.0294
3	Volts	0.0102	0.0097	0.0103	0.0101
	Amps	0.0305	0.0292	0.0333	0.0310
4	Volts	0.0103	0.0095	0.0108	0.0102
	Amps	0.0467	0.0377	0.0443	0.0429
5	Volts	0.0095	0.0090	0.0102	0.0096
	Amps	0.0462	0.0388	0.0415	0.0422
6	Volts	0.0088	0.0085	0.0093	0.0089
	Amps	0.0395	0.0377	0.0437	0.0403
7	Volts	0.0093	0.0087	0.0090	0.0090
	Amps	0.0400	0.0335	0.0422	0.0386
8	Volts	0.0100	0.0093	0.0105	0.0099
	Amps	0.0340	0.0300	0.0303	0.0314
9	Volts	0.0103	0.0095	0.0107	0.0102
	Amps	0.0498	0.0405	0.0490	0.0464
10	Volts	0.0088	0.0087	0.0093	0.0089
	Amps	0.0328	0.0277	0.0278	0.0294
11	Volts	0.0102	0.0097	0.0108	0.0102
	Amps	0.0472	0.0427	0.0475	0.0458
12	Volts	0.0103	0.0097	0.0107	0.0102
	Amps	0.0393	0.0345	0.0345	0.0361
13	Volts	0.0092	0.0085	0.0092	0.0089
	Amps	0.0317	0.0258	0.0303	0.0293
14	Volts	0.0093	0.0090	0.0095	0.0093
	Amps	0.0382	0.0352	0.0393	0.0376
15	Volts	0.0095	0.0093	0.0097	0.0095
	Amps	0.0443	0.0363	0.0407	0.0404
16	Volts	0.0088	0.0088	0.0087	0.0088
		0.0345	0.0280	0.0298	0.0308

Table 30. Data From Test 1



					Measured Parameters										
Block		Variables			gas pres	gas flow	gas temp	ambient	intake1	intake2	intake3	ave 123	scfh	Gas Watts	efficiency
RUN #	1	Gas Pressure	5	Average	26.9732	145.7925	64.3199	63.8080	80.3419	81.3094	78.5072	80.0504	417.7865	125208.4310	0.1901
		Inductive load	1	Maximun	27.0071	146.7073	64.7040	64.3478	81.4216	82.7739	78.9916	80.7358	420.4857	126017.3567	0.1912
		Intake Temp	80	Minimum	26.9529	145.0851	63.9497	63.1344	79.1725	79.9592	77.5510	79.3177	415.3857	124488.9135	0.1889
		Turbine Output	24	STD Deviation	0.0143	0.3185	0.1932	0.2674	0.4781	0.5707	0.3061	0.2999	0.9699	290.6698	0.0004
RUN #	2	Gas Pressure	5	Average	26.8404	144.9052	64.2570	63.7392	91.1565	94.7215	86.4777	90.7860	413.9696	124064.5143	0.1866
		Inductive load	-1	Maximun	26.9124	145.3451	64.6200	64.2925	92.3059	95.6096	86.7733	91.2360	415.4232	124500.1521	0.1875
		Intake Temp	90	Minimum	26.7373	144.1541	63.8661	63.0795	90.1609	93.2901	86.2049	90.2509	411.9131	123448.1935	0.1859
		Turbine Output	24	STD Deviation	0.0555	0.2017	0.1883	0.3159	0.3747	0.4407	0.1297	0.1955	0.6970	208.8843	0.0003
RUN #	3	Gas Pressure	5	Average	26.8190	149.1254	65.3944	64.1681	76.0389	83.4377	79.7160	79.7374	424.8818	127334.8479	0.1871
		Inductive load	-1	Maximun	26.9124	153.7892	65.7986	64.8470	77.1929	84.8238	80.9327	81.0040	437.7493	131191.1670	0.1887
		Intake Temp	80	Minimum	26.7104	147.5009	64.8720	63.4644	74.8845	81.4828	78.8710	78.8347	421.1468	126215.4849	0.1816
		Turbine Output	24	STD Deviation	0.0568	1.2889	0.2195	0.3901	0.5696	0.6660	0.4655	0.5105	3.3084	991.5244	0.0014
RUN #	4	Gas Pressure	5	Average	27.4768	100.6462	65.2291	64.6523	83.8178	78.7694	75.2604	79.2832	291.3934	87329.0643	0.1816
		Inductive load	-1	Maximun	27.5961	100.9804	65.7142	65.1806	86.7733	80.3235	75.9458	80.2124	292.5952	87689.2453	0.1824
		Intake Temp	80	Minimum	27.3892	100.2682	64.7880	64.0712	80.6278	77.7902	74.5910	78.4055	290.1445	86954.7834	0.1808
		Turbine Output	16	STD Deviation	0.0660	0.1772	0.1996	0.2791	1.3343	0.5331	0.2878	0.4471	0.4024	120.6038	0.0003
RUN #	5	Gas Pressure	10	Average	27.9644	99.2088	66.2623	65.4396	91.4222	91.5426	84.9510	89.3044	289.9825	86906.2383	0.1825
		Inductive load	-1	Maximun	28.0062	99.6860	66.6449	66.0739	92.3059	92.5023	85.5129	89.7832	291.4798	87354.9658	0.1835
		Intake Temp	90	Minimum	27.9265	98.6562	65.7986	64.7914	90.6136	90.0963	84.3868	88.7525	288.3536	86418.0601	0.1816
		Turbine Output	16	STD Deviation	0.0196	0.2361	0.2014	0.3014	0.3638	0.5227	0.2813	0.2204	0.6641	199.0145	0.0004
RUN #	6	Gas Pressure	10	Average	26.7555	103.3414	66.3721	65.4994	84.3358	80.5492	77.5873	80.8288	293.4404	87942.5554	0.1803
		Inductive load	1	Maximun	26.8989	104.0893	66.8146	66.0739	87.6613	84.9489	78.6904	82.6571	295.2326	88479.6602	0.1816
		Intake Temp	80	Minimum	26.6702	102.2738	66.0521	64.9025	79.9592	76.5978	75.7684	78.8554	291.2639	87290.2617	0.1792
		Turbine Output	16	STD Deviation	0.0714	0.4411	0.1912	0.2782	2.3281	2.0446	0.7735	0.9225	0.8603	257.8289	0.0005
RUN #	7	Gas Pressure	10	Average	27.1836	103.7068	66.6761	66.0386	102.6916	86.6517	83.5403	90.9643	297.3479	89113.6170	0.1779
		Inductive load	1	Maximun	27.2932	104.1727	67.0694	66.4663	105.8578	88.6182	84.0132	91.7955	298.3539	89415.0975	0.1786
		Intake Temp	90	Minimum	27.0750	103.3834	66.1367	65.4035	100.0728	85.5757	82.9592	90.4622	296.2889	88796.2278	0.1773
		Turbine Output	16	STD Deviation	0.0611	0.1734	0.2183	0.2251	1.5903	0.7195	0.2590	0.3253	0.4767	142.8727	0.0003
RUN #	8	Gas Pressure	10	Average	27.8727	144.3203	66.9876	65.9015	83.5765	79.5230	76.5339	79.8738	420.3542	125977.9357	0.1892
		Inductive load	-1	Maximun	28.0062	145.0331	67.3245	66.5786	84.5116	81.7893	77.7902	81.3017	421.7688	126401.8951	0.1899
		Intake Temp	80	Minimum	27.7546	143.6916	66.5601	65.2363	81.3604	77.7304	75.6503	78.6823	418.8532	125528.1051	0.1886
		Turbine Output	24	STD Deviation	0.0583	0.2739	0.1978	0.3174	0.5927	1.0591	0.5693	0.6081	0.5943	178.1091	0.0003
RUN #	9	Gas Pressure	5	Average	27.7470	103.8447	66.2956	65.4042	108.7846	82.0008	80.5365	90.4263	301.9673	90498.0147	0.1753
		Inductive load	-1	Maximun	27.7678	104.1310	66.6449	65.9620	113.0846	84.5740	81.0548	92.8432	302.8516	90763.0345	0.1758
		Intake Temp	90	Minimum	27.7151	103.5076	65.8831	64.9025	104.7977	80.8716	79.5351	88.5033	301.0372	90219.2684	0.1747
		Turbine Output	16	STD Deviation	0.0123	0.1271	0.1753	0.2501	1.5393	0.6449	0.3755	0.7905	0.3861	115.7158	0.0002
RUN #	10	Gas Pressure	10	Average	27.6299	144.2891	66.9156	66.1085	109.4125	82.2416	80.0309	90.5624	417.9147	125246.8412	0.1863
		Inductive load	1	Maximun	27.7019	145.0851	67.4948	66.8598	111.5514	84.9489	80.8106	92.1022	420.0451	125885.3112	0.2667
		Intake Temp	90	Minimum	27.0919	98.3739	47.9196	52.0253	91.2757	80.5669	70.1383	81.2582	291.8336	87460.9978	0.1853
		Turbine Output	24	STD Deviation	0.0575	2.6833	1.1224	0.8832	1.4194	1.2281	0.7074	0.9179	7.3524	2203.4814	0.0047
RUN #	11	Gas Pressure	10	Average	27.4029	101.4429	67.5867	66.9856	89.4106	75.2170	74.5520	79.7281	291.8759	87473.6864	0.1815
		Inductive load	-1	Maximun	27.4718	101.8258	68.2629	67.6496	90.6783	76.1233	75.1197	80.3984	293.0847	87835.9459	0.1825
		Intake Temp	80	Minimum	27.3481	101.0645	66.8995	66.2980	87.6613	74.2395	74.0056	79.0501	290.2993	87001.1761	0.1808
		Turbine Output	16	STD Deviation	0.0409	0.1663	0.2629	0.2951	0.7384	0.4098	0.2278	0.3707	0.5462	163.6993	0.0003
RUN #	12	Gas Pressure	10	Average	27.2984	146.1832	68.1901	67.5933	98.7193	91.7319	84.2002	91.5504	419.0822	125596.7248	0.1869
		Inductive load	-1	Maximun	27.3206	147.3417	68.8624	68.3298	101.8639	95.8767	85.9529	93.2218	422.7579	126698.3232	0.1879
		Intake Temp	90	Minimum	27.2795	145.3972	67.5800	66.6910	96.4123	88.4903	82.8357	89.7079	416.7878	124909.1155	0.1853
		Turbine Output	24	STD Deviation	0.0078	0.3720	0.2588	0.3713	1.3799	1.6930	0.7566	0.8837	1.1570	346.7525	0.0005
RUN #	13	Gas Pressure	10	Average	27.2086	146.6324	68.7230	68.0314	90.4884	75.5499	75.1916	80.4089	419.0478	125586.4328	0.1897
		Inductive load	1	Maximun	27.2385	147.0240	69.2058	68.5572	91.8486	76.3011	75.5912	80.8510	420.2858	125957.4478	0.1907
		Intake Temp	80	Minimum	27.1839	145.9193	68.0065	67.5931	89.6451	75.1786	74.8845	79.9848	416.9257	124950.4434	0.1892
		Turbine Output	24	STD Deviation	0.0117	0.1898	0.2198	0.2002	0.5931	0.2377	0.1603	0.2027	0.6224	186.5275	0.0003
RUN #	14	Gas Pressure	5	Average	27.4030	105.3882	69.7176	69.0923	107.7023	84.6746	82.5787	91.6479	302.0090	90510.5215	0.1753
		Inductive load	1	Maximun	27.4305	105.9428	70.4988	69.7564	111.6980	86.3310	83.3924	93.5100	303.6943	91015.5873	0.1763
		Intake Temp	90	Minimum	27.3755	104.8849	69.0340	68.3298	104.1648	83.3924	82.0349	89.9697	300.3195	90004.1775	0.1743
		Turbine Output	16	STD Deviation	0.0151	0.1966	0.2810	0.3457	2.0790	0.6676	0.3146	0.9537	0.6275	188.0485	0.0004
RUN #	15	Gas Pressure	5	Average	27.3734	103.7180	70.0431	68.4027	85.2446	75.4453	74.8985	78.5276	296.8314	88958.8075	0.1783
		Inductive load	1	Maximun	27.4030	104.0060	70.6719	69.2414	86.8998	76.0641	75.2375	79.1437	297.6826	89213.9124	0.1790
		Intake Temp	80	Minimum	27.3069	103.3421	69.4637	67.7628	84.0132	74.8258	74.5910	77.9908	295.6293	88598.5492	0.1778
		Turbine Output	16	STD Deviation	0.0243	0.1228	0.2279	0.3345	0.7716	0.2772	0.1286	0.3095	0.4073	122.0518	0.0002
RUN #	16	Gas Pressure	5	Average	27.4332	145.3580	70.0607	68.9041	107.3347	84.6578	81.6740	91.2136	416.5770	124845.9541	0.1823
		Inductive load	1	Maximun	27.5546	146.7600	70.5853	69.9285	110.0922	90.4194	82.8974	93.7019	420.2059	125933.5021	0.1834
		Intake Temp	90	Minimum	27.3618	144.5152	69.3777	67.8760	103.1849	80.8106	80.0198	88.1066	413.9282	124052.1084	0.1807
		Turbine Output	24	STD Deviation	0.0557	0.6249	0.2404	0.4334	2.0041	1.9496	0.8946	1.5482	1.4978	448.8919	0.0007

4.5.2 Test 2

Test 2 was performed with another model of microturbine, System 2, but was identical to Test 1 in all other ways.

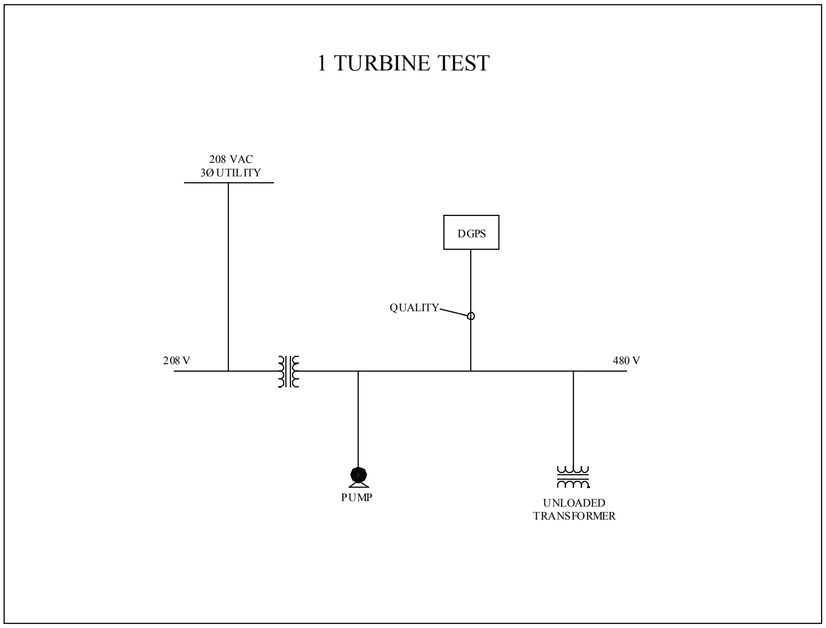


Figure 25. Line drawing of the test configuration for microturbine System 2

The following table describes the experimental design for Test 2 on System 2.

Table 31. Experimental Design Parameters for Testing the Second Microturbine Performance

Order		Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Std	Run	Gas Pressure	Transformer (Inductor)	Intake Temp	Turbine Output	Efficiency (Fraction)	THD (Current)
12	1	10.00	on	80.00	24.00	0.197	0.0289
72	2	5.00	on	90.00	16.00	0.179	0.0423
9	3	5.00	off	80.00	24.00	0.1929	0.0321
5	4	5.00	off	90.00	16.00	0.1789	0.0439
2	5	10.00	off	80.00	16.00	0.1858	0.0414
1	6	5.00	off	80.00	16.00	0.1828	0.0403
16	7	10.00	on	90.00	24.00	0.1886	0.0301
6	8	10.00	off	90.00	16.00	0.1799	0.0409
10	9	10.00	off	80.00	24.00	0.194	0.0310
4	10	10.00	on	80.00	16.00	0.1846	0.0396
14	11	10.00	off	90.00	24.00	0.1845	0.0327
15	12	5.00	on	90.00	24.00	0.1808	0.0318
11	13	5.00	on	80.00	24.00	0.1911	0.1911
3	14	5.00	on	80.00	16.00	0.1799	0.0423
13	15	5.00	off	90.00	24.00	0.1837	0.0322
8	16	10.00	on	90.00	16.00	0.1819	0.0424

The statistical results for the model are given in the following table.

Table 32. Statistical Results for Test 2

Degrees of Freedom for Evaluation

Model	4
Residuals	11
Lack of Fit	11
Pure Error	0
Corr Total	15

				Power at 5% alpha level for effect of:		
Term	Std Err[1]	VIF	Ri-Squared	1/2 Std. Dev.	1 Std. Dev.	2 Std. Dev
A	0.25	1	0	15.00%	44.60%	95.30%
B	0.25	1	0	15.00%	44.60%	95.30%
C	0.25	1	0	15.00%	44.60%	95.30%
D	0.25	1	0	15.00%	44.60%	95.30%

Degrees of Freedom for Evaluation

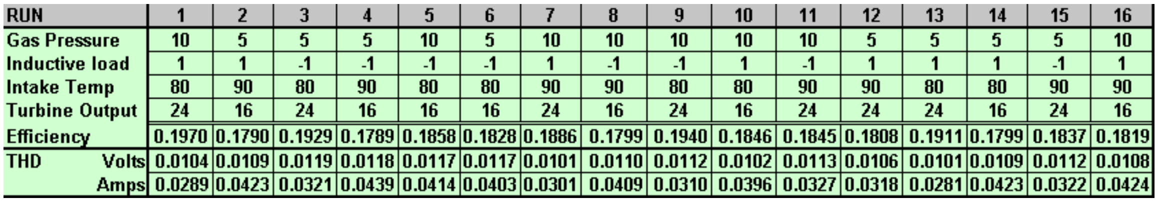
[1] Basis Std. Dev. = 1.0

As can be seen, the power for a signal-to-noise ratio of two standard deviations is 95.3%. Hence, only one replicate was run.

Details of the results are included in the appendix. See page A-2.

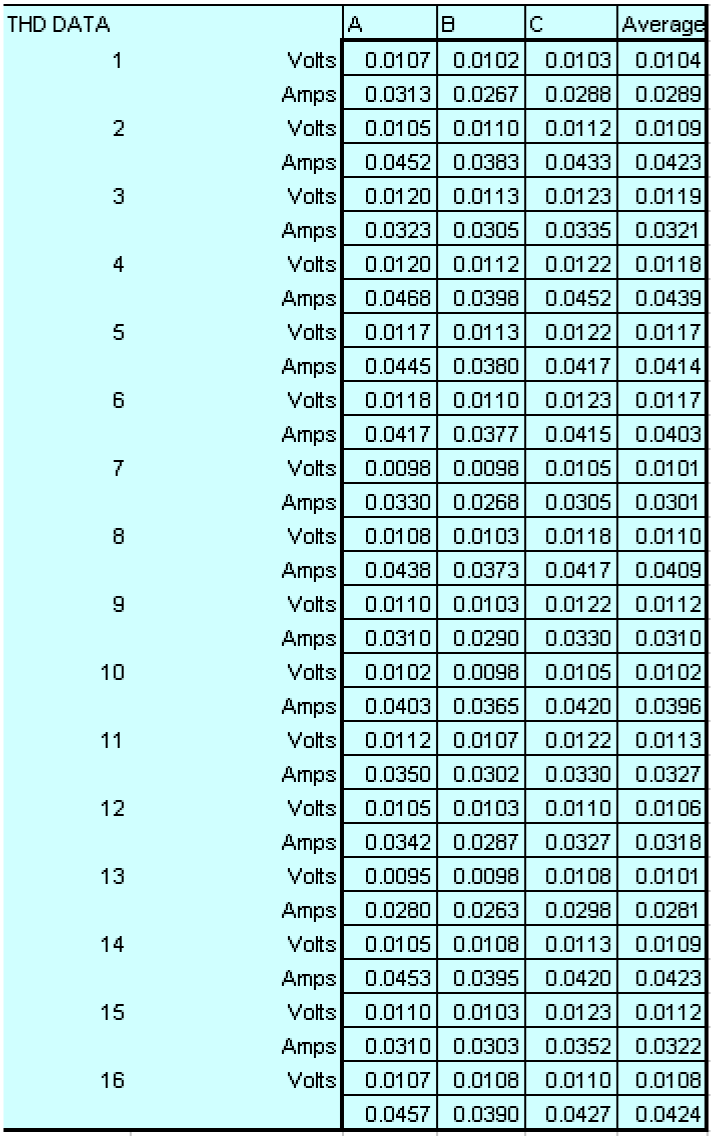
Data Summary
Test 2

Table 33. Test 2 Data Set



RUN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gas Pressure	10	5	5	5	10	5	10	10	10	10	10	5	5	5	5	10
Inductive load	1	1	-1	-1	-1	-1	1	-1	-1	1	-1	1	1	1	-1	1
Intake Temp	80	90	80	90	80	80	90	90	80	80	90	90	80	80	90	90
Turbine Output	24	16	24	16	16	16	24	16	24	16	24	24	24	16	24	16
Efficiency	0.1970	0.1790	0.1929	0.1789	0.1858	0.1828	0.1886	0.1799	0.1940	0.1846	0.1845	0.1808	0.1911	0.1799	0.1837	0.1819
THD Volts	0.0104	0.0109	0.0119	0.0118	0.0117	0.0117	0.0101	0.0110	0.0112	0.0102	0.0113	0.0106	0.0101	0.0109	0.0112	0.0108
Amps	0.0289	0.0423	0.0321	0.0439	0.0414	0.0403	0.0301	0.0409	0.0310	0.0396	0.0327	0.0318	0.0281	0.0423	0.0322	0.0424

Table 34. Backup THD Data for Table 33



THD DATA		A	B	C	Average
1	Volts	0.0107	0.0102	0.0103	0.0104
	Amps	0.0313	0.0267	0.0288	0.0289
2	Volts	0.0105	0.0110	0.0112	0.0109
	Amps	0.0452	0.0383	0.0433	0.0423
3	Volts	0.0120	0.0113	0.0123	0.0119
	Amps	0.0323	0.0305	0.0335	0.0321
4	Volts	0.0120	0.0112	0.0122	0.0118
	Amps	0.0468	0.0398	0.0452	0.0439
5	Volts	0.0117	0.0113	0.0122	0.0117
	Amps	0.0445	0.0380	0.0417	0.0414
6	Volts	0.0118	0.0110	0.0123	0.0117
	Amps	0.0417	0.0377	0.0415	0.0403
7	Volts	0.0098	0.0098	0.0105	0.0101
	Amps	0.0330	0.0268	0.0305	0.0301
8	Volts	0.0108	0.0103	0.0118	0.0110
	Amps	0.0438	0.0373	0.0417	0.0409
9	Volts	0.0110	0.0103	0.0122	0.0112
	Amps	0.0310	0.0290	0.0330	0.0310
10	Volts	0.0102	0.0098	0.0105	0.0102
	Amps	0.0403	0.0365	0.0420	0.0396
11	Volts	0.0112	0.0107	0.0122	0.0113
	Amps	0.0350	0.0302	0.0330	0.0327
12	Volts	0.0105	0.0103	0.0110	0.0106
	Amps	0.0342	0.0287	0.0327	0.0318
13	Volts	0.0095	0.0098	0.0108	0.0101
	Amps	0.0280	0.0263	0.0298	0.0281
14	Volts	0.0105	0.0108	0.0113	0.0109
	Amps	0.0453	0.0395	0.0420	0.0423
15	Volts	0.0110	0.0103	0.0123	0.0112
	Amps	0.0310	0.0303	0.0352	0.0322
16	Volts	0.0107	0.0108	0.0110	0.0108
		0.0457	0.0390	0.0427	0.0424

Table 35. Data From Test 2

					Measured Parameters										
Block		Variables			gas pres	gas flow	gas temp	ambient	intake1	intake2	intake3	ave 123	scfh	Gas Watts	efficiency
RUN #	1	Gas Pressure	10	Average	26.8461	138.7707	51.4287	53.3364	88.8980	81.2342	71.5302	80.5525	406.4447	121809.3533	0.1970
		Inductive load	1	Maximun	26.9291	139.1703	51.9849	53.9534	92.1788	83.6202	72.5992	82.2455	407.8442	122228.7656	0.1978
		Intake Temp	80	Minimum	26.7537	138.1546	51.0831	52.6837	83.8190	79.8864	70.5663	78.5307	404.7923	121314.1272	0.1963
		Turbine Output	24	STD Deviation	0.0487	0.2099	0.2112	0.2728	1.8043	0.8041	0.4909	0.8017	0.6520	195.3917	0.0003
RUN #	2	Gas Pressure	5	Average	26.5432	102.3867	51.7149	54.1889	102.7401	89.3046	76.9010	89.6375	297.5272	89167.3378	0.1790
		Inductive load	1	Maximun	26.6062	102.8066	52.1493	55.0101	108.5383	90.9296	78.5315	92.6022	298.9229	89585.6238	0.1797
		Intake Temp	90	Minimum	26.5261	101.9066	51.3286	53.4553	98.4199	87.8457	75.9177	87.5147	296.3797	88823.4401	0.1782
		Turbine Output	16	STD Deviation	0.0175	0.2543	0.1723	0.3043	2.1883	0.6968	0.6677	1.0423	0.6614	198.2321	0.0004
RUN #	3	Gas Pressure	5	Average	26.6226	142.6476	51.8739	54.7286	85.0971	79.9094	71.3745	78.7919	415.1905	124430.4273	0.1929
		Inductive load	-1	Maximun	26.7537	143.4330	52.3139	55.2894	89.1410	80.6005	72.2895	80.5729	417.0816	124997.1658	0.1940
		Intake Temp	80	Minimum	26.5128	141.7564	51.4925	54.0643	80.9913	79.0464	70.6275	77.3287	412.8507	123729.1873	0.1920
		Turbine Output	24	STD Deviation	0.0619	0.2763	0.1790	0.2772	1.5765	0.2801	0.4507	0.6550	0.8359	250.5106	0.0004
RUN #	4	Gas Pressure	5	Average	27.6757	99.4715	50.4238	54.4218	106.8209	90.8023	75.4696	91.0315	297.7439	89232.2898	0.1789
		Inductive load	-1	Maximun	27.7028	99.9403	51.0013	55.0659	108.7296	91.9004	76.7420	91.7696	299.0463	89622.6061	0.1802
		Intake Temp	90	Minimum	27.6371	98.8655	49.9415	53.5659	104.8176	89.4835	74.1562	90.0846	295.5123	88563.4849	0.1781
		Turbine Output	16	STD Deviation	0.0189	0.2104	0.2327	0.4105	0.7251	0.5560	0.6298	0.3719	0.7026	210.5739	0.0004
RUN #	5	Gas Pressure	10	Average	27.4824	96.2234	49.8810	53.5874	86.2866	79.6695	69.5746	78.5120	287.0133	86016.3688	0.1858
		Inductive load	-1	Maximun	27.5999	96.8357	50.3484	54.1753	88.9358	80.9913	70.9954	79.9965	288.6487	86506.5000	0.1876
		Intake Temp	80	Minimum	27.3241	95.6407	49.5354	52.7937	84.0181	78.4031	68.0754	77.3011	284.5855	85288.7803	0.1847
		Turbine Output	16	STD Deviation	0.0770	0.1984	0.1747	0.3598	1.1127	0.6251	0.7390	0.6987	0.7332	219.7385	0.0005
RUN #	6	Gas Pressure	5	Average	27.3626	98.0007	49.8267	53.3316	87.5181	79.8257	69.6044	78.9829	291.5156	87365.6864	0.1828
		Inductive load	-1	Maximun	27.3791	98.3331	50.1855	54.0088	89.6893	80.3405	70.4439	79.9124	292.7391	87732.3714	0.1836
		Intake Temp	80	Minimum	27.3379	97.6418	49.3732	52.4639	84.1510	79.0464	68.7400	78.1845	290.2600	86989.3981	0.1820
		Turbine Output	16	STD Deviation	0.0088	0.1480	0.1822	0.3259	0.9389	0.2437	0.4697	0.2736	0.5153	154.4307	0.0003
RUN #	7	Gas Pressure	10	Average	27.0724	139.0293	50.4314	53.4971	106.1267	90.5228	77.0717	91.2454	410.2202	122940.8374	0.1886
		Inductive load	1	Maximun	27.0919	139.6305	50.7562	54.8985	110.5892	91.7614	78.2105	92.7844	411.8627	123433.0889	0.1953
		Intake Temp	90	Minimum	27.0375	138.4076	50.0228	52.2993	100.8193	89.4835	75.7281	89.6827	408.3792	122389.1022	0.1878
		Turbine Output	24	STD Deviation	0.0116	0.2323	0.1996	0.7499	2.1192	0.5268	0.6722	0.7507	0.7655	229.4184	0.0005
RUN #	8	Gas Pressure	10	Average	27.6138	98.7913	48.8167	50.9562	103.6137	88.9761	73.4988	88.6978	296.2076	88771.8600	0.1799
		Inductive load	-1	Maximun	27.7688	99.6496	49.2922	51.9159	106.3847	90.0329	74.7831	89.6211	297.5693	89179.9570	0.1805
		Intake Temp	90	Minimum	27.4479	98.2923	48.2417	50.1750	97.6993	88.1176	72.4133	86.7920	295.2514	88485.2945	0.1791
		Turbine Output	16	STD Deviation	0.0916	0.2706	0.2316	0.3322	1.5150	0.4085	0.5605	0.5216	0.4979	149.2064	0.0003

4.5.3 Test 3

Test 3 consisted of testing the previous two turbines in parallel with the grid, as illustrated in the following diagram.

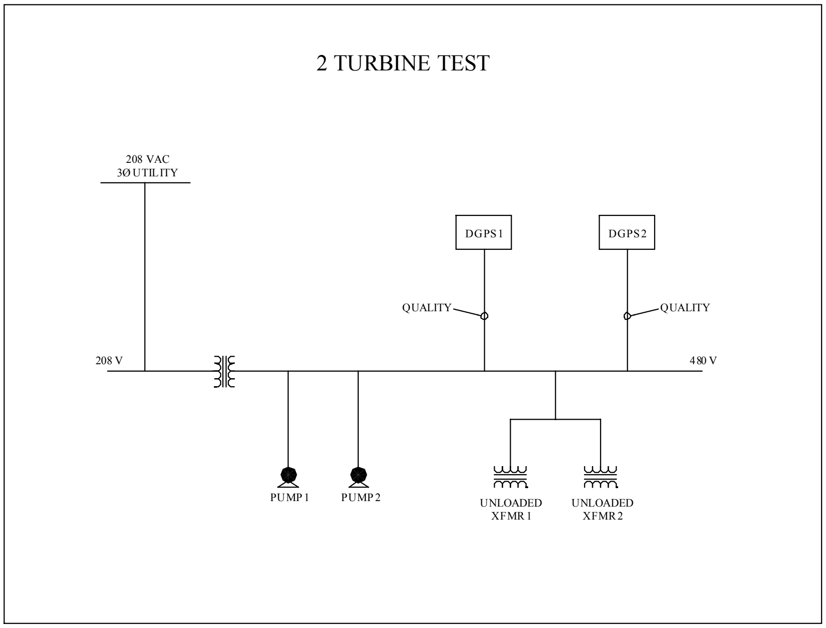


Figure 26. Line diagram of the test layout for testing two microturbines in parallel with the grid

The data presented in Table 36 are the parameters used for the factorial analysis of two microturbines operating in parallel.

Table 36. Experimental Design for Factorial Analysis Conducted in Test 3

Order		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Resp 1	Resp 2	Resp 3	Resp 4
Std	Run	Turb 1 Output	Turb 2 Output	Xfmr (Ind)	Turb 1 Temp	Turb 2 Temp	Eff (Fract)	Eff (Fract)	THD 1 (Current)	THD 2 (Current)
32	1	24.00	24.00	on	90.00	90.00	0.18970	0.20022	0.03139	0.02083
11	2	16.00	24.00	off	90.00	80.00	0.18322	0.20424	0.0483	0.03094
15	3	16.00	24.00	on	90.00	80.00	0.18342	0.20462	0.04139	0.02672
18	4	24.00	16.00	off	80.00	90.00	0.19378	0.18754	0.03372	0.04478
26	5	24.00	16.00	off	90.00	90.00	0.19062	0.18874	0.03278	0.04300
16	6	24.00	24.00	on	90.00	80.00	0.19023	0.20316	0.03056	0.02683
6	7	24.00	16.00	on	80.00	80.00	0.19220	0.19137	0.03272	0.04261
2	8	24.00	16.00	off	80.00	80.00	0.19253	0.19300	0.03606	0.04439
21	9	16.00	16.00	on	80.00	90.00	0.18486	0.18960	0.04167	0.03922
3	10	16.00	24.00	off	80.00	80.00	0.18601	0.20304	0.04267	0.03656
5	11	16.00	16.00	on	80.00	80.00	0.18543	0.19161	0.04028	0.04178
13	12	16.00	16.00	on	90.00	80.00	0.18409	0.19355	0.04194	0.04178
9	13	16.00	16.00	off	90.00	80.00	0.18385	0.19369	0.04844	0.04872
31	14	16.00	24.00	on	90.00	90.00	0.18345	0.19982	0.04039	0.03139
19	15	16.00	24.00	off	80.00	90.00	0.18588	0.19966	0.04700	0.03656
12	16	24.00	24.00	off	90.00	80.00	0.19180	0.20353	0.04206	0.04006
4	17	24.00	24.00	off	80.00	80.00	0.19369	0.20337	0.04139	0.03911
28	18	24.00	24.00	off	90.00	90.00	0.19013	0.20019	0.03744	0.03489
1	19	16.00	16.00	off	80.00	80.00	0.18545	0.19232	0.04478	0.04467
17	20	16.00	16.00	off	80.00	90.00	0.18585	0.19062	0.04283	0.04394
23	21	16.00	24.00	on	80.00	90.00	0.18609	0.20017	0.04144	0.02883
24	22	24.00	24.00	on	80.00	90.00	0.19356	0.19939	0.03061	0.03150
30	23	24.00	16.00	on	90.00	90.00	0.18996	0.18648	0.03228	0.04283
22	24	24.00	16.00	on	80.00	90.00	0.19257	0.18722	0.03294	0.04072
25	25	16.00	16.00	off	90.00	90.00	0.18263	0.18749	0.04639	0.04778
29	26	16.00	16.00	on	90.00	90.00	0.18270	0.18965	0.04478	0.03900
27	27	16.00	24.00	off	90.00	90.00	0.18276	0.20064	0.04633	0.03683
14	28	24.00	16.00	on	90.00	80.00	0.18960	0.19296	0.03411	0.04328
20	29	24.00	24.00	off	80.00	90.00	0.19302	0.19968	0.03894	0.03833
8	30	24.00	24.00	on	80.00	80.00	0.19179	0.20351	0.03317	0.02833
7	31	16.00	24.00	on	80.00	80.00	0.18527	0.20319	0.04467	0.03039
10	32	24.00	16.00	off	90.00	80.00	0.19010	0.19342	0.04211	0.05033

The statistical characteristics of the model are described in the following table.

Table 37. Standardized Data From Test 3

Degrees of Freedom for Evaluation	
Model	5
Residuals	26
Lack of Fit	26
Pure Error	0
Corr Total	31

				Power at 5% alpha level for effect of:		
Term	Std Err[1]	VIF	Ri-Squared	1/2 Std Dev.	1 Std Dev.	2 Std Dev
A	0.18	1	0	27.50%	77.70%	99.90%
B	0.18	1	0	27.50%	77.70%	99.90%
C	0.18	1	0	27.50%	77.70%	99.90%
D	0.18	1	0	27.50%	77.70%	99.90%
E	0.18	1	0	27.50%	77.70%	99.90%

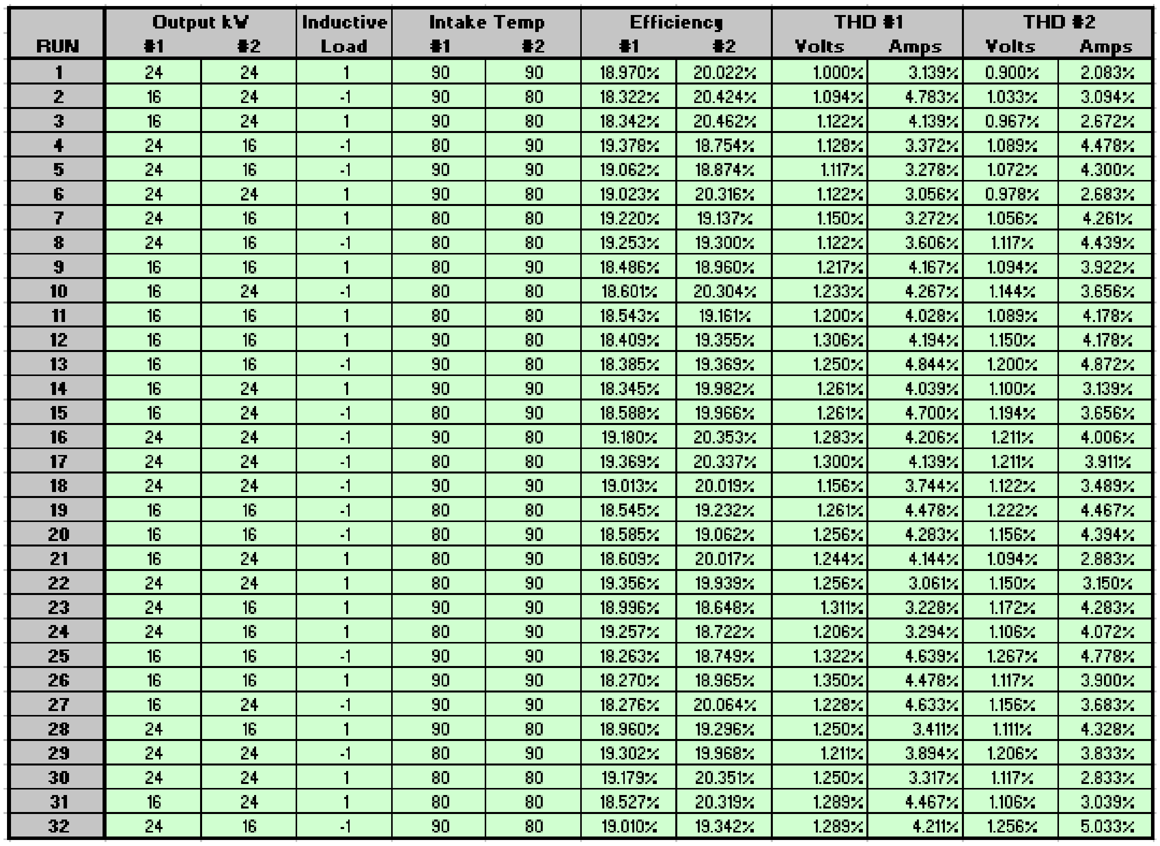
[1] Basis Std. Dev. = 1.0

As can be seen, the power for a signal-to-noise ratio of two standard deviations is 99.9%. Hence, only one replicate was run.

Details of the results, including plots as illustrated for Test 3 are presented in the appendix.

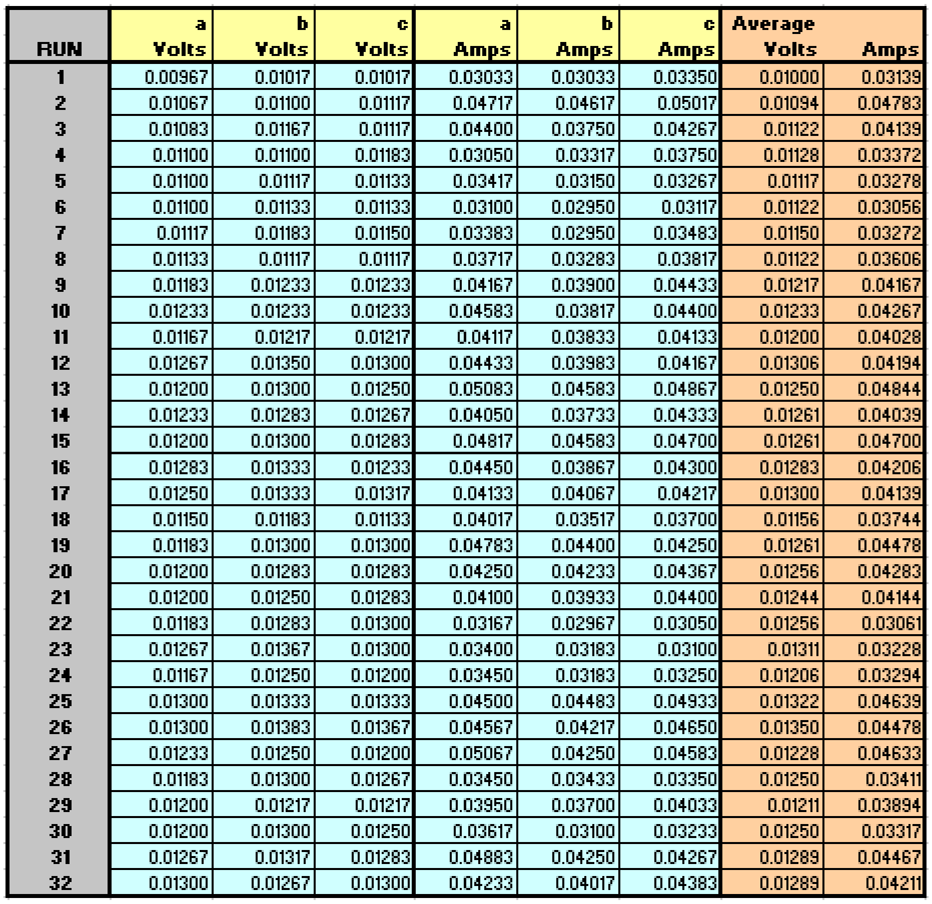
Data Summary
Test 3

Table 38. Test 3 Data Summary



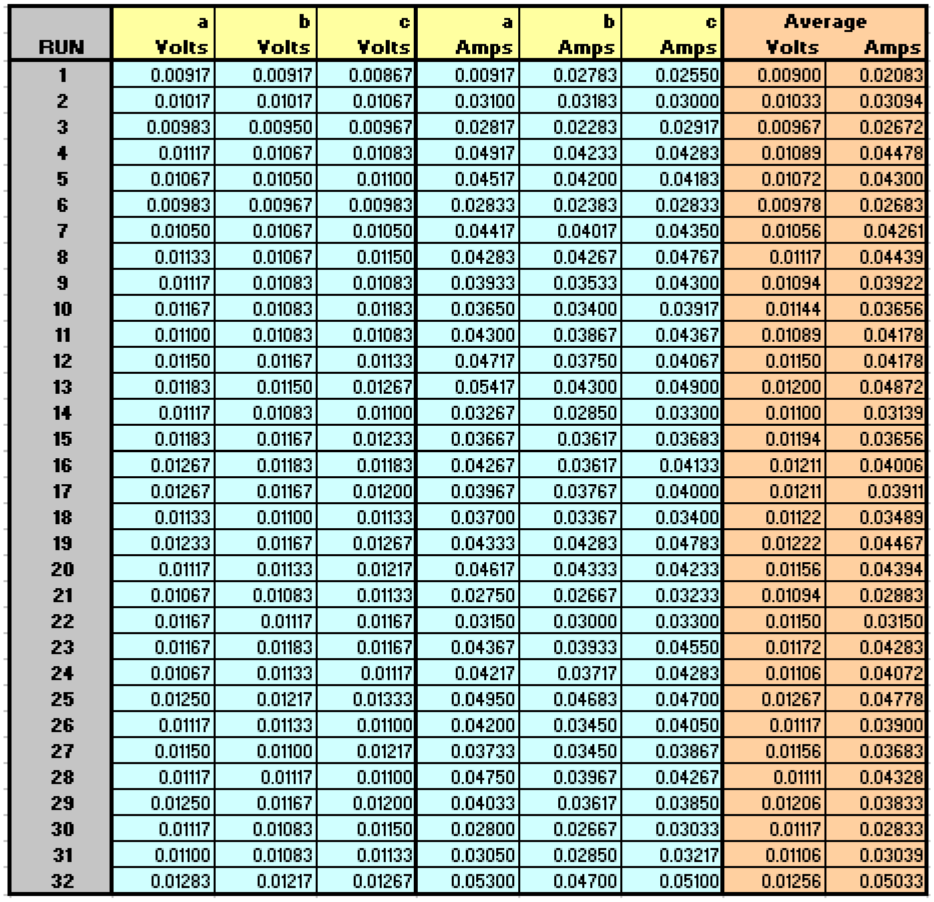
	Output kV		Inductive	Intake Temp		Efficiency		THD #1		THD #2	
RUN	#1	#2	Load	#1	#2	#1	#2	Volts	Amps	Volts	Amps
1	24	24	1	90	90	18.970%	20.022%	1.000%	3.139%	0.900%	2.083%
2	16	24	-1	90	80	18.322%	20.424%	1.094%	4.783%	1.033%	3.094%
3	16	24	1	90	80	18.342%	20.462%	1.122%	4.139%	0.967%	2.672%
4	24	16	-1	80	90	19.378%	18.754%	1.128%	3.372%	1.089%	4.478%
5	24	16	-1	90	90	19.062%	18.874%	1.117%	3.278%	1.072%	4.300%
6	24	24	1	90	80	19.023%	20.316%	1.122%	3.056%	0.978%	2.683%
7	24	16	1	80	80	19.220%	19.137%	1.150%	3.272%	1.056%	4.261%
8	24	16	-1	80	80	19.253%	19.300%	1.122%	3.606%	1.117%	4.439%
9	16	16	1	80	90	18.486%	18.960%	1.217%	4.167%	1.094%	3.922%
10	16	24	-1	80	80	18.601%	20.304%	1.233%	4.267%	1.144%	3.656%
11	16	16	1	80	80	18.543%	19.161%	1.200%	4.028%	1.089%	4.178%
12	16	16	1	90	80	18.409%	19.355%	1.306%	4.194%	1.150%	4.178%
13	16	16	-1	90	80	18.385%	19.369%	1.250%	4.844%	1.200%	4.872%
14	16	24	1	90	90	18.345%	19.982%	1.261%	4.039%	1.100%	3.139%
15	16	24	-1	80	90	18.588%	19.966%	1.261%	4.700%	1.194%	3.656%
16	24	24	-1	90	80	19.180%	20.353%	1.283%	4.206%	1.211%	4.006%
17	24	24	-1	80	80	19.369%	20.337%	1.300%	4.139%	1.211%	3.911%
18	24	24	-1	90	90	19.013%	20.019%	1.156%	3.744%	1.122%	3.489%
19	16	16	-1	80	80	18.545%	19.232%	1.261%	4.478%	1.222%	4.467%
20	16	16	-1	80	90	18.585%	19.062%	1.256%	4.283%	1.156%	4.394%
21	16	24	1	80	90	18.609%	20.017%	1.244%	4.144%	1.094%	2.883%
22	24	24	1	80	90	19.356%	19.939%	1.256%	3.061%	1.150%	3.150%
23	24	16	1	90	90	18.996%	18.648%	1.311%	3.228%	1.172%	4.283%
24	24	16	1	80	90	19.257%	18.722%	1.206%	3.294%	1.106%	4.072%
25	16	16	-1	90	90	18.263%	18.749%	1.322%	4.639%	1.267%	4.778%
26	16	16	1	90	90	18.270%	18.965%	1.350%	4.478%	1.117%	3.900%
27	16	24	-1	90	90	18.276%	20.064%	1.228%	4.633%	1.156%	3.683%
28	24	16	1	90	80	18.960%	19.296%	1.250%	3.411%	1.111%	4.328%
29	24	24	-1	80	90	19.302%	19.968%	1.211%	3.894%	1.206%	3.833%
30	24	24	1	80	80	19.179%	20.351%	1.250%	3.317%	1.117%	2.833%
31	16	24	1	80	80	18.527%	20.319%	1.289%	4.467%	1.106%	3.039%
32	24	16	-1	90	80	19.010%	19.342%	1.289%	4.211%	1.256%	5.033%

Table 39. Test 3 Turbine 1 THD Data



	a	b	c	a	b	c	Average	
RUN	Volts	Volts	Volts	Amps	Amps	Amps	Volts	Amps
1	0.00967	0.01017	0.01017	0.03033	0.03033	0.03350	0.01000	0.03139
2	0.01067	0.01100	0.01117	0.04717	0.04617	0.05017	0.01094	0.04783
3	0.01083	0.01167	0.01117	0.04400	0.03750	0.04267	0.01122	0.04139
4	0.01100	0.01100	0.01183	0.03050	0.03317	0.03750	0.01128	0.03372
5	0.01100	0.01117	0.01133	0.03417	0.03150	0.03267	0.01117	0.03278
6	0.01100	0.01133	0.01133	0.03100	0.02950	0.03117	0.01122	0.03056
7	0.01117	0.01183	0.01150	0.03383	0.02950	0.03483	0.01150	0.03272
8	0.01133	0.01117	0.01117	0.03717	0.03283	0.03817	0.01122	0.03606
9	0.01183	0.01233	0.01233	0.04167	0.03900	0.04433	0.01217	0.04167
10	0.01233	0.01233	0.01233	0.04583	0.03817	0.04400	0.01233	0.04267
11	0.01167	0.01217	0.01217	0.04117	0.03833	0.04133	0.01200	0.04028
12	0.01267	0.01350	0.01300	0.04433	0.03983	0.04167	0.01306	0.04194
13	0.01200	0.01300	0.01250	0.05083	0.04583	0.04867	0.01250	0.04844
14	0.01233	0.01283	0.01267	0.04050	0.03733	0.04333	0.01261	0.04039
15	0.01200	0.01300	0.01283	0.04817	0.04583	0.04700	0.01261	0.04700
16	0.01283	0.01333	0.01233	0.04450	0.03867	0.04300	0.01283	0.04206
17	0.01250	0.01333	0.01317	0.04133	0.04067	0.04217	0.01300	0.04139
18	0.01150	0.01183	0.01133	0.04017	0.03517	0.03700	0.01156	0.03744
19	0.01183	0.01300	0.01300	0.04783	0.04400	0.04250	0.01261	0.04478
20	0.01200	0.01283	0.01283	0.04250	0.04233	0.04367	0.01256	0.04283
21	0.01200	0.01250	0.01283	0.04100	0.03933	0.04400	0.01244	0.04144
22	0.01183	0.01283	0.01300	0.03167	0.02967	0.03050	0.01256	0.03061
23	0.01267	0.01367	0.01300	0.03400	0.03183	0.03100	0.01311	0.03228
24	0.01167	0.01250	0.01200	0.03450	0.03183	0.03250	0.01206	0.03294
25	0.01300	0.01333	0.01333	0.04500	0.04483	0.04933	0.01322	0.04639
26	0.01300	0.01383	0.01367	0.04567	0.04217	0.04650	0.01350	0.04478
27	0.01233	0.01250	0.01200	0.05067	0.04250	0.04583	0.01228	0.04633
28	0.01183	0.01300	0.01267	0.03450	0.03433	0.03350	0.01250	0.03411
29	0.01200	0.01217	0.01217	0.03950	0.03700	0.04033	0.01211	0.03894
30	0.01200	0.01300	0.01250	0.03617	0.03100	0.03233	0.01250	0.03317
31	0.01267	0.01317	0.01283	0.04883	0.04250	0.04267	0.01289	0.04467
32	0.01300	0.01267	0.01300	0.04233	0.04017	0.04383	0.01289	0.04211

Table 40. Test 3 Turbine 2 THD Data



	a	b	c	a	b	c	Average	
RUN	Volts	Volts	Volts	Amps	Amps	Amps	Volts	Amps
1	0.00917	0.00917	0.00867	0.00917	0.02783	0.02550	0.00900	0.02083
2	0.01017	0.01017	0.01067	0.03100	0.03183	0.03000	0.01033	0.03094
3	0.00983	0.00950	0.00967	0.02817	0.02283	0.02917	0.00967	0.02672
4	0.01117	0.01067	0.01083	0.04917	0.04233	0.04283	0.01089	0.04478
5	0.01067	0.01050	0.01100	0.04517	0.04200	0.04183	0.01072	0.04300
6	0.00983	0.00967	0.00983	0.02833	0.02383	0.02833	0.00978	0.02683
7	0.01050	0.01067	0.01050	0.04417	0.04017	0.04350	0.01056	0.04261
8	0.01133	0.01067	0.01150	0.04283	0.04267	0.04767	0.01117	0.04439
9	0.01117	0.01083	0.01083	0.03933	0.03533	0.04300	0.01094	0.03922
10	0.01167	0.01083	0.01183	0.03650	0.03400	0.03917	0.01144	0.03656
11	0.01100	0.01083	0.01083	0.04300	0.03867	0.04367	0.01089	0.04178
12	0.01150	0.01167	0.01133	0.04717	0.03750	0.04067	0.01150	0.04178
13	0.01183	0.01150	0.01267	0.05417	0.04300	0.04900	0.01200	0.04872
14	0.01117	0.01083	0.01100	0.03267	0.02850	0.03300	0.01100	0.03139
15	0.01183	0.01167	0.01233	0.03667	0.03617	0.03683	0.01194	0.03656
16	0.01267	0.01183	0.01183	0.04267	0.03617	0.04133	0.01211	0.04006
17	0.01267	0.01167	0.01200	0.03967	0.03767	0.04000	0.01211	0.03911
18	0.01133	0.01100	0.01133	0.03700	0.03367	0.03400	0.01122	0.03489
19	0.01233	0.01167	0.01267	0.04333	0.04283	0.04783	0.01222	0.04467
20	0.01117	0.01133	0.01217	0.04617	0.04333	0.04233	0.01156	0.04394
21	0.01067	0.01083	0.01133	0.02750	0.02667	0.03233	0.01094	0.02883
22	0.01167	0.01117	0.01167	0.03150	0.03000	0.03300	0.01150	0.03150
23	0.01167	0.01183	0.01167	0.04367	0.03933	0.04550	0.01172	0.04283
24	0.01067	0.01133	0.01117	0.04217	0.03717	0.04283	0.01106	0.04072
25	0.01250	0.01217	0.01333	0.04950	0.04683	0.04700	0.01267	0.04778
26	0.01117	0.01133	0.01100	0.04200	0.03450	0.04050	0.01117	0.03900
27	0.01150	0.01100	0.01217	0.03733	0.03450	0.03867	0.01156	0.03683
28	0.01117	0.01117	0.01100	0.04750	0.03967	0.04267	0.01111	0.04328
29	0.01250	0.01167	0.01200	0.04033	0.03617	0.03850	0.01206	0.03833
30	0.01117	0.01083	0.01150	0.02800	0.02667	0.03033	0.01117	0.02833
31	0.01100	0.01083	0.01133	0.03050	0.02850	0.03217	0.01106	0.03039
32	0.01283	0.01217	0.01267	0.05300	0.04700	0.05100	0.01256	0.05033

4.5.4 Test 4

A series of transient tests was also run to assess stability during standalone operation. To consider the interaction among components that might be found in a standalone system, various typical energy sources and loads were employed.

Electric energy was supplied by the second microturbine and a flywheel energy storage and power quality device. This device consisted of a motor, a flywheel, and a generator. This output to an inverter that, in turn, fed a motor-generator combination connected to the load. The inverter could change its output to ensure proper power quality during power disturbances on the gird. In this mode, the individual load supplied by the flywheel is separated from the grid. A 14-hp pump was attached as a typical load that might be present in an isolated application. This was a submersible pump that was placed in a tank of water with a valve on the output to regulate the pressure of the re-circulated water and, consequently, the load on the pump. An electric heater and an unloaded transformer were then switched in and out to consider the effects of resistive and inductive transients on the operation and stability of the energy supply system.

The following is a description of the equipment used.

Equipment

- Microturbine distributed generator
- Natural gas flow meter – Roots meter model 15M175 with Roots magnetic coupled EL transmitter model R-3 (three pulses per impeller revolution)
- Induction load – transformer 45 kVA
- Induction load – pump 14 hp 460 V-3ph-60 Hz
- “E” type thermocouples
- Artificial load boxes providing heat to combustion air (resistance heat)
- RF Technologies Inc. pressure transducer mo. PTXI-60 psi
- Metrosonics PA-9
- Submersible pumps

Data Collection

- Microturbine input
    - Labtech Control software (version 10.1); data logged in Microsoft Excel format

- Microturbine Output
    - Metrosoft MSPA-9W exported to Microsoft Excel format

The general test configuration is illustrated in Figure 27.

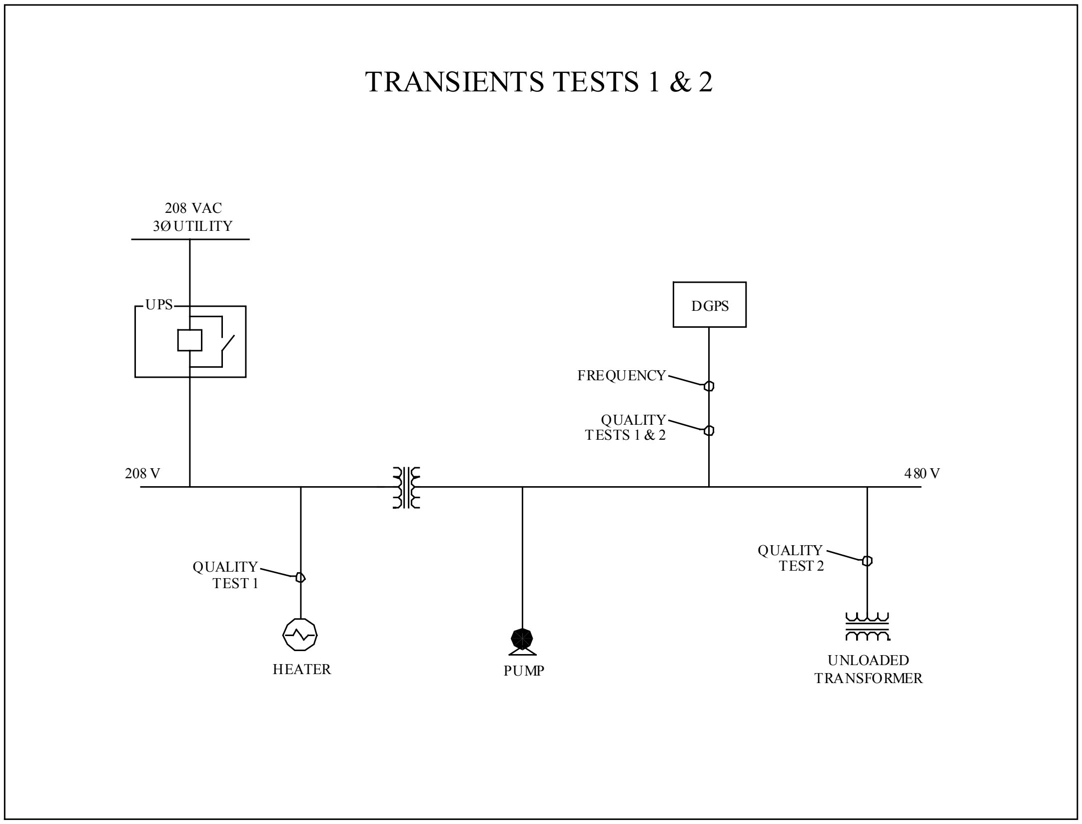


Figure 27. Test configuration for evaluating standalone operation with storage

The initial test system consisted of a microturbine connected in parallel to the flywheel system and a 14-hp pump as load. The following traces (Figure 28 and Figure 29) are the current and voltage waveforms for all three phases in the initial condition. As shown by the graphs, there is a 60-Hz sine wave for both the current and voltage.

To test the stability of the system, a 15-kW heater was then switched on, and the wave shapes were recorded. The following wave shapes resulted from the step increase in resistive load at the heater for the cycle following the transient.

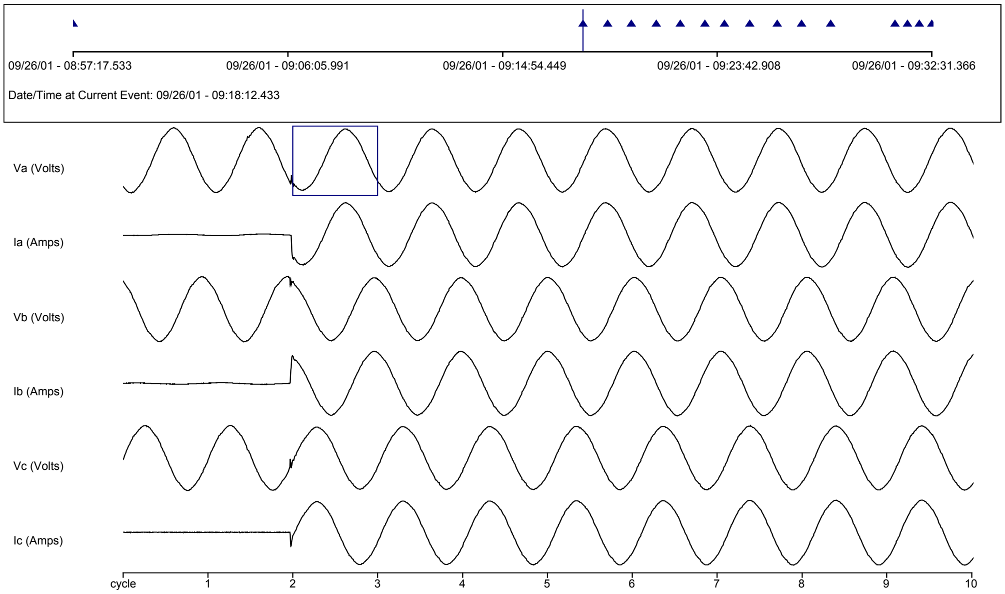
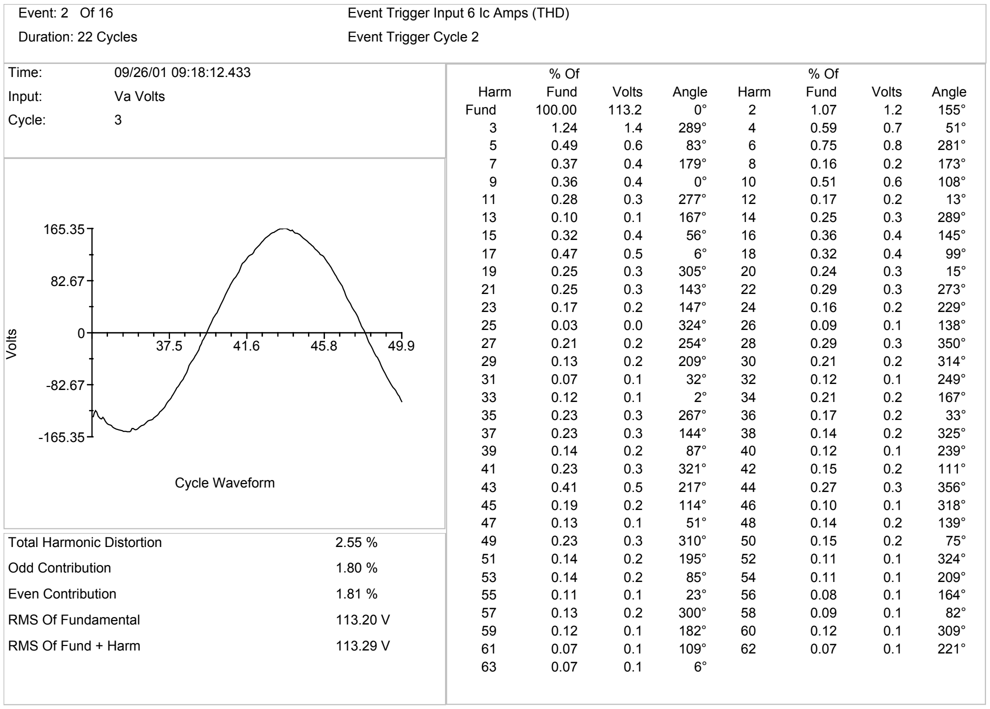


Figure 28. Wave shapes

The following figure is a more detailed view of the wave shape segment marked by the square in the figure above.


Event: 2 Of 16
Event Trigger Input 6 Ic Amps (THD)
Duration: 22 Cycles
Event Trigger Cycle 2

Time: 09/26/01 09:18:12.433
Input: Va Volts
Cycle: 3

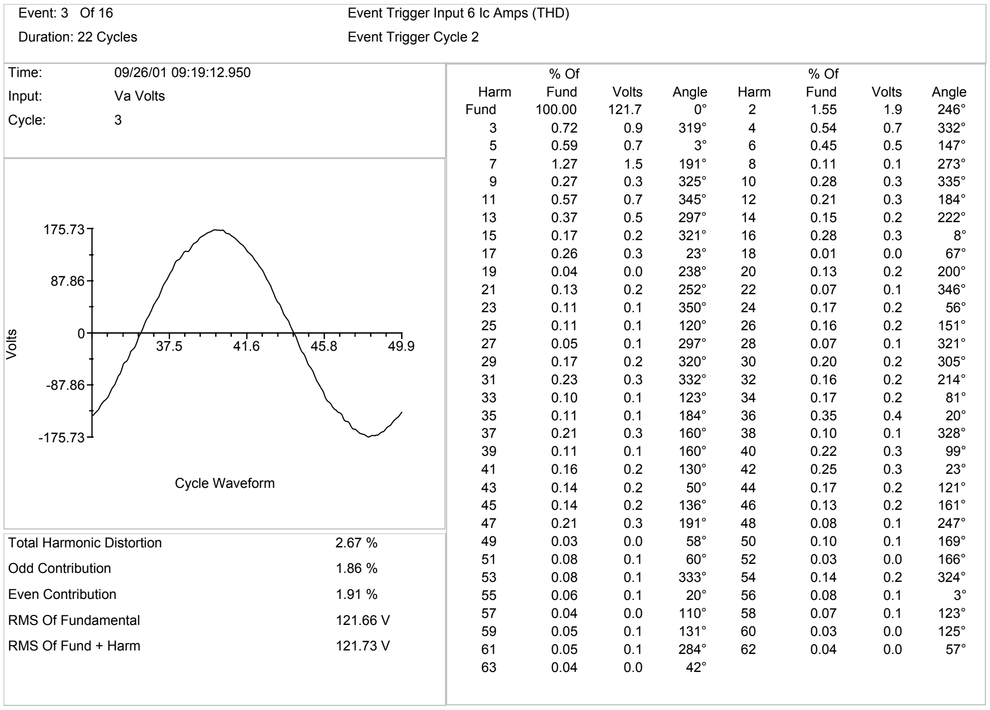
Total Harmonic Distortion	2.55 %
Odd Contribution	1.80 %
Even Contribution	1.81 %
RMS Of Fundamental	113.20 V
RMS Of Fund + Harm	113.29 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	113.2	0°	2	1.07	1.2	155°
3	1.24	1.4	289°	4	0.59	0.7	51°
5	0.49	0.6	83°	6	0.75	0.8	281°
7	0.37	0.4	179°	8	0.16	0.2	173°
9	0.36	0.4	0°	10	0.51	0.6	108°
11	0.28	0.3	277°	12	0.17	0.2	13°
13	0.10	0.1	167°	14	0.25	0.3	289°
15	0.32	0.4	56°	16	0.36	0.4	145°
17	0.47	0.5	6°	18	0.32	0.4	99°
19	0.25	0.3	305°	20	0.24	0.3	15°
21	0.25	0.3	143°	22	0.29	0.3	273°
23	0.17	0.2	147°	24	0.16	0.2	229°
25	0.03	0.0	324°	26	0.09	0.1	138°
27	0.21	0.2	254°	28	0.29	0.3	350°
29	0.13	0.2	209°	30	0.21	0.2	314°
31	0.07	0.1	32°	32	0.12	0.1	249°
33	0.12	0.1	2°	34	0.21	0.2	167°
35	0.23	0.3	267°	36	0.17	0.2	33°
37	0.23	0.3	144°	38	0.14	0.2	325°
39	0.14	0.2	87°	40	0.12	0.1	239°
41	0.23	0.3	321°	42	0.15	0.2	111°
43	0.41	0.5	217°	44	0.27	0.3	356°
45	0.19	0.2	114°	46	0.10	0.1	318°
47	0.13	0.1	51°	48	0.14	0.2	139°
49	0.23	0.3	310°	50	0.15	0.2	75°
51	0.14	0.2	195°	52	0.11	0.1	324°
53	0.14	0.2	85°	54	0.11	0.1	209°
55	0.11	0.1	23°	56	0.08	0.1	164°
57	0.13	0.2	300°	58	0.09	0.1	82°
59	0.12	0.1	182°	60	0.12	0.1	309°
61	0.07	0.1	109°	62	0.07	0.1	221°
63	0.07	0.1	6°				

Figure 29. Enlargement detailing the wave shape from Figure 28

As shown in the plots, there was little distortion initially, and after a few cycles, the transient died out.

The following data are after 21 cycles after the load was turned on.



Event: 3 Of 16
Duration: 22 Cycles

Event Trigger Input 6 Ic Amps (THD)
Event Trigger Cycle 2

Time: 09/26/01 09:19:12.950
Input: Va Volts
Cycle: 3

Total Harmonic Distortion	2.67 %
Odd Contribution	1.86 %
Even Contribution	1.91 %
RMS Of Fundamental	121.66 V
RMS Of Fund + Harm	121.73 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	121.7	0°	2	1.55	1.9	246°
3	0.72	0.9	319°	4	0.54	0.7	332°
5	0.59	0.7	3°	6	0.45	0.5	147°
7	1.27	1.5	191°	8	0.11	0.1	273°
9	0.27	0.3	325°	10	0.28	0.3	335°
11	0.57	0.7	345°	12	0.21	0.3	184°
13	0.37	0.5	297°	14	0.15	0.2	222°
15	0.17	0.2	321°	16	0.28	0.3	8°
17	0.26	0.3	23°	18	0.01	0.0	67°
19	0.04	0.0	238°	20	0.13	0.2	200°
21	0.13	0.2	252°	22	0.07	0.1	346°
23	0.11	0.1	350°	24	0.17	0.2	56°
25	0.11	0.1	120°	26	0.16	0.2	151°
27	0.05	0.1	297°	28	0.07	0.1	321°
29	0.17	0.2	320°	30	0.20	0.2	305°
31	0.23	0.3	332°	32	0.16	0.2	214°
33	0.10	0.1	123°	34	0.17	0.2	81°
35	0.11	0.1	184°	36	0.35	0.4	20°
37	0.21	0.3	160°	38	0.10	0.1	328°
39	0.11	0.1	160°	40	0.22	0.3	99°
41	0.16	0.2	130°	42	0.25	0.3	23°
43	0.14	0.2	50°	44	0.17	0.2	121°
45	0.14	0.2	136°	46	0.13	0.2	161°
47	0.21	0.3	191°	48	0.08	0.1	247°
49	0.03	0.0	58°	50	0.10	0.1	169°
51	0.08	0.1	60°	52	0.03	0.0	166°
53	0.08	0.1	333°	54	0.14	0.2	324°
55	0.06	0.1	20°	56	0.08	0.1	3°
57	0.04	0.0	110°	58	0.07	0.1	123°
59	0.05	0.1	131°	60	0.03	0.0	125°
61	0.05	0.1	284°	62	0.04	0.0	57°
63	0.04	0.0	42°				

Figure 30. Enlargement of waveform from standalone operation with flywheel storage

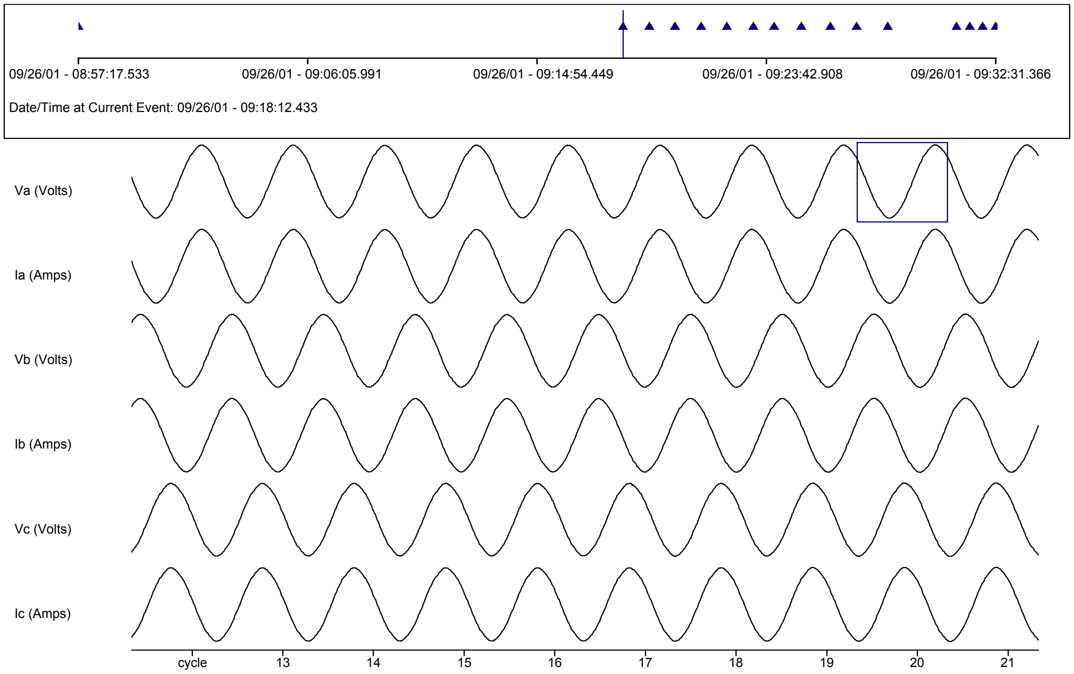


Figure 31. Detail for standalone operation after 21 cycles

The following figures are the waveforms taken at the flywheel for the case of the cycle at the end of the resistive transient. Data are also presented for a cycle after reaching steady state, and additional details are presented in Figure 34.

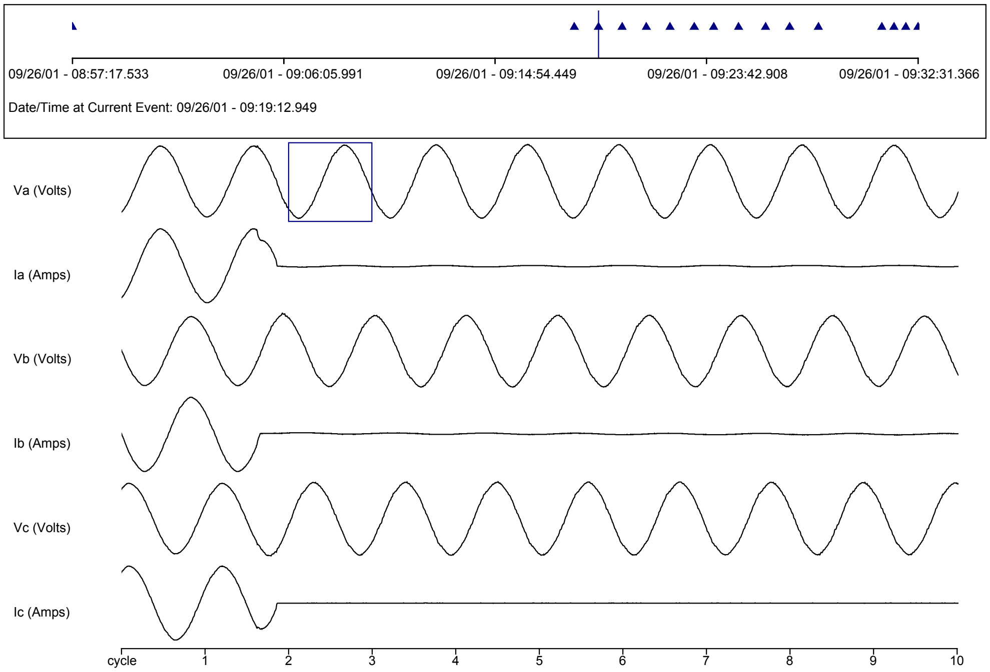


Figure 32. Standalone operation with flywheel storage

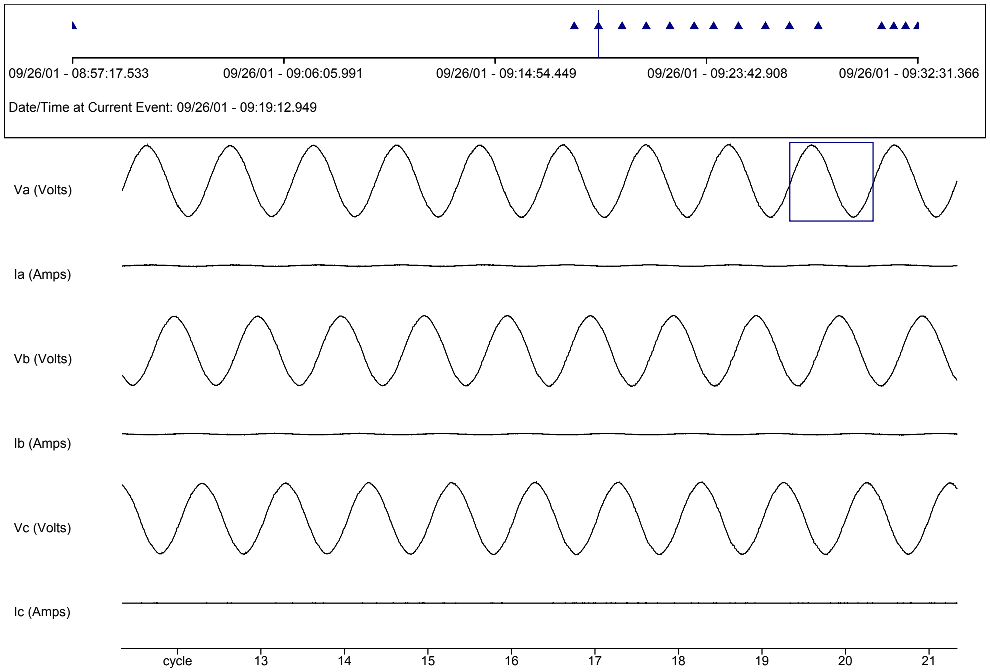
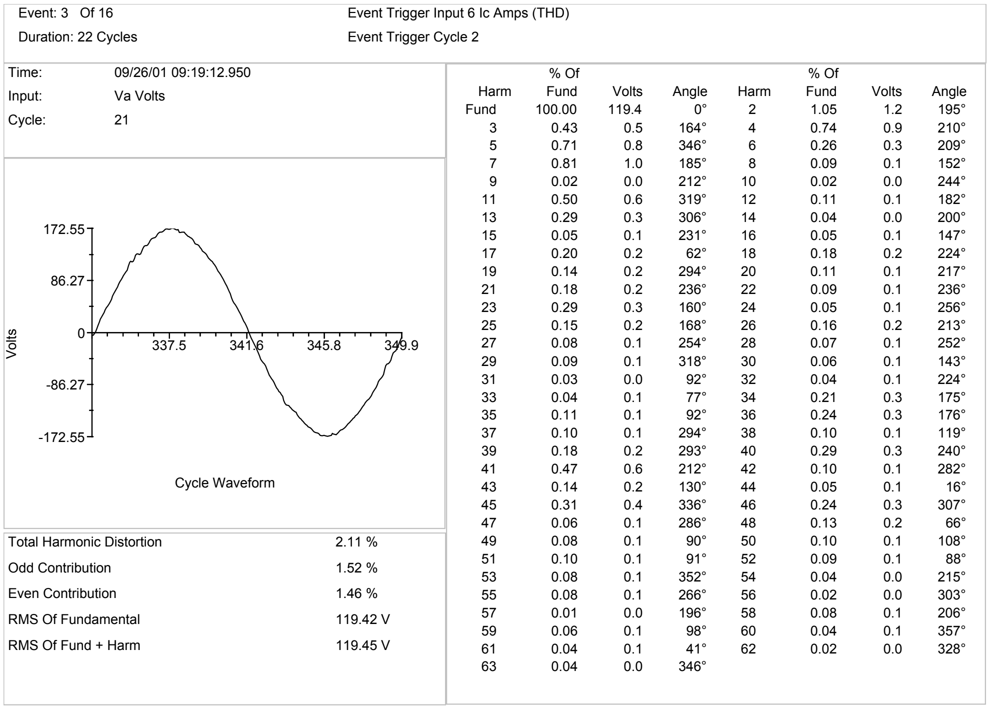


Figure 33. Standalone operation with flywheel storage at steady-state operation



Event: 3 Of 16
Duration: 22 Cycles
Event Trigger Input 6 Ic Amps (THD)
Event Trigger Cycle 2

Time:	09/26/01 09:19:12.950
Input:	Va Volts
Cycle:	21

Total Harmonic Distortion	2.11 %
Odd Contribution	1.52 %
Even Contribution	1.46 %
RMS Of Fundamental	119.42 V
RMS Of Fund + Harm	119.45 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	119.4	0°	2	1.05	1.2	195°
3	0.43	0.5	164°	4	0.74	0.9	210°
5	0.71	0.8	346°	6	0.26	0.3	209°
7	0.81	1.0	185°	8	0.09	0.1	152°
9	0.02	0.0	212°	10	0.02	0.0	244°
11	0.50	0.6	319°	12	0.11	0.1	182°
13	0.29	0.3	306°	14	0.04	0.0	200°
15	0.05	0.1	231°	16	0.05	0.1	147°
17	0.20	0.2	62°	18	0.18	0.2	224°
19	0.14	0.2	294°	20	0.11	0.1	217°
21	0.18	0.2	236°	22	0.09	0.1	236°
23	0.29	0.3	160°	24	0.05	0.1	256°
25	0.15	0.2	168°	26	0.16	0.2	213°
27	0.08	0.1	254°	28	0.07	0.1	252°
29	0.09	0.1	318°	30	0.06	0.1	143°
31	0.03	0.0	92°	32	0.04	0.1	224°
33	0.04	0.1	77°	34	0.21	0.3	175°
35	0.11	0.1	92°	36	0.24	0.3	176°
37	0.10	0.1	294°	38	0.10	0.1	119°
39	0.18	0.2	293°	40	0.29	0.3	240°
41	0.47	0.6	212°	42	0.10	0.1	282°
43	0.14	0.2	130°	44	0.05	0.1	16°
45	0.31	0.4	336°	46	0.24	0.3	307°
47	0.06	0.1	286°	48	0.13	0.2	66°
49	0.08	0.1	90°	50	0.10	0.1	108°
51	0.10	0.1	91°	52	0.09	0.1	88°
53	0.08	0.1	352°	54	0.04	0.0	215°
55	0.08	0.1	266°	56	0.02	0.0	303°
57	0.01	0.0	196°	58	0.08	0.1	206°
59	0.06	0.1	98°	60	0.04	0.1	357°
61	0.04	0.1	41°	62	0.02	0.0	328°
63	0.04	0.0	346°				

Figure 34. Enlargement of waveform from Figure 33

The following figures (Figure 35 and Figure 36) are the waveforms taken at the turbine for the case of a cycle after the resistive transient and a cycle after reaching steady state.

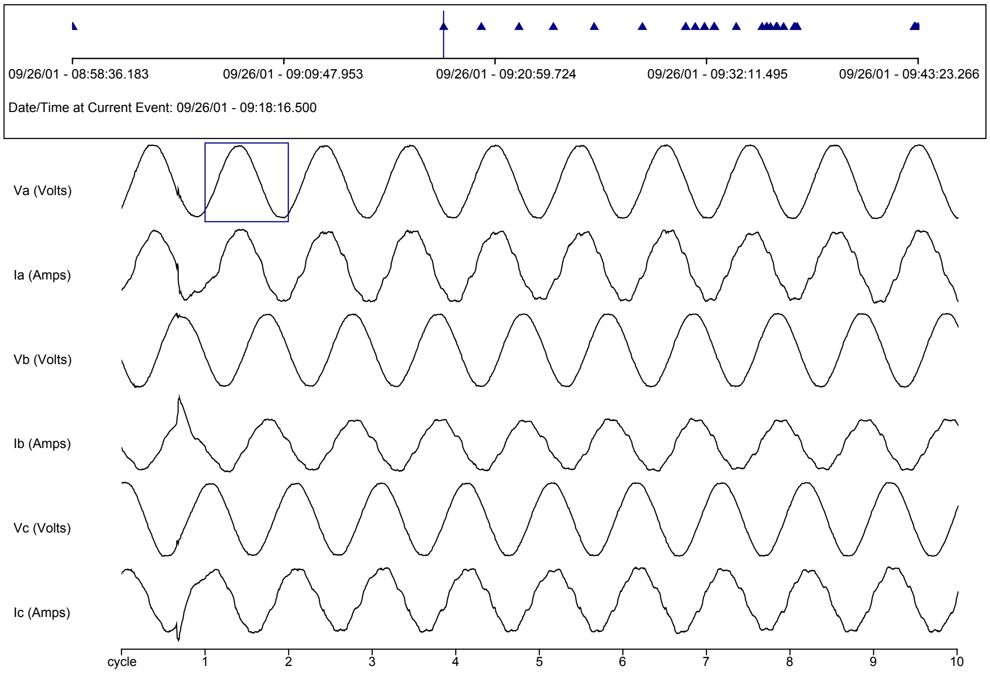
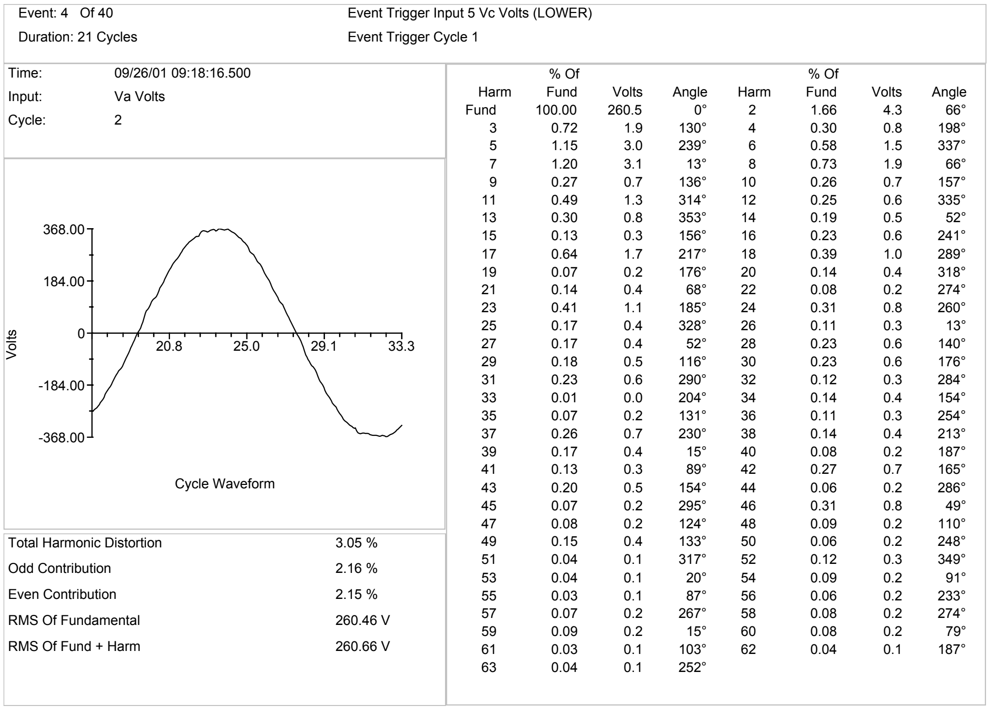


Figure 35. Waveform of standalone operation after a resistive transient



Event: 4 Of 40
Duration: 21 Cycles
Event Trigger Input 5 Vc Volts (LOWER)
Event Trigger Cycle 1

Time: 09/26/01 09:18:16.500
Input: Va Volts
Cycle: 2

Total Harmonic Distortion	3.05 %
Odd Contribution	2.16 %
Even Contribution	2.15 %
RMS Of Fundamental	260.46 V
RMS Of Fund + Harm	260.66 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	260.5	0°	2	1.66	4.3	66°
3	0.72	1.9	130°	4	0.30	0.8	198°
5	1.15	3.0	239°	6	0.58	1.5	337°
7	1.20	3.1	13°	8	0.73	1.9	66°
9	0.27	0.7	136°	10	0.26	0.7	157°
11	0.49	1.3	314°	12	0.25	0.6	335°
13	0.30	0.8	353°	14	0.19	0.5	52°
15	0.13	0.3	156°	16	0.23	0.6	241°
17	0.64	1.7	217°	18	0.39	1.0	289°
19	0.07	0.2	176°	20	0.14	0.4	318°
21	0.14	0.4	68°	22	0.08	0.2	274°
23	0.41	1.1	185°	24	0.31	0.8	260°
25	0.17	0.4	328°	26	0.11	0.3	13°
27	0.17	0.4	52°	28	0.23	0.6	140°
29	0.18	0.5	116°	30	0.23	0.6	176°
31	0.23	0.6	290°	32	0.12	0.3	284°
33	0.01	0.0	204°	34	0.14	0.4	154°
35	0.07	0.2	131°	36	0.11	0.3	254°
37	0.26	0.7	230°	38	0.14	0.4	213°
39	0.17	0.4	15°	40	0.08	0.2	187°
41	0.13	0.3	89°	42	0.27	0.7	165°
43	0.20	0.5	154°	44	0.06	0.2	286°
45	0.07	0.2	295°	46	0.31	0.8	49°
47	0.08	0.2	124°	48	0.09	0.2	110°
49	0.15	0.4	133°	50	0.06	0.2	248°
51	0.04	0.1	317°	52	0.12	0.3	349°
53	0.04	0.1	20°	54	0.09	0.2	91°
55	0.03	0.1	87°	56	0.06	0.2	233°
57	0.07	0.2	267°	58	0.08	0.2	274°
59	0.09	0.2	15°	60	0.08	0.2	79°
61	0.03	0.1	103°	62	0.04	0.1	187°
63	0.04	0.1	252°				

Figure 36. Enlargement of waveform from Figure 35

The waveforms from Test 4, standalone operation with a resistive load recorded after steady state is reached, are illustrated in Figure 37 and Figure 38.

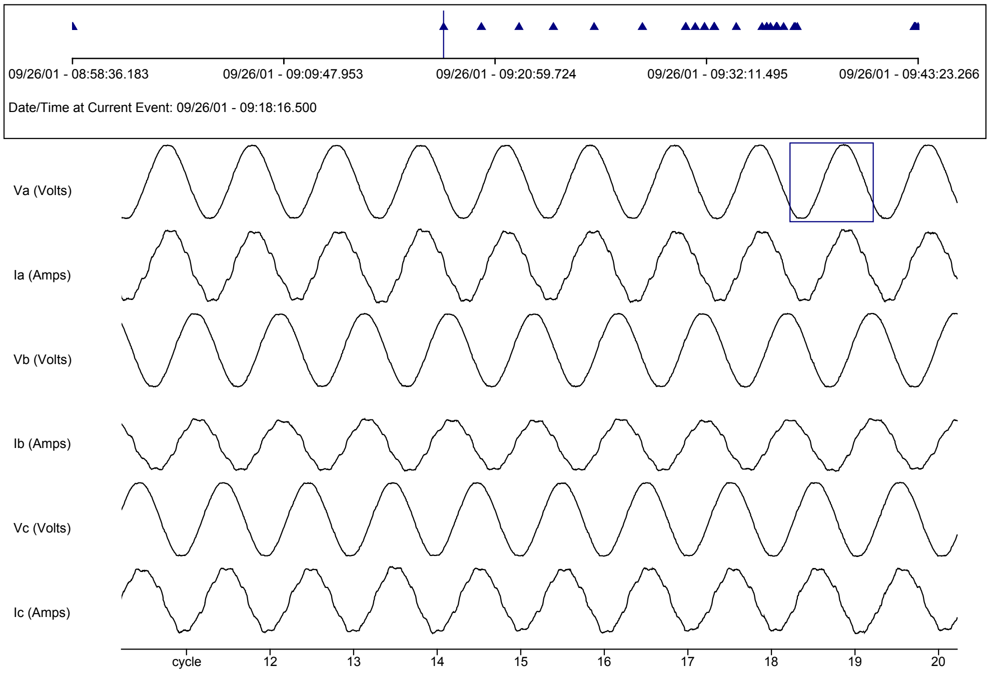
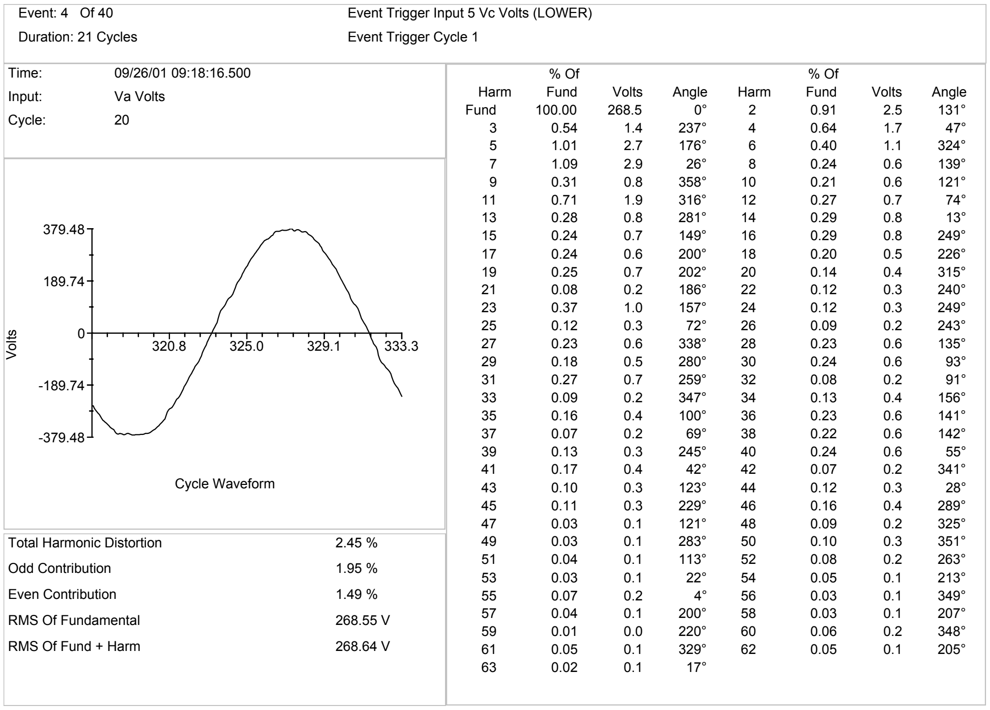


Figure 37. Waveform



Event: 4 Of 40
Duration: 21 Cycles
Event Trigger Input 5 Vc Volts (LOWER)
Event Trigger Cycle 1

Time: 09/26/01 09:18:16.500
Input: Va Volts
Cycle: 20

Total Harmonic Distortion	2.45 %
Odd Contribution	1.95 %
Even Contribution	1.49 %
RMS Of Fundamental	268.55 V
RMS Of Fund + Harm	268.64 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	268.5	0°	2	0.91	2.5	131°
3	0.54	1.4	237°	4	0.64	1.7	47°
5	1.01	2.7	176°	6	0.40	1.1	324°
7	1.09	2.9	26°	8	0.24	0.6	139°
9	0.31	0.8	358°	10	0.21	0.6	121°
11	0.71	1.9	316°	12	0.27	0.7	74°
13	0.28	0.8	281°	14	0.29	0.8	13°
15	0.24	0.7	149°	16	0.29	0.8	249°
17	0.24	0.6	200°	18	0.20	0.5	226°
19	0.25	0.7	202°	20	0.14	0.4	315°
21	0.08	0.2	186°	22	0.12	0.3	240°
23	0.37	1.0	157°	24	0.12	0.3	249°
25	0.12	0.3	72°	26	0.09	0.2	243°
27	0.23	0.6	338°	28	0.23	0.6	135°
29	0.18	0.5	280°	30	0.24	0.6	93°
31	0.27	0.7	259°	32	0.08	0.2	91°
33	0.09	0.2	347°	34	0.13	0.4	156°
35	0.16	0.4	100°	36	0.23	0.6	141°
37	0.07	0.2	69°	38	0.22	0.6	142°
39	0.13	0.3	245°	40	0.24	0.6	55°
41	0.17	0.4	42°	42	0.07	0.2	341°
43	0.10	0.3	123°	44	0.12	0.3	28°
45	0.11	0.3	229°	46	0.16	0.4	289°
47	0.03	0.1	121°	48	0.09	0.2	325°
49	0.03	0.1	283°	50	0.10	0.3	351°
51	0.04	0.1	113°	52	0.08	0.2	263°
53	0.03	0.1	22°	54	0.05	0.1	213°
55	0.07	0.2	4°	56	0.03	0.1	349°
57	0.04	0.1	200°	58	0.03	0.1	207°
59	0.01	0.0	220°	60	0.06	0.2	348°
61	0.05	0.1	329°	62	0.05	0.1	205°
63	0.02	0.1	17°				

Figure 38. Detail of waveform from Figure 37

The following four figures (figures 39, 40, 41, and 42) are repeated trials showing the cycle after the start of the resistive transient.

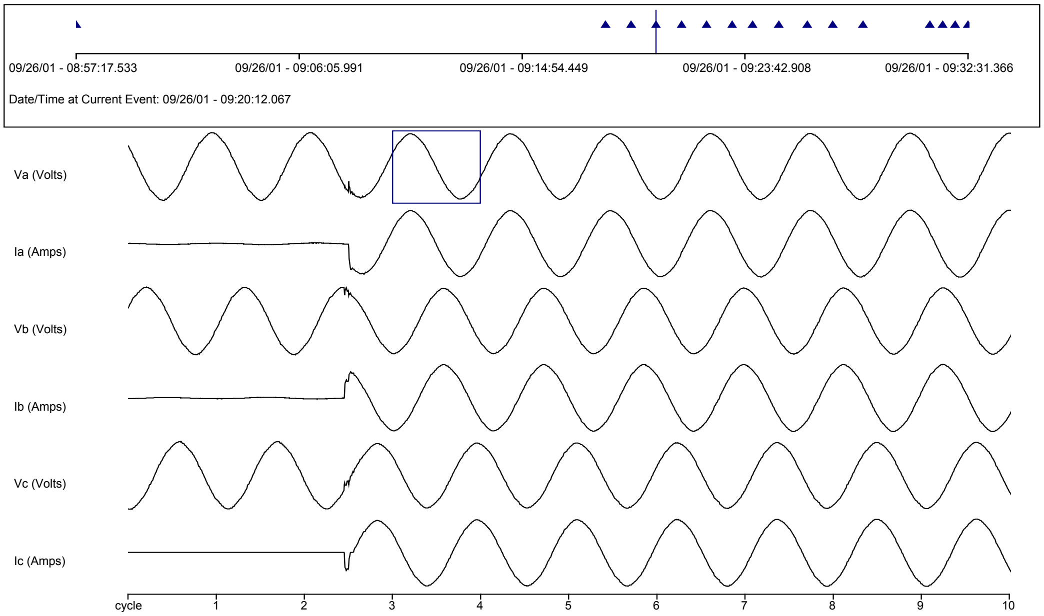
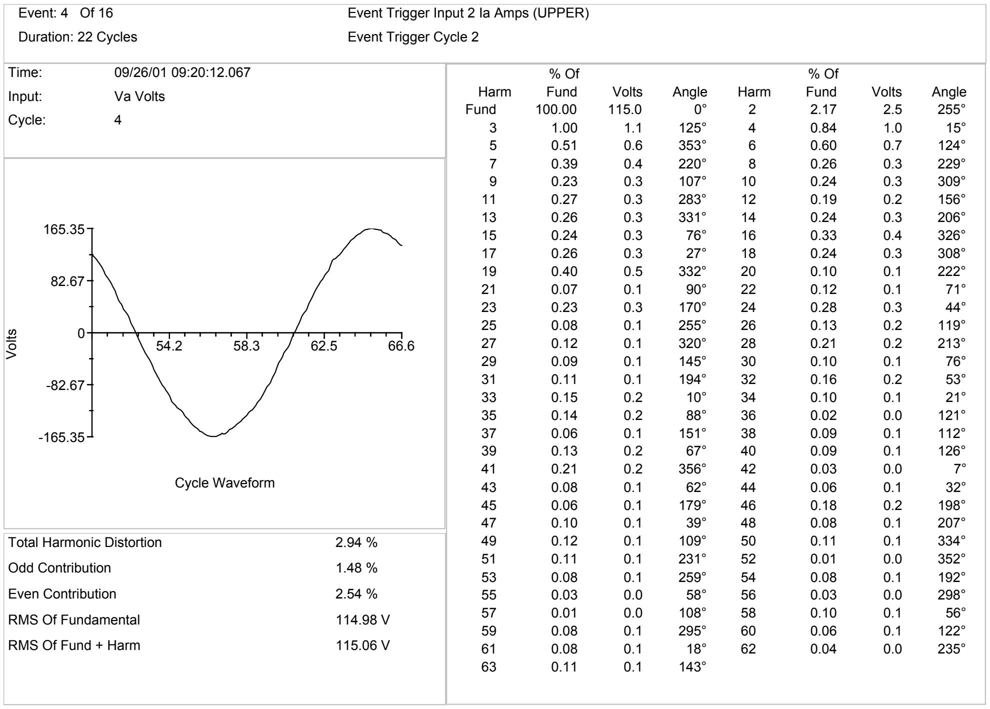


Figure 39. Waveform at the flywheel



Event: 4 Of 16
Duration: 22 Cycles

Event Trigger Input 2 Ia Amps (UPPER)
Event Trigger Cycle 2

Time: 09/26/01 09:20:12.067
Input: Va Volts
Cycle: 4

Total Harmonic Distortion	2.94 %
Odd Contribution	1.48 %
Even Contribution	2.54 %
RMS Of Fundamental	114.98 V
RMS Of Fund + Harm	115.06 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	115.0	0°	2	2.17	2.5	255°
3	1.00	1.1	125°	4	0.84	1.0	15°
5	0.51	0.6	353°	6	0.60	0.7	124°
7	0.39	0.4	220°	8	0.26	0.3	229°
9	0.23	0.3	107°	10	0.24	0.3	309°
11	0.27	0.3	283°	12	0.19	0.2	156°
13	0.26	0.3	331°	14	0.24	0.3	206°
15	0.24	0.3	76°	16	0.33	0.4	326°
17	0.26	0.3	27°	18	0.24	0.3	308°
19	0.40	0.5	332°	20	0.10	0.1	222°
21	0.07	0.1	90°	22	0.12	0.1	71°
23	0.23	0.3	170°	24	0.28	0.3	44°
25	0.08	0.1	255°	26	0.13	0.2	119°
27	0.12	0.1	320°	28	0.21	0.2	213°
29	0.09	0.1	145°	30	0.10	0.1	76°
31	0.11	0.1	194°	32	0.16	0.2	53°
33	0.15	0.2	10°	34	0.10	0.1	21°
35	0.14	0.2	88°	36	0.02	0.0	121°
37	0.06	0.1	151°	38	0.09	0.1	112°
39	0.13	0.2	67°	40	0.09	0.1	126°
41	0.21	0.2	356°	42	0.03	0.0	7°
43	0.08	0.1	62°	44	0.06	0.1	32°
45	0.06	0.1	179°	46	0.18	0.2	198°
47	0.10	0.1	39°	48	0.08	0.1	207°
49	0.12	0.1	109°	50	0.11	0.1	334°
51	0.11	0.1	231°	52	0.01	0.0	352°
53	0.08	0.1	259°	54	0.08	0.1	192°
55	0.03	0.0	58°	56	0.03	0.0	298°
57	0.01	0.0	108°	58	0.10	0.1	56°
59	0.08	0.1	295°	60	0.06	0.1	122°
61	0.08	0.1	18°	62	0.04	0.0	235°
63	0.11	0.1	143°				

Figure 40. Expanded waveform at the flywheel

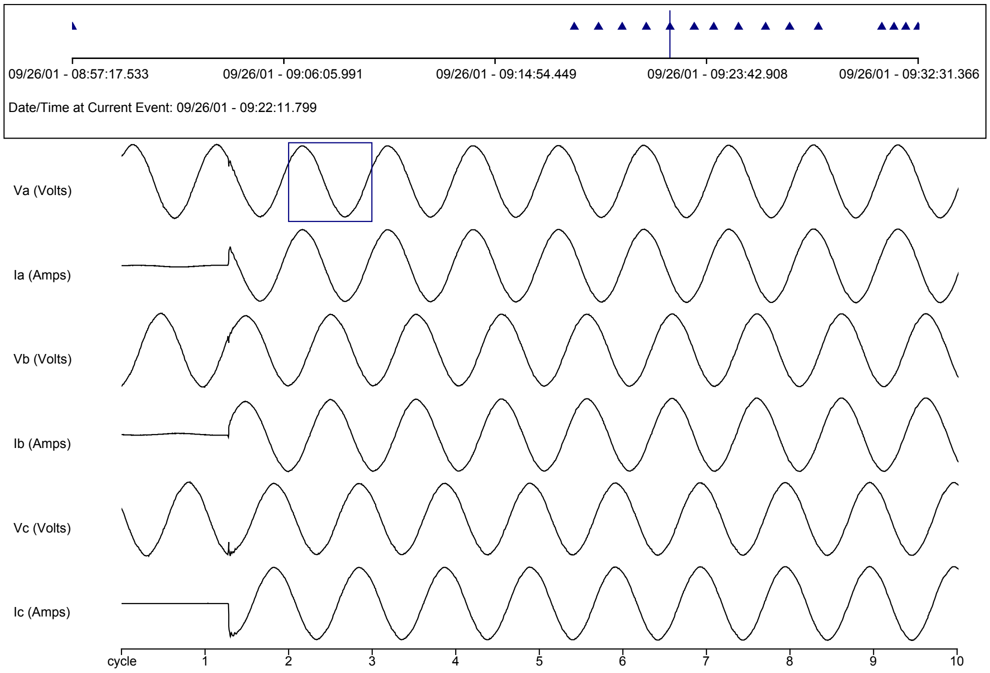
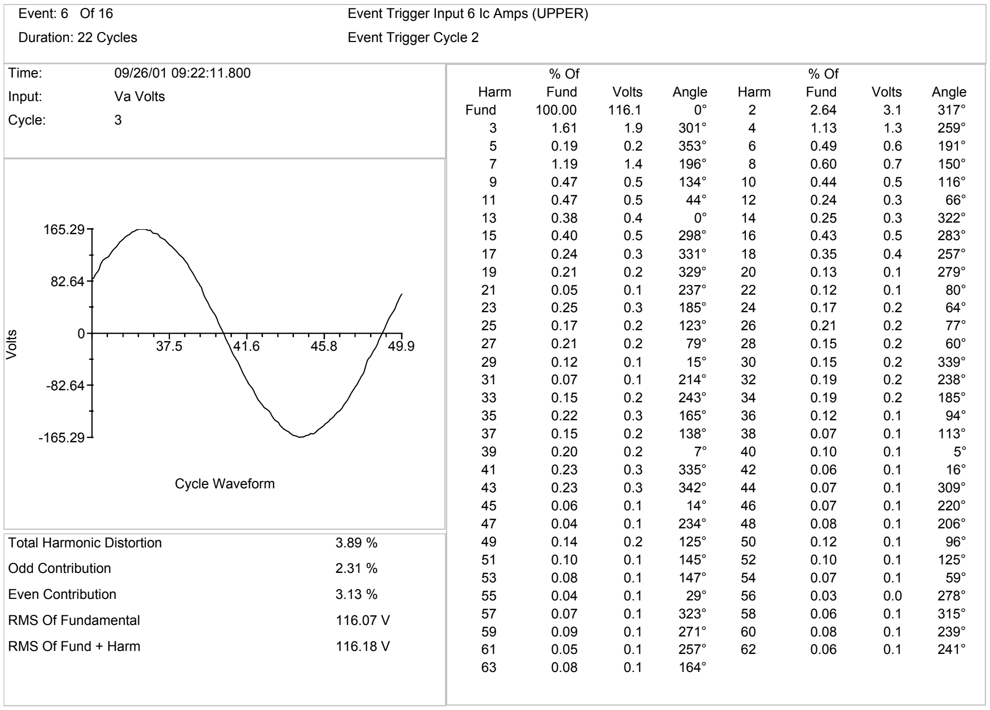


Figure 41. Waveform at the flywheel after the resistive transient


Event: 6 Of 16
Duration: 22 Cycles

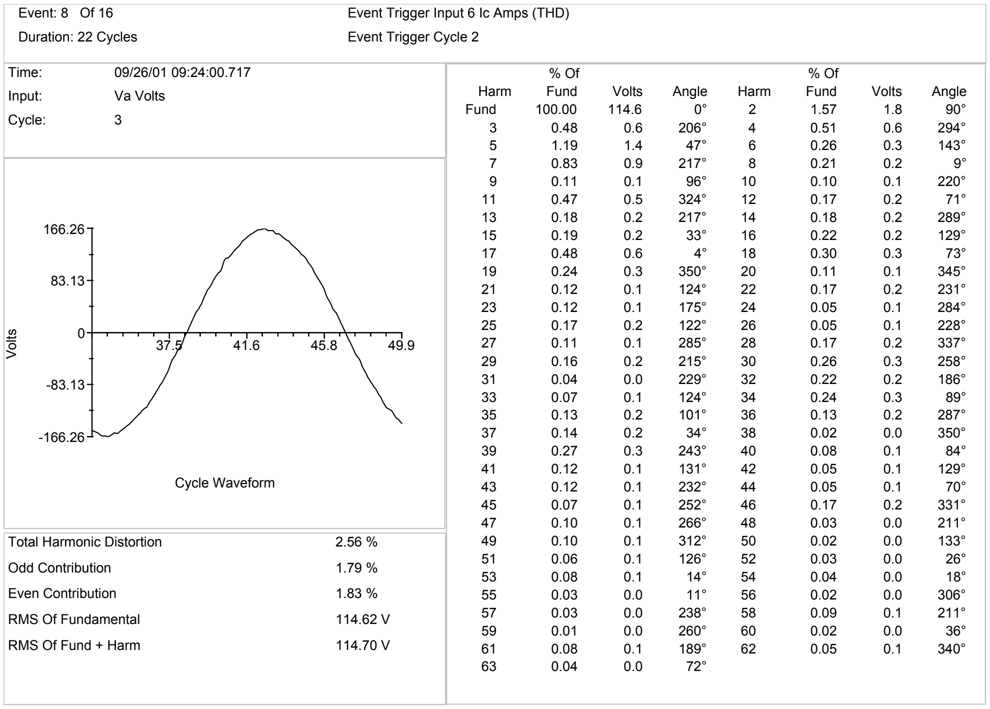
Event Trigger Input 6 Ic Amps (UPPER)
Event Trigger Cycle 2

Time: 09/26/01 09:22:11.800
Input: Va Volts
Cycle: 3

Total Harmonic Distortion	3.89 %
Odd Contribution	2.31 %
Even Contribution	3.13 %
RMS Of Fundamental	116.07 V
RMS Of Fund + Harm	116.18 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	116.1	0°	2	2.64	3.1	317°
3	1.61	1.9	301°	4	1.13	1.3	259°
5	0.19	0.2	353°	6	0.49	0.6	191°
7	1.19	1.4	196°	8	0.60	0.7	150°
9	0.47	0.5	134°	10	0.44	0.5	116°
11	0.47	0.5	44°	12	0.24	0.3	66°
13	0.38	0.4	0°	14	0.25	0.3	322°
15	0.40	0.5	298°	16	0.43	0.5	283°
17	0.24	0.3	331°	18	0.35	0.4	257°
19	0.21	0.2	329°	20	0.13	0.1	279°
21	0.05	0.1	237°	22	0.12	0.1	80°
23	0.25	0.3	185°	24	0.17	0.2	64°
25	0.17	0.2	123°	26	0.21	0.2	77°
27	0.21	0.2	79°	28	0.15	0.2	60°
29	0.12	0.1	15°	30	0.15	0.2	339°
31	0.07	0.1	214°	32	0.19	0.2	238°
33	0.15	0.2	243°	34	0.19	0.2	185°
35	0.22	0.3	165°	36	0.12	0.1	94°
37	0.15	0.2	138°	38	0.07	0.1	113°
39	0.20	0.2	7°	40	0.10	0.1	5°
41	0.23	0.3	335°	42	0.06	0.1	16°
43	0.23	0.3	342°	44	0.07	0.1	309°
45	0.06	0.1	14°	46	0.07	0.1	220°
47	0.04	0.1	234°	48	0.08	0.1	206°
49	0.14	0.2	125°	50	0.12	0.1	96°
51	0.10	0.1	145°	52	0.10	0.1	125°
53	0.08	0.1	147°	54	0.07	0.1	59°
55	0.04	0.1	29°	56	0.03	0.0	278°
57	0.07	0.1	323°	58	0.06	0.1	315°
59	0.09	0.1	271°	60	0.08	0.1	239°
61	0.05	0.1	257°	62	0.06	0.1	241°
63	0.08	0.1	164°				

Figure 42. Expanded waveform at the flywheel after the resistive transient



Event: 8 Of 16
Duration: 22 Cycles
Event Trigger Input 6 Ic Amps (THD)
Event Trigger Cycle 2

Time:	09/26/01 09:24:00.717
Input:	Va Volts
Cycle:	3

Total Harmonic Distortion	2.56 %
Odd Contribution	1.79 %
Even Contribution	1.83 %
RMS Of Fundamental	114.62 V
RMS Of Fund + Harm	114.70 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	114.6	0°	2	1.57	1.8	90°
3	0.48	0.6	206°	4	0.51	0.6	294°
5	1.19	1.4	47°	6	0.26	0.3	143°
7	0.83	0.9	217°	8	0.21	0.2	9°
9	0.11	0.1	96°	10	0.10	0.1	220°
11	0.47	0.5	324°	12	0.17	0.2	71°
13	0.18	0.2	217°	14	0.18	0.2	289°
15	0.19	0.2	33°	16	0.22	0.2	129°
17	0.48	0.6	4°	18	0.30	0.3	73°
19	0.24	0.3	350°	20	0.11	0.1	345°
21	0.12	0.1	124°	22	0.17	0.2	231°
23	0.12	0.1	175°	24	0.05	0.1	284°
25	0.17	0.2	122°	26	0.05	0.1	228°
27	0.11	0.1	285°	28	0.17	0.2	337°
29	0.16	0.2	215°	30	0.26	0.3	258°
31	0.04	0.0	229°	32	0.22	0.2	186°
33	0.07	0.1	124°	34	0.24	0.3	89°
35	0.13	0.2	101°	36	0.13	0.2	287°
37	0.14	0.2	34°	38	0.02	0.0	350°
39	0.27	0.3	243°	40	0.08	0.1	84°
41	0.12	0.1	131°	42	0.05	0.1	129°
43	0.12	0.1	232°	44	0.05	0.1	70°
45	0.07	0.1	252°	46	0.17	0.2	331°
47	0.10	0.1	266°	48	0.03	0.0	211°
49	0.10	0.1	312°	50	0.02	0.0	133°
51	0.06	0.1	126°	52	0.03	0.0	26°
53	0.08	0.1	14°	54	0.04	0.0	18°
55	0.03	0.0	11°	56	0.02	0.0	306°
57	0.03	0.0	238°	58	0.09	0.1	211°
59	0.01	0.0	260°	60	0.02	0.0	36°
61	0.08	0.1	189°	62	0.05	0.1	340°
63	0.04	0.0	72°				

Figure 43. Expanded waveform for previous figure

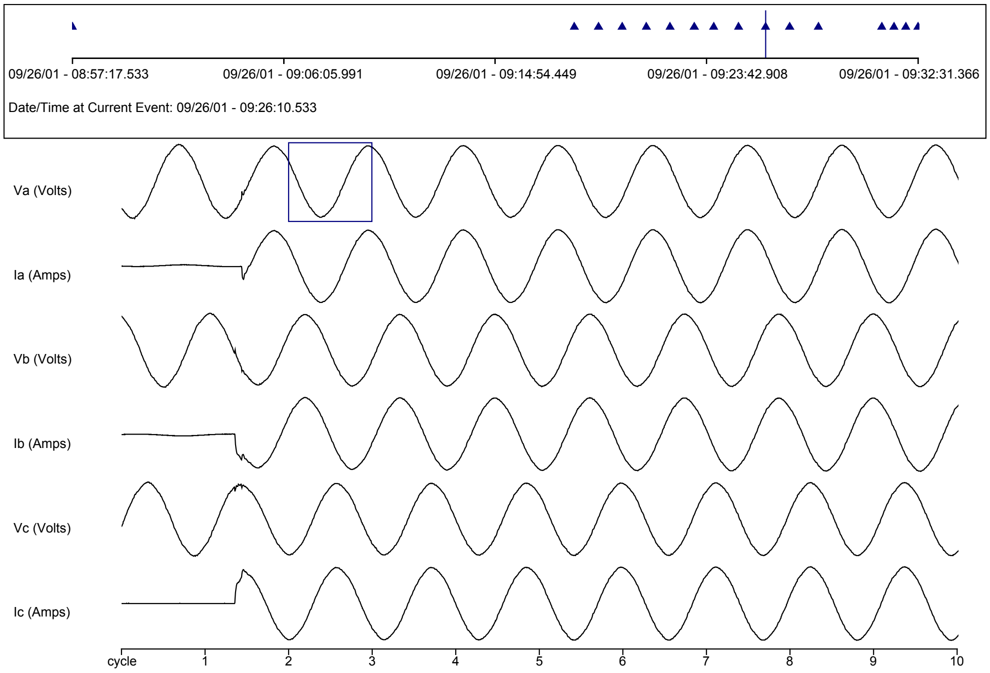
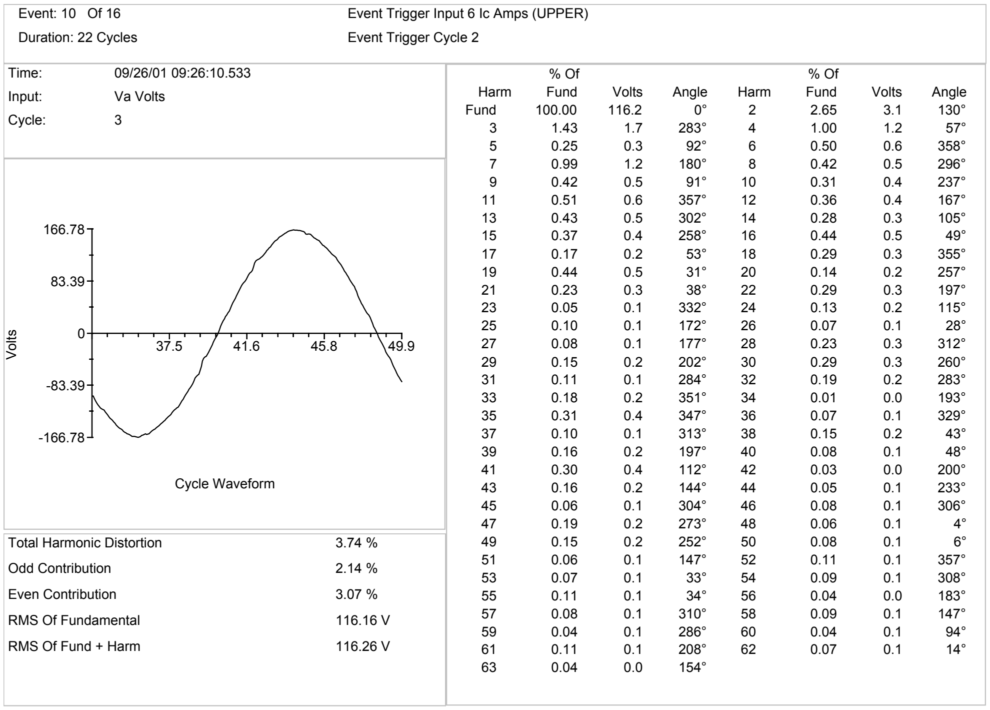


Figure 44. Waveform at end of transient



Event: 10 Of 16
Duration: 22 Cycles

Event Trigger Input 6 Ic Amps (UPPER)
Event Trigger Cycle 2

Time: 09/26/01 09:26:10.533
Input: Va Volts
Cycle: 3

Total Harmonic Distortion	3.74 %
Odd Contribution	2.14 %
Even Contribution	3.07 %
RMS Of Fundamental	116.16 V
RMS Of Fund + Harm	116.26 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	116.2	0°	2	2.65	3.1	130°
3	1.43	1.7	283°	4	1.00	1.2	57°
5	0.25	0.3	92°	6	0.50	0.6	358°
7	0.99	1.2	180°	8	0.42	0.5	296°
9	0.42	0.5	91°	10	0.31	0.4	237°
11	0.51	0.6	357°	12	0.36	0.4	167°
13	0.43	0.5	302°	14	0.28	0.3	105°
15	0.37	0.4	258°	16	0.44	0.5	49°
17	0.17	0.2	53°	18	0.29	0.3	355°
19	0.44	0.5	31°	20	0.14	0.2	257°
21	0.23	0.3	38°	22	0.29	0.3	197°
23	0.05	0.1	332°	24	0.13	0.2	115°
25	0.10	0.1	172°	26	0.07	0.1	28°
27	0.08	0.1	177°	28	0.23	0.3	312°
29	0.15	0.2	202°	30	0.29	0.3	260°
31	0.11	0.1	284°	32	0.19	0.2	283°
33	0.18	0.2	351°	34	0.01	0.0	193°
35	0.31	0.4	347°	36	0.07	0.1	329°
37	0.10	0.1	313°	38	0.15	0.2	43°
39	0.16	0.2	197°	40	0.08	0.1	48°
41	0.30	0.4	112°	42	0.03	0.0	200°
43	0.16	0.2	144°	44	0.05	0.1	233°
45	0.06	0.1	304°	46	0.08	0.1	306°
47	0.19	0.2	273°	48	0.06	0.1	4°
49	0.15	0.2	252°	50	0.08	0.1	6°
51	0.06	0.1	147°	52	0.11	0.1	357°
53	0.07	0.1	33°	54	0.09	0.1	308°
55	0.11	0.1	34°	56	0.04	0.0	183°
57	0.08	0.1	310°	58	0.09	0.1	147°
59	0.04	0.1	286°	60	0.04	0.1	94°
61	0.11	0.1	208°	62	0.07	0.1	14°
63	0.04	0.0	154°				

Figure 45. Detail for Figure 44

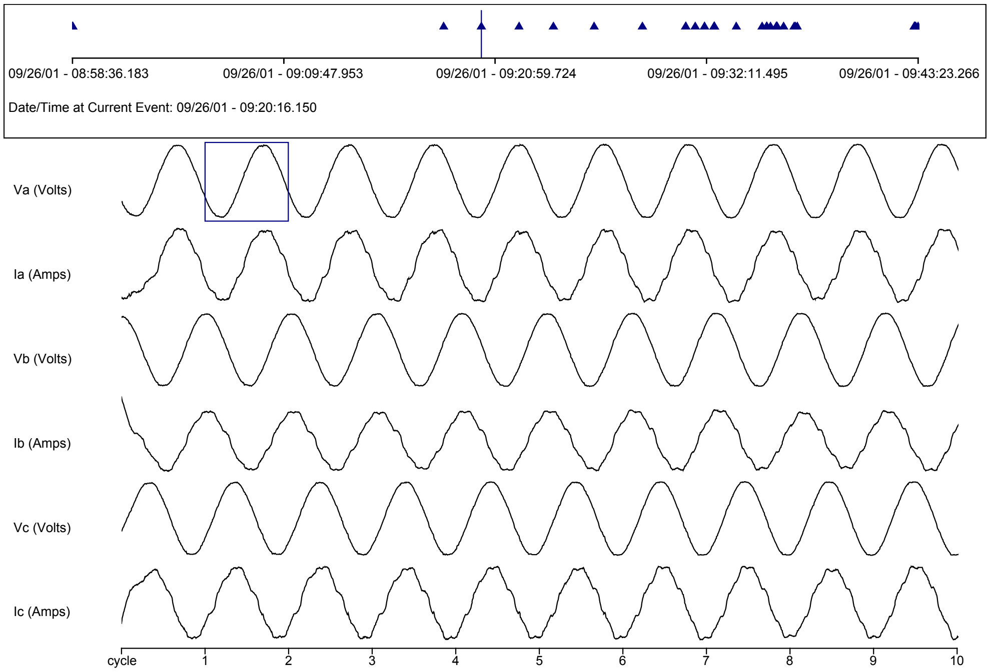
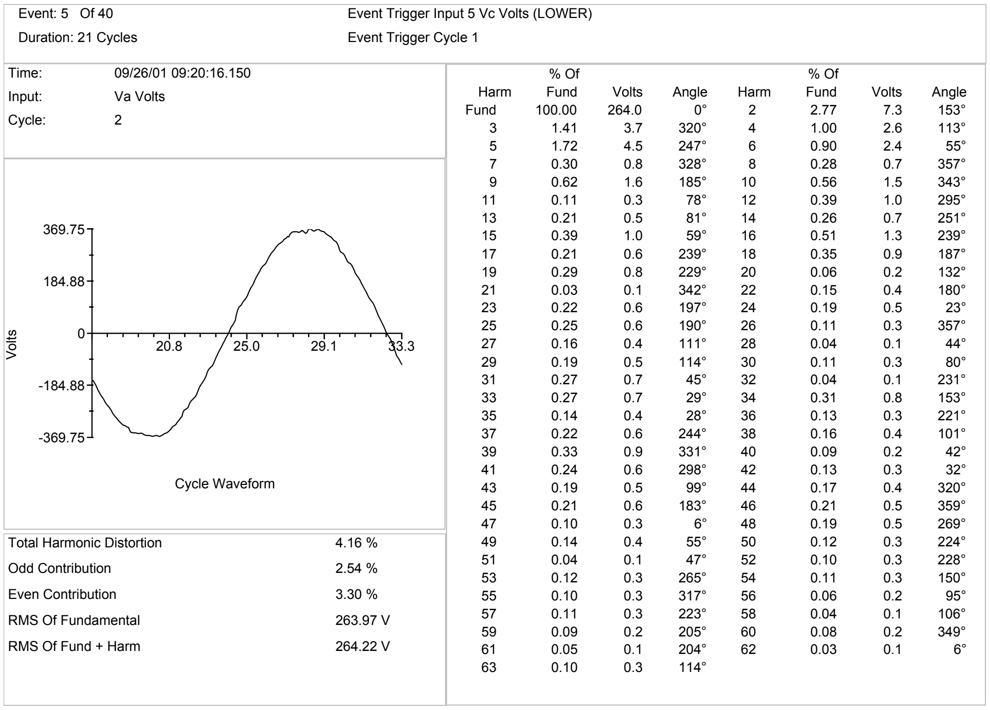


Figure 46. Waveform at the turbine



Event: 5 Of 40
Duration: 21 Cycles
Event Trigger Input 5 Vc Volts (LOWER)
Event Trigger Cycle 1

Time: 09/26/01 09:20:16.150
Input: Va Volts
Cycle: 2

Total Harmonic Distortion	4.16 %
Odd Contribution	2.54 %
Even Contribution	3.30 %
RMS Of Fundamental	263.97 V
RMS Of Fund + Harm	264.22 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	264.0	0°	2	2.77	7.3	153°
3	1.41	3.7	320°	4	1.00	2.6	113°
5	1.72	4.5	247°	6	0.90	2.4	55°
7	0.30	0.8	328°	8	0.28	0.7	357°
9	0.62	1.6	185°	10	0.56	1.5	343°
11	0.11	0.3	78°	12	0.39	1.0	295°
13	0.21	0.5	81°	14	0.26	0.7	251°
15	0.39	1.0	59°	16	0.51	1.3	239°
17	0.21	0.6	239°	18	0.35	0.9	187°
19	0.29	0.8	229°	20	0.06	0.2	132°
21	0.03	0.1	342°	22	0.15	0.4	180°
23	0.22	0.6	197°	24	0.19	0.5	23°
25	0.25	0.6	190°	26	0.11	0.3	357°
27	0.16	0.4	111°	28	0.04	0.1	44°
29	0.19	0.5	114°	30	0.11	0.3	80°
31	0.27	0.7	45°	32	0.04	0.1	231°
33	0.27	0.7	29°	34	0.31	0.8	153°
35	0.14	0.4	28°	36	0.13	0.3	221°
37	0.22	0.6	244°	38	0.16	0.4	101°
39	0.33	0.9	331°	40	0.09	0.2	42°
41	0.24	0.6	298°	42	0.13	0.3	32°
43	0.19	0.5	99°	44	0.17	0.4	320°
45	0.21	0.6	183°	46	0.21	0.5	359°
47	0.10	0.3	6°	48	0.19	0.5	269°
49	0.14	0.4	55°	50	0.12	0.3	224°
51	0.04	0.1	47°	52	0.10	0.3	228°
53	0.12	0.3	265°	54	0.11	0.3	150°
55	0.10	0.3	317°	56	0.06	0.2	95°
57	0.11	0.3	223°	58	0.04	0.1	106°
59	0.09	0.2	205°	60	0.08	0.2	349°
61	0.05	0.1	204°	62	0.03	0.1	6°
63	0.10	0.3	114°				

Figure 47. Detail for Figure 46

The following figures are the case of an inductive transient. In this case, an unloaded transformer (inductive load) is turned on and off (resistive load off), and the corresponding waveforms are recorded as measured at the inductive load.

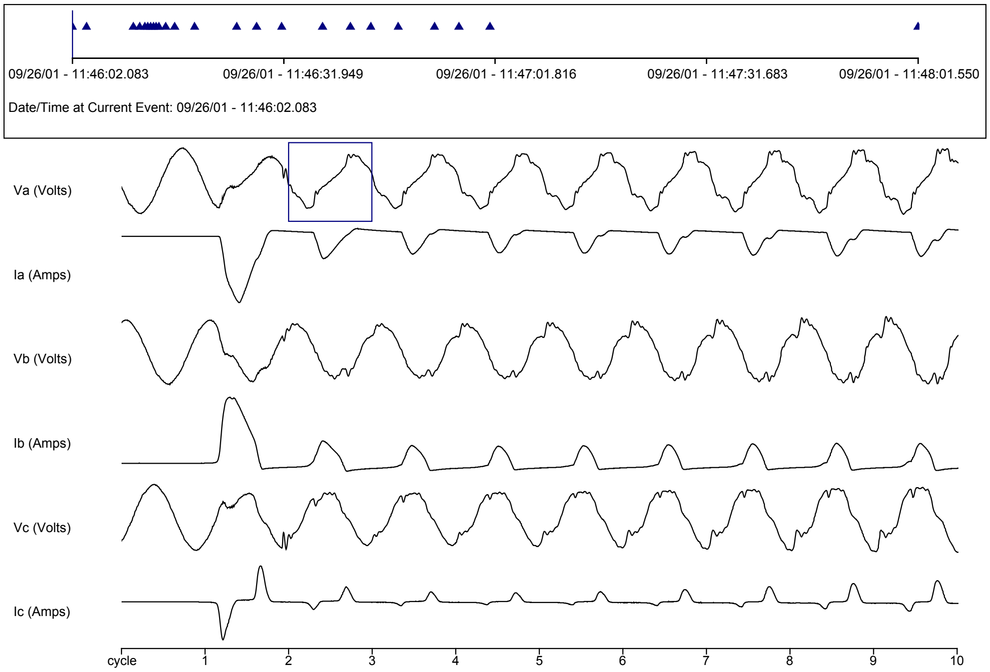
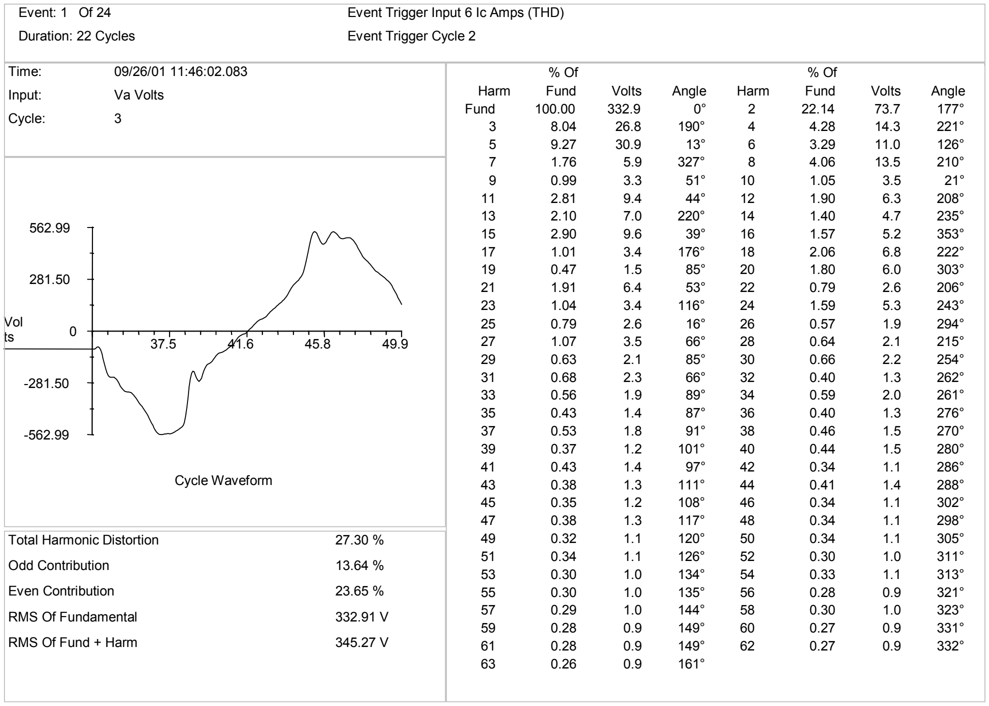


Figure 48. Waveform as measured at the inductive load for the cycle after the start of the transient for the standalone Test 4



Event: 1 Of 24
Duration: 22 Cycles

Event Trigger Input 6 Ic Amps (THD)
Event Trigger Cycle 2

Time: 09/26/01 11:46:02.083
Input: Va Volts
Cycle: 3

Total Harmonic Distortion	27.30 %
Odd Contribution	13.64 %
Even Contribution	23.65 %
RMS Of Fundamental	332.91 V
RMS Of Fund + Harm	345.27 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	332.9	0°	2	22.14	73.7	177°
3	8.04	26.8	190°	4	4.28	14.3	221°
5	9.27	30.9	13°	6	3.29	11.0	126°
7	1.76	5.9	327°	8	4.06	13.5	210°
9	0.99	3.3	51°	10	1.05	3.5	21°
11	2.81	9.4	44°	12	1.90	6.3	208°
13	2.10	7.0	220°	14	1.40	4.7	235°
15	2.90	9.6	39°	16	1.57	5.2	353°
17	1.01	3.4	176°	18	2.06	6.8	222°
19	0.47	1.5	85°	20	1.80	6.0	303°
21	1.91	6.4	53°	22	0.79	2.6	206°
23	1.04	3.4	116°	24	1.59	5.3	243°
25	0.79	2.6	16°	26	0.57	1.9	294°
27	1.07	3.5	66°	28	0.64	2.1	215°
29	0.63	2.1	85°	30	0.66	2.2	254°
31	0.68	2.3	66°	32	0.40	1.3	262°
33	0.56	1.9	89°	34	0.59	2.0	261°
35	0.43	1.4	87°	36	0.40	1.3	276°
37	0.53	1.8	91°	38	0.46	1.5	270°
39	0.37	1.2	101°	40	0.44	1.5	280°
41	0.43	1.4	97°	42	0.34	1.1	286°
43	0.38	1.3	111°	44	0.41	1.4	288°
45	0.35	1.2	108°	46	0.34	1.1	302°
47	0.38	1.3	117°	48	0.34	1.1	298°
49	0.32	1.1	120°	50	0.34	1.1	305°
51	0.34	1.1	126°	52	0.30	1.0	311°
53	0.30	1.0	134°	54	0.33	1.1	313°
55	0.30	1.0	135°	56	0.28	0.9	321°
57	0.29	1.0	144°	58	0.30	1.0	323°
59	0.28	0.9	149°	60	0.27	0.9	331°
61	0.28	0.9	149°	62	0.27	0.9	332°
63	0.26	0.9	161°				

Figure 49. Expanded waveform from Figure 48

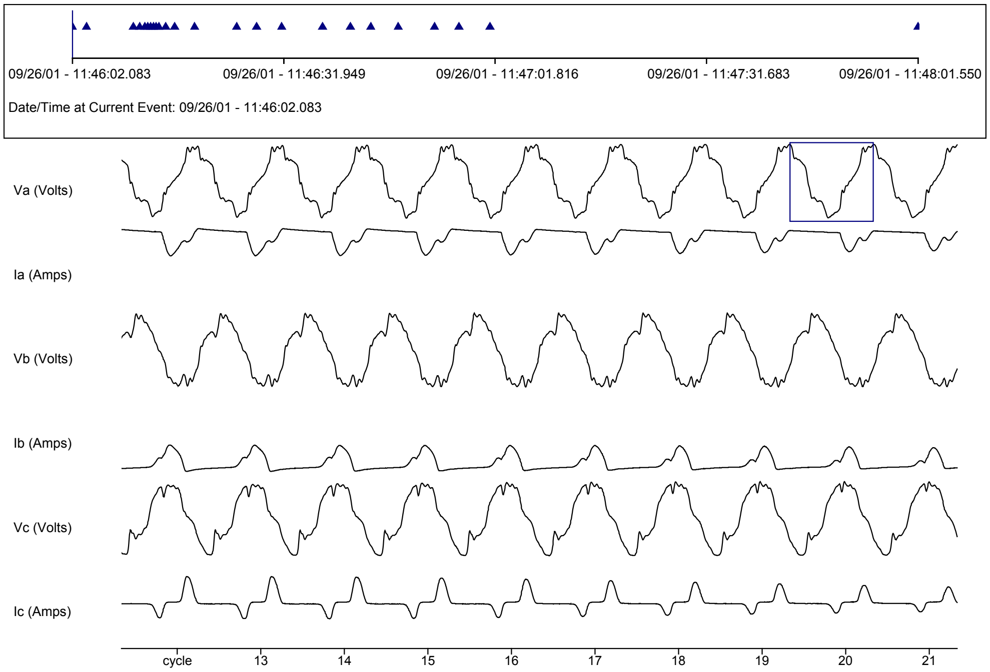
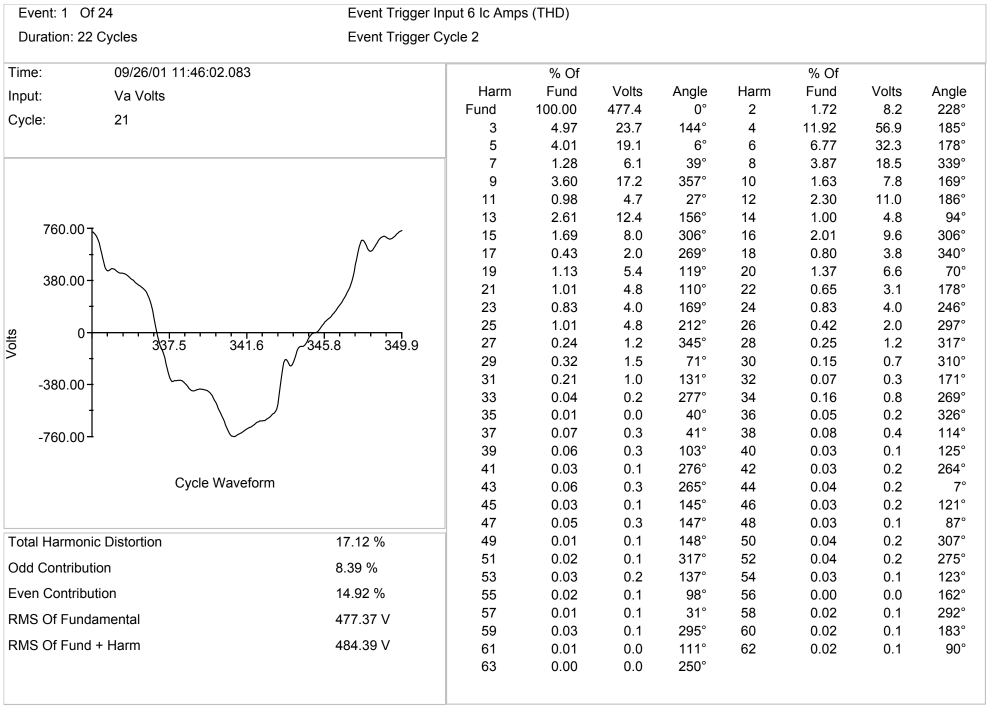


Figure 50. Waveform of standalone test measured at the inductive load after 21 cycles



Event: 1 Of 24

Duration: 22 Cycles

Event Trigger Input 6 Ic Amps (THD)

Event Trigger Cycle 2

Time:	09/26/01 11:46:02.083
Input:	Va Volts
Cycle:	21

Total Harmonic Distortion	17.12 %
Odd Contribution	8.39 %
Even Contribution	14.92 %
RMS Of Fundamental	477.37 V
RMS Of Fund + Harm	484.39 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	477.4	0°	2	1.72	8.2	228°
3	4.97	23.7	144°	4	11.92	56.9	185°
5	4.01	19.1	6°	6	6.77	32.3	178°
7	1.28	6.1	39°	8	3.87	18.5	339°
9	3.60	17.2	357°	10	1.63	7.8	169°
11	0.98	4.7	27°	12	2.30	11.0	186°
13	2.61	12.4	156°	14	1.00	4.8	94°
15	1.69	8.0	306°	16	2.01	9.6	306°
17	0.43	2.0	269°	18	0.80	3.8	340°
19	1.13	5.4	119°	20	1.37	6.6	70°
21	1.01	4.8	110°	22	0.65	3.1	178°
23	0.83	4.0	169°	24	0.83	4.0	246°
25	1.01	4.8	212°	26	0.42	2.0	297°
27	0.24	1.2	345°	28	0.25	1.2	317°
29	0.32	1.5	71°	30	0.15	0.7	310°
31	0.21	1.0	131°	32	0.07	0.3	171°
33	0.04	0.2	277°	34	0.16	0.8	269°
35	0.01	0.0	40°	36	0.05	0.2	326°
37	0.07	0.3	41°	38	0.08	0.4	114°
39	0.06	0.3	103°	40	0.03	0.1	125°
41	0.03	0.1	276°	42	0.03	0.2	264°
43	0.06	0.3	265°	44	0.04	0.2	7°
45	0.03	0.1	145°	46	0.03	0.2	121°
47	0.05	0.3	147°	48	0.03	0.1	87°
49	0.01	0.1	148°	50	0.04	0.2	307°
51	0.02	0.1	317°	52	0.04	0.2	275°
53	0.03	0.2	137°	54	0.03	0.1	123°
55	0.02	0.1	98°	56	0.00	0.0	162°
57	0.01	0.1	31°	58	0.02	0.1	292°
59	0.03	0.1	295°	60	0.02	0.1	183°
61	0.01	0.0	111°	62	0.02	0.1	90°
63	0.00	0.0	250°				

Figure 51. Expanded waveform from Figure 50

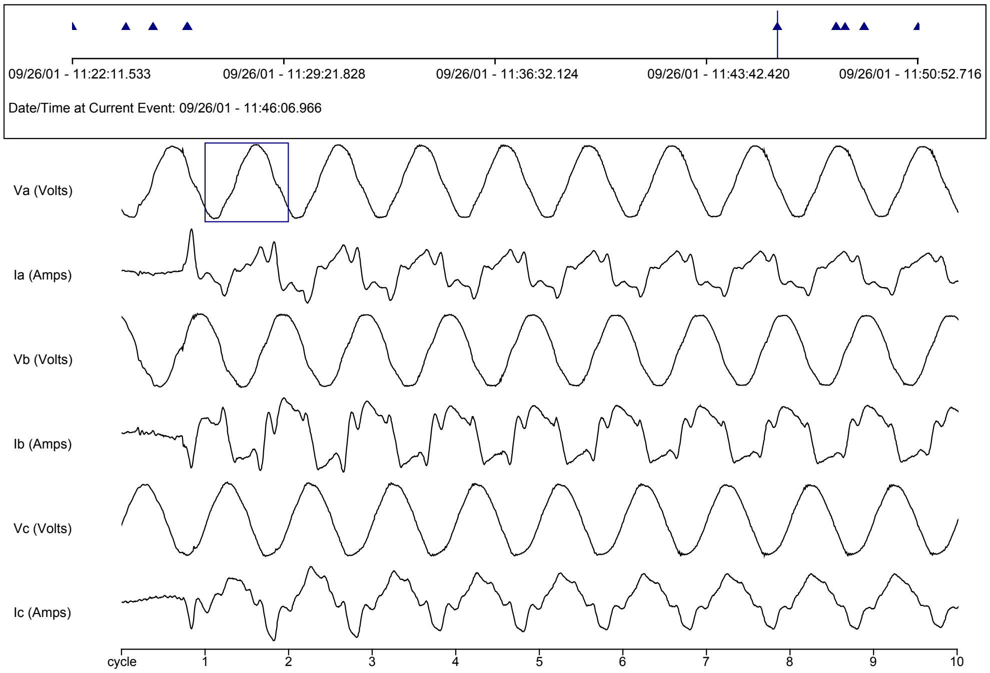
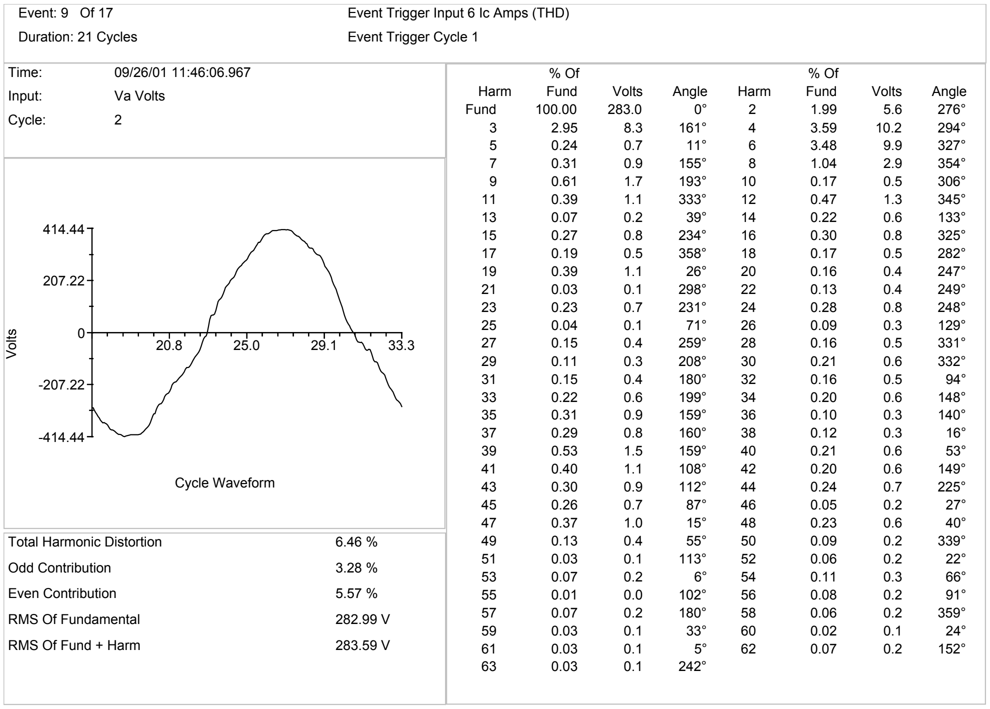


Figure 52. Waveform of standalone Test 4 under induction load as measured at the turbine



Event: 9 Of 17

Duration: 21 Cycles

Event Trigger Input 6 Ic Amps (THD)

Event Trigger Cycle 1

Time:	09/26/01 11:46:06.967
Input:	Va Volts
Cycle:	2

Total Harmonic Distortion	6.46 %
Odd Contribution	3.28 %
Even Contribution	5.57 %
RMS Of Fundamental	282.99 V
RMS Of Fund + Harm	283.59 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	283.0	0°	2	1.99	5.6	276°
3	2.95	8.3	161°	4	3.59	10.2	294°
5	0.24	0.7	11°	6	3.48	9.9	327°
7	0.31	0.9	155°	8	1.04	2.9	354°
9	0.61	1.7	193°	10	0.17	0.5	306°
11	0.39	1.1	333°	12	0.47	1.3	345°
13	0.07	0.2	39°	14	0.22	0.6	133°
15	0.27	0.8	234°	16	0.30	0.8	325°
17	0.19	0.5	358°	18	0.17	0.5	282°
19	0.39	1.1	26°	20	0.16	0.4	247°
21	0.03	0.1	298°	22	0.13	0.4	249°
23	0.23	0.7	231°	24	0.28	0.8	248°
25	0.04	0.1	71°	26	0.09	0.3	129°
27	0.15	0.4	259°	28	0.16	0.5	331°
29	0.11	0.3	208°	30	0.21	0.6	332°
31	0.15	0.4	180°	32	0.16	0.5	94°
33	0.22	0.6	199°	34	0.20	0.6	148°
35	0.31	0.9	159°	36	0.10	0.3	140°
37	0.29	0.8	160°	38	0.12	0.3	16°
39	0.53	1.5	159°	40	0.21	0.6	53°
41	0.40	1.1	108°	42	0.20	0.6	149°
43	0.30	0.9	112°	44	0.24	0.7	225°
45	0.26	0.7	87°	46	0.05	0.2	27°
47	0.37	1.0	15°	48	0.23	0.6	40°
49	0.13	0.4	55°	50	0.09	0.2	339°
51	0.03	0.1	113°	52	0.06	0.2	22°
53	0.07	0.2	6°	54	0.11	0.3	66°
55	0.01	0.0	102°	56	0.08	0.2	91°
57	0.07	0.2	180°	58	0.06	0.2	359°
59	0.03	0.1	33°	60	0.02	0.1	24°
61	0.03	0.1	5°	62	0.07	0.2	152°
63	0.03	0.1	242°				

Figure 53. Expanded waveform of standalone Test 4 under induction load in previous figure

Figures 54, 55, 56, and 57 illustrate waveform as measured at the microturbine after 21 cycles for the inductive transient.

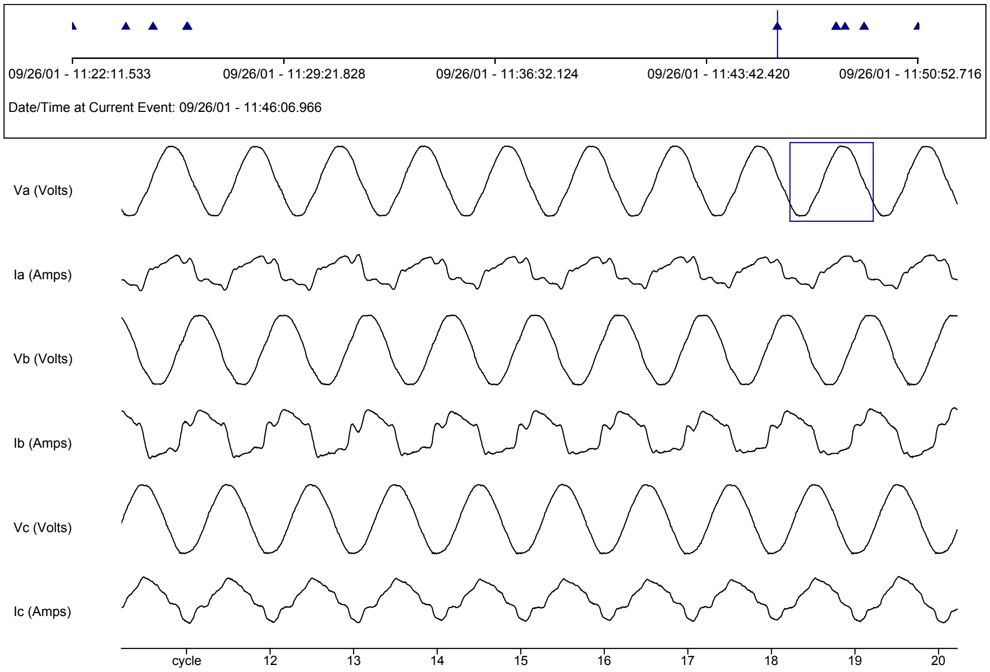
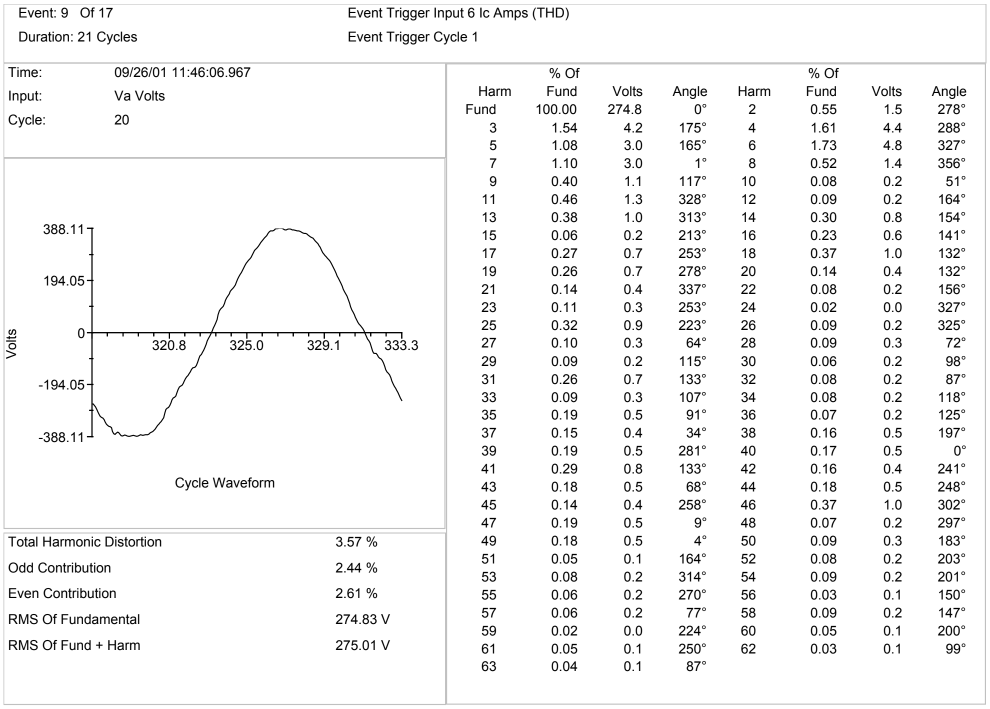


Figure 54. The waveform as measured at the microturbine after 21 cycles for the inductive transient under Test 4



Event: 9 Of 17

Duration: 21 Cycles

Event Trigger Input 6 Ic Amps (THD)

Event Trigger Cycle 1

Time:	09/26/01 11:46:06.967
Input:	Va Volts
Cycle:	20

Total Harmonic Distortion	3.57 %
Odd Contribution	2.44 %
Even Contribution	2.61 %
RMS Of Fundamental	274.83 V
RMS Of Fund + Harm	275.01 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	274.8	0°	2	0.55	1.5	278°
3	1.54	4.2	175°	4	1.61	4.4	288°
5	1.08	3.0	165°	6	1.73	4.8	327°
7	1.10	3.0	1°	8	0.52	1.4	356°
9	0.40	1.1	117°	10	0.08	0.2	51°
11	0.46	1.3	328°	12	0.09	0.2	164°
13	0.38	1.0	313°	14	0.30	0.8	154°
15	0.06	0.2	213°	16	0.23	0.6	141°
17	0.27	0.7	253°	18	0.37	1.0	132°
19	0.26	0.7	278°	20	0.14	0.4	132°
21	0.14	0.4	337°	22	0.08	0.2	156°
23	0.11	0.3	253°	24	0.02	0.0	327°
25	0.32	0.9	223°	26	0.09	0.2	325°
27	0.10	0.3	64°	28	0.09	0.3	72°
29	0.09	0.2	115°	30	0.06	0.2	98°
31	0.26	0.7	133°	32	0.08	0.2	87°
33	0.09	0.3	107°	34	0.08	0.2	118°
35	0.19	0.5	91°	36	0.07	0.2	125°
37	0.15	0.4	34°	38	0.16	0.5	197°
39	0.19	0.5	281°	40	0.17	0.5	0°
41	0.29	0.8	133°	42	0.16	0.4	241°
43	0.18	0.5	68°	44	0.18	0.5	248°
45	0.14	0.4	258°	46	0.37	1.0	302°
47	0.19	0.5	9°	48	0.07	0.2	297°
49	0.18	0.5	4°	50	0.09	0.3	183°
51	0.05	0.1	164°	52	0.08	0.2	203°
53	0.08	0.2	314°	54	0.09	0.2	201°
55	0.06	0.2	270°	56	0.03	0.1	150°
57	0.06	0.2	77°	58	0.09	0.2	147°
59	0.02	0.0	224°	60	0.05	0.1	200°
61	0.05	0.1	250°	62	0.03	0.1	99°
63	0.04	0.1	87°				

Figure 55. The expanded waveform from Figure 54

The following data present more detail for the test of the response of the system to a step change in inductive load. For this test, a 45-kVA unloaded transformer was switched into the circuit. This resulted in erratic system behavior, as illustrated in Figure 56 and Figure 57.

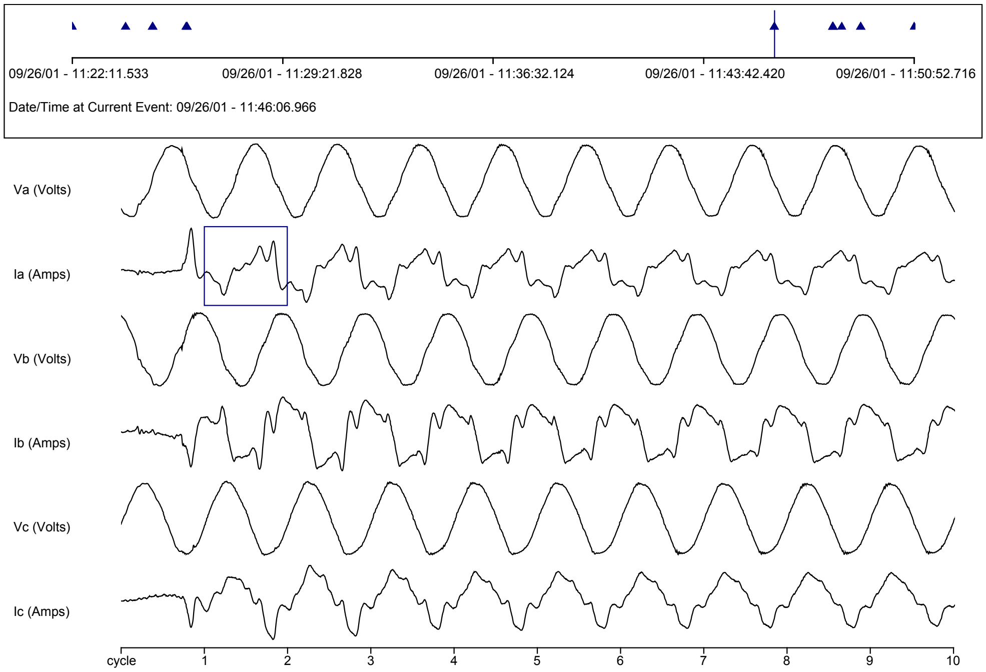
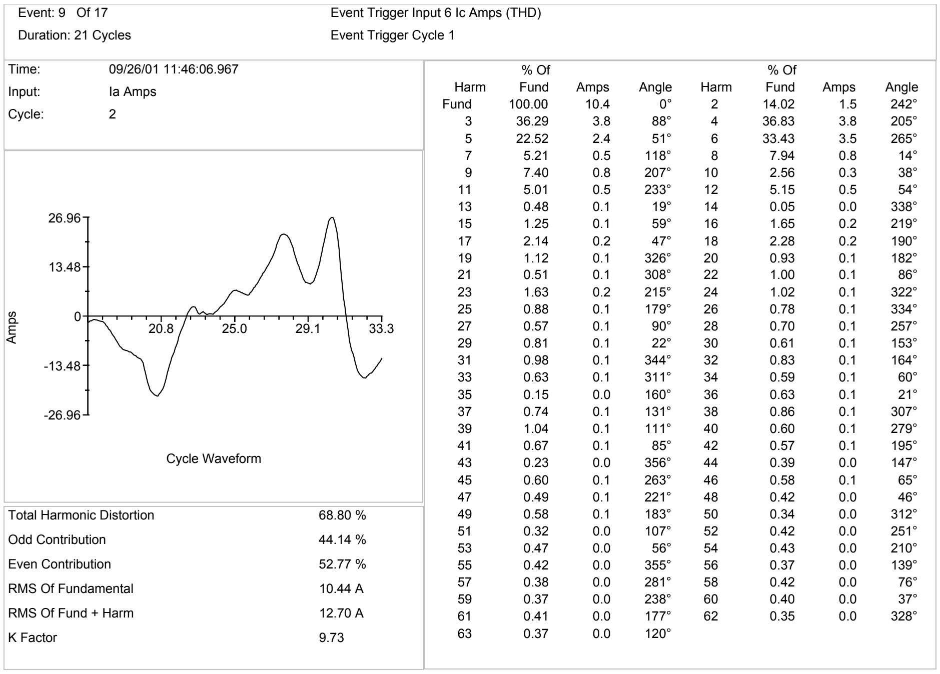


Figure 56. Waveforms for the current and voltage response of the system to a step change in inductive load under Test 4



Event: 9 Of 17
Duration: 21 Cycles

Event Trigger Input 6 Ic Amps (THD)
Event Trigger Cycle 1

Time: 09/26/01 11:46:06.967
Input: Ia Amps
Cycle: 2

Total Harmonic Distortion	68.80 %
Odd Contribution	44.14 %
Even Contribution	52.77 %
RMS Of Fundamental	10.44 A
RMS Of Fund + Harm	12.70 A
K Factor	9.73

Harm	% Of Fund	Amps	Angle	Harm	% Of Fund	Amps	Angle
Fund	100.00	10.4	0°	2	14.02	1.5	242°
3	36.29	3.8	88°	4	36.83	3.8	205°
5	22.52	2.4	51°	6	33.43	3.5	265°
7	5.21	0.5	118°	8	7.94	0.8	14°
9	7.40	0.8	207°	10	2.56	0.3	38°
11	5.01	0.5	233°	12	5.15	0.5	54°
13	0.48	0.1	19°	14	0.05	0.0	338°
15	1.25	0.1	59°	16	1.65	0.2	219°
17	2.14	0.2	47°	18	2.28	0.2	190°
19	1.12	0.1	326°	20	0.93	0.1	182°
21	0.51	0.1	308°	22	1.00	0.1	86°
23	1.63	0.2	215°	24	1.02	0.1	322°
25	0.88	0.1	179°	26	0.78	0.1	334°
27	0.57	0.1	90°	28	0.70	0.1	257°
29	0.81	0.1	22°	30	0.61	0.1	153°
31	0.98	0.1	344°	32	0.83	0.1	164°
33	0.63	0.1	311°	34	0.59	0.1	60°
35	0.15	0.0	160°	36	0.63	0.1	21°
37	0.74	0.1	131°	38	0.86	0.1	307°
39	1.04	0.1	111°	40	0.60	0.1	279°
41	0.67	0.1	85°	42	0.57	0.1	195°
43	0.23	0.0	356°	44	0.39	0.0	147°
45	0.60	0.1	263°	46	0.58	0.1	65°
47	0.49	0.1	221°	48	0.42	0.0	46°
49	0.58	0.1	183°	50	0.34	0.0	312°
51	0.32	0.0	107°	52	0.42	0.0	251°
53	0.47	0.0	56°	54	0.43	0.0	210°
55	0.42	0.0	355°	56	0.37	0.0	139°
57	0.38	0.0	281°	58	0.42	0.0	76°
59	0.37	0.0	238°	60	0.40	0.0	37°
61	0.41	0.0	177°	62	0.35	0.0	328°
63	0.37	0.0	120°				

Figure 57. Expanded waveform from Figure 56

As shown in the previous waveforms (figures 56 and 57), the system produced various harmonics that did not die out with time. To consider the nature and stability of these harmonics, consider the following segment of the Phase A current data (Figure 58).

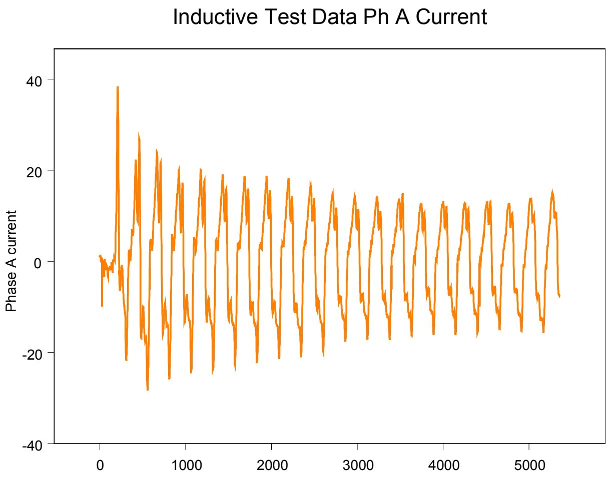


Figure 58. Phase A current data from the test for a step change in inductive load under Test 4

The data in Figure 58 are plotted below. These were acquired at 128 points per cycle.

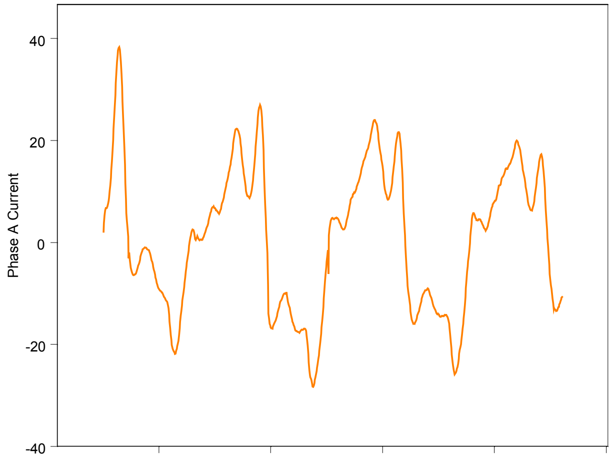


Figure 59. Phase A current data acquired at 128 points per cycle

This data seem to indicate a component that is unstable. To verify this, the Lyapunov exponent was calculated based on embedding the data stream. As shown in Figure 60, there is a positive value for one and a portion of two of the Lyapunov exponents.

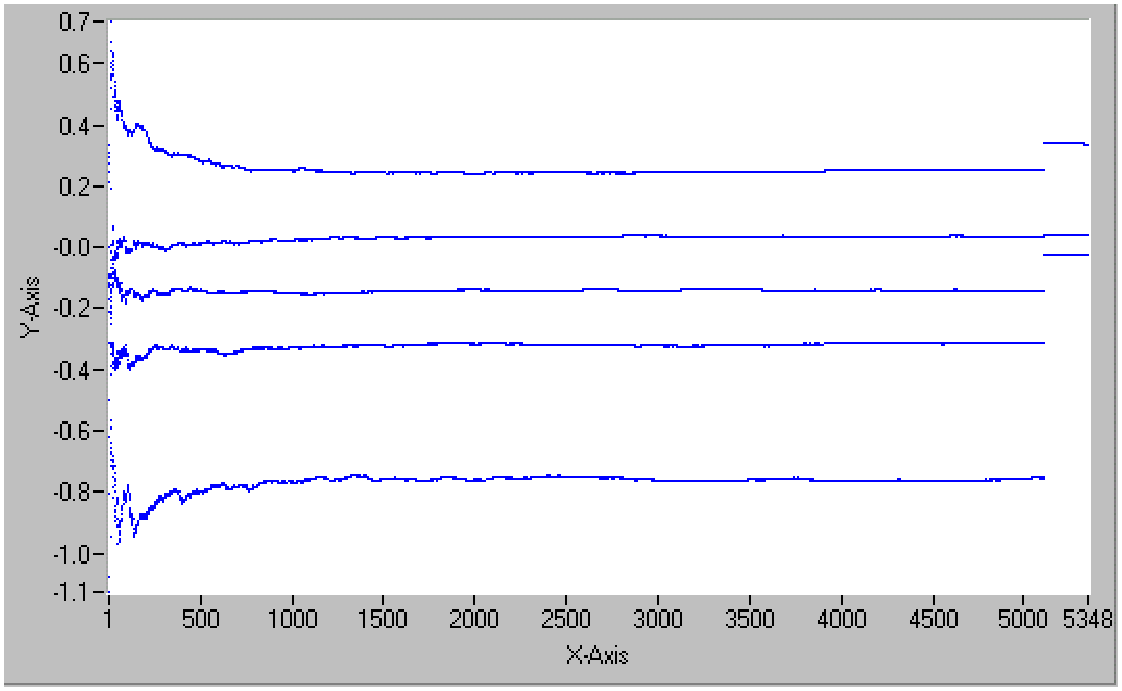


Figure 60. Plot of the Lyapunov spectrum Phase A current inductive transient

4.5.5 Test 5

4.5.5.1 Results

No problems were encountered with the testing equipment during the test program. Source operation appeared normal during the entire test program. Unit operating data were recorded and retained.

4.5.5.2 Test Procedures

All testing, sampling, analytical, and calibration procedures used for this test program were performed as described in Title 40, *Code of Federal Regulations*, Part 60 (40CFR60), Appendix A, Methods 1, 2, 3A, 4, 7E, 10, and 25A and USEPA Method TO-5, *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*, the latest revisions thereof. Where applicable, the *Quality Assurance Handbook for Air Pollution Measurement Systems*, Volume III, Stationary Source-Specific Methods (United States Environmental Protection Agency 600/4-77-027b) was used to determine precise procedures.

4.5.5.2.1 Volumetric Flowrate Determination

To determine the emission rate on a pounds-per-hour basis, the stack gas velocity and volumetric flowrate were determined using Method 2, 40CFR60.

Velocity pressures were determined by traversing the test location with a P-type pilot tube. Temperatures were measured using a K-type thermocouple with a calibrated digital temperature indicator. The molecular weight and moisture content of the gases were determined to permit the calculation of the volumetric flowrate. Sampling points were determined using Method 1, 40CFR60.

4.5.5.2.2 Oxygen Determination

An oxygen (O_2) analyzer was used to determine O_2 concentrations in the stack gas in accordance with Method 3A, 40CFR60. This instrument has a paramagnetic-based detector and operates in the range of 0%–25% O_2. High-range calibrations were performed using Protocol One gas at 22.64% O_2. Zero nitrogen (low ppm pollutants in balance nitrogen calibration gases were used as zero gas on these analyzers) was introduced during other instrument calibrations to check instrument zero, and a mid-range percent O_2 level in balance nitrogen was also introduced. Mid-range calibrations were performed using Protocol One gas prior to and between each test run.

4.5.5.2.3 Carbon Dioxide Determination

A carbon dioxide (CO_2) analyzer was used to determine CO_2 concentrations in the stack gas in accordance with Method 3A, 40CFR60. This instrument has a nondispersive infrared-based detector and operates in a range of 0%–10% CO_2. A high- and a mid-range calibration were performed using certified standard gases, and non-CO_2 gas mixtures were used for the CO_2 zero. Mid-range and zero calibrations were performed prior to and between each test run.

4.5.5.2.4 Moisture Determination

An Alternative Method for Stack Gas Moisture Determination, written by John Stanley and Peter Westlin (August 1978) was used to determine water (H_2O) content of the exhaust gas. The sampling equipment was the same as specified for the moisture approximation method in Method 4, 40CFR60, except for the addition of two impingers, one containing silica gel.

Approximately 15 milliliters (mL) of water were added to each of the first two impingers, and the third was left empty. An impinger containing approximately 15 grams of silica gel and a glass wool-packed outlet was attached following the third impinger. The entire impinger train, excluding the inlet and outlet connectors, was weighed to the nearest 0.05 gram. The impingers were placed in an ice bath to maintain the sampled gas passed through the silica gel impinger outlet below 68°F. Maintaining the temperature increases the accuracy of the sampled dry gas volume measurement.

Each sample was extracted through a stainless steel probe at a constant sample rate of 1–4 liters per minute, which was maintained during the course of the other simultaneous reference method sampling. An adequate volume was drawn to ensure accuracy. A minimum of the equivalent to one gram of moisture must be collected to acquire that accuracy.

After each test run, a check of the sample train was performed at a vacuum greater than the sampling vacuum to determine if any leakage had occurred during sampling. Following the leak check, the impingers were removed from the ice bath and allowed to warm. Any condensed moisture on the exterior was removed and the train reweighed.

4.5.5.2.5 Nitrogen Oxides Determination

Method 7E, 40CFR60, was used to determine nitrogen oxide (NO_x) emissions from the test location. A gas sample was continuously extracted from the gas stream through a heated sampling probe and a gas conditioning system to remove moisture. A portion of the sample stream was conveyed via a sampling line to gas analyzers for determination of NO_x content. Prior to emissions sampling, the nitric oxide (NO)/NO_x analyzer was zeroed and calibrated. High-range, mid-range, and zero gases were introduced into the NO_x sampling system.

The sample gas manifold was then adjusted for emissions sampling. In the course of the testing, the zeroes were checked, and mid-range NO_x gas was introduced into the sampling system to check calibration.

The chemiluminescent reaction of NO and ozone (O_3) provides the basis for this instrument operation. Specifically:

$$NO + O_3 \rightarrow NO_2 + O_2 + h_{\upsilon}$$

where h_{υ} = light

Light emission results when electronically excited nitrogen dioxide (NO_2) molecules revert to their ground state. To measure NO concentrations, the gas sample to be analyzed was blended with O_3 in a reaction chamber. The resulting chemiluminescence was monitored through an optical filter by a high-sensitivity photomultiplier positioned at one end of the chamber. The filter/photomultiplier combination responds to light in a narrow-wavelength band unique to the above reaction (hence, no interference). The output from the photomultiplier is linearly proportional to the NO concentration.

To measure NO_x concentrations (i.e., NO plus NO_2), the sample gas flow was diverted through a NO_2-to-NO converter. The chemiluminescent response in the reaction chamber to the converted effluent is linearly proportional to the NO_x concentration entering the converter. The instrument was operated in the NO_x mode during all tests and calibrations.

4.5.5.2.6 Carbon Monoxide Determination

Method 10, 40CFR60, was used to determine carbon monoxide (CO) concentrations. A continuous gas sample was extracted from a sampling point and analyzed for CO content using a nondispersive infrared analyzer. The gas stream was conditioned by condensing moisture and filtering particulate prior to the analyzer. This instrument employs an internal gas correlation filter wheel that eliminates potential detector interference. Instruments so equipped do not require an interference removal trap.

After an appropriate warm-up time, the analyzer was calibrated using certified calibration gases at concentrations corresponding to approximately 30%, 60%, and 90% of the applicable instrument range of 100 ppm, with a CO-free calibration gas used as a zero gas.

The analyzer calibration was verified with the mid-range and zero gases after each test run.

4.5.5.2.7 Total Organic Concentration Determination

The Method 25A, 40CFR60, sampling and measurement system meets the requirements for stack sampling of volatile organic compounds (VOCs) set forth by the USEPA. In particular, it meets the requirements of USEPA Reference Method 25A, "Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer," 40CFR60, Appendix A. This method applies to the measurement of total gaseous organic concentration of hydrocarbons. With this method, a gas sample was extracted from the stack through a heated Teflon® sample line to the analyzer.

The flame ionization detector used during this program was a JUM model VE-7 high-temperature total hydrocarbon analyzer. It is a highly sensitive flame ionization detector that provides a direct reading of total organic vapor concentrations with linear ranges of 0–10, 100, 1,000, and 10,000 ppm by volume. The instrument was calibrated using ultra-zero air and propane in air certified standards. The calibrations were performed before and after sampling, with calibration checks performed between each test run. Sampling was conducted continuously for three 1-hour periods. Sample times and location were logged simultaneously on a data logger.

4.5.5.2.8 HCOH Determination

A flue gas sample was drawn through a set of midget impingers containing 10 mL of 2 N HCl/0.05% 2,4-dinitrophenylhydrazine (DNPH reagent) and 10 mL of isooctane. Two tests were performed. Aldehydes and ketones readily form stable 2,4-dinitrophenylhydrazones (DNPH derivatives). The impinger solution was placed in a screw-capped vial having a Teflon-lined cap and returned to the laboratory for analysis. The DNPH derivatives are recovered by removing the isooctane layer, extracting the aqueous layer with 10 mL of 70/30 mixture of hexane/methylene chloride, and combining the organic layers. The combined organic layers are evaporated to dryness under a steam of nitrogen and the residue dissolved in methanol. The aldehydes are determined using reversed phase high-pressure liquid chromatography with an ultraviolet adsorption detector operated at 370 nm.

Sample recovery was performed at the test site by the test crew. Samples were transported to an approved lab for formaldehyde analysis.

4.5.5.3 Quality Assurance Procedures

- GE Mostardi Platt recognizes the previously described reference methods to be very technique-oriented and attempts to minimize all factors that can increase error by implementing its quality assurance program into every segment of its testing activities.
- Shelf life of chemical reagents prepared at the GE Mostardi Platt laboratory or at the job site did not exceed those specified in the above-mentioned methods. Those reagents having a shelf life of one week were prepared daily at the job site. When on-site analyses were required, all reagent standardization was performed daily by the same person performing the analysis.
- Dry and wet test meters were calibrated according to methods described in the Quality Assurance Handbook sections 3.3.2, 3.4.2, and 3.5.2. Percent error for the wet test meter according to the methods was less than the allowable error of 1%. The dry test meters measured the test sample volumes to within 2% at the flowrate and conditions encountered during sampling. Calibration gases were Protocol One gases. Analyzer interference data is kept on file at GE Mostardi Platt.

4.5.5.4 Test 5 Results Summary

The test results are summarized in tables 41 and 42. Figure 61 and Figure 62 are diagrams of the gas testing apparatus.

Table 41. Sample Data Collected for the HCHO Test

Test No.	Time	Sample Volume (dscf)	Volumetric Flow (dscfm)	(μg)	(ppm)	(lbs/hr)
1	0840–0940	1.968	465.0	68.9	0.99	0.002
2	1058–1158	2.065	468.0	65.6	0.90	0.002
3	1210–1310	1.997	467.0	62.2	0.88	0.002
	Average		467.0		0.92	0.002

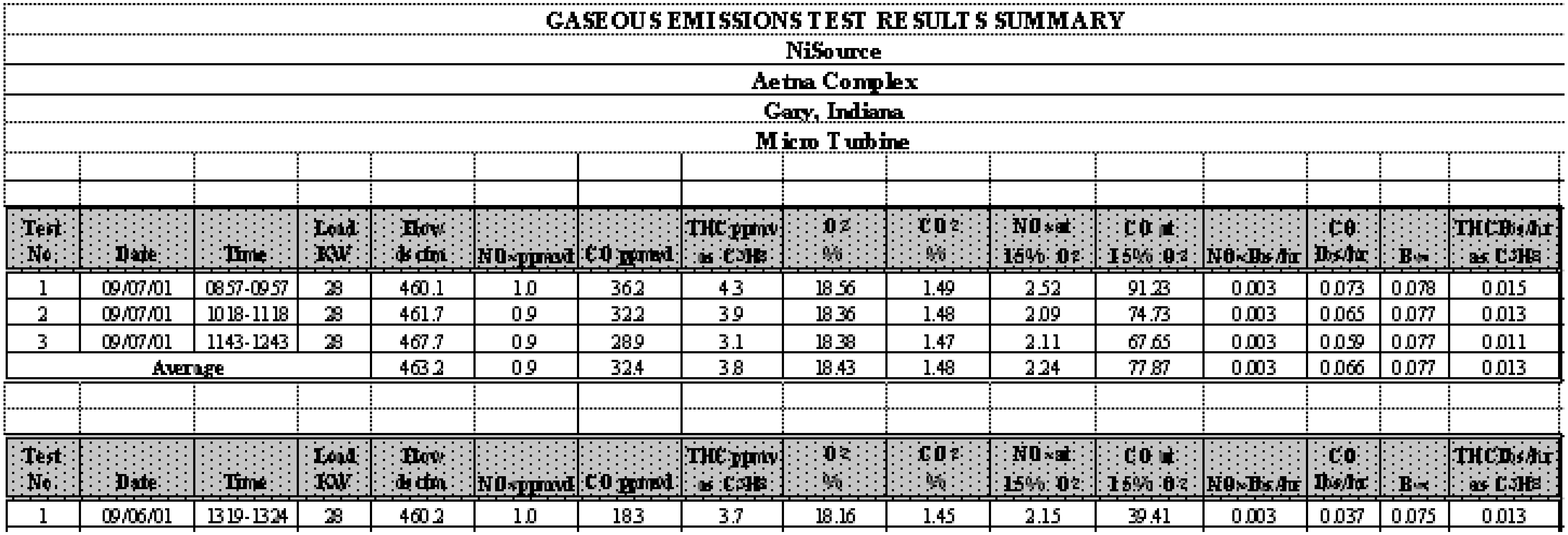
Calculations:

$$\text{HCHO lbs/dscf} = \frac{\left(\mu\text{g CH}_3\text{OH}\times 10^{-6}\right)\times\left(2.2046\times 10^{-3}\right)}{\text{dscf sampled}}$$

$$\text{HCHO ppm} = \frac{\text{lbs/dscf}}{7.792\times 10^{-8}}$$

$$\text{HCHO lbs/hr} = \text{lbs/dscf}\times\text{dscfm}\times 60$$

Table 42. Summary of Sample Test Data From the Gaseous Emissions Test



GASEOUS EMISSIONS TEST RESULTS SUMMARY

NiSource

Aetna Complex

Gary, Indiana

Micro Turbine

Test No.	Date	Time	Load KW	Flow dscfm	NO_x ppmvd	CO ppmvd	THC ppmv as C_3H_8	O_2 %	CO_2 %	NO_x at 15% O_2	CO at 15% O_2	NO_x lbs/hr	CO lbs/hr	B_{ws}	THC lbs/hr as C_3H_8
1	09/07/01	0857-0957	28	460.1	1.0	36.2	4.3	18.56	1.49	2.52	91.23	0.003	0.073	0.078	0.015
2	09/07/01	1018-1118	28	461.7	0.9	32.2	3.9	18.36	1.48	2.09	74.73	0.003	0.065	0.077	0.013
3	09/07/01	1143-1243	28	467.7	0.9	28.9	3.1	18.38	1.47	2.11	67.65	0.003	0.059	0.077	0.011
Average				463.2	0.9	32.4	3.8	18.43	1.48	2.24	77.87	0.003	0.066	0.077	0.013

Test No.	Date	Time	Load KW	Flow dscfm	NO_x ppmvd	CO ppmvd	THC ppmv as C_3H_8	O_2 %	CO_2 %	NO_x at 15% O_2	CO at 15% O_2	NO_x lbs/hr	CO lbs/hr	B_{ws}	THC lbs/hr as C_3H_8
1	09/06/01	1319-1324	28	460.2	1.0	18.3	3.7	18.16	1.45	2.15	39.41	0.003	0.037	0.075	0.013

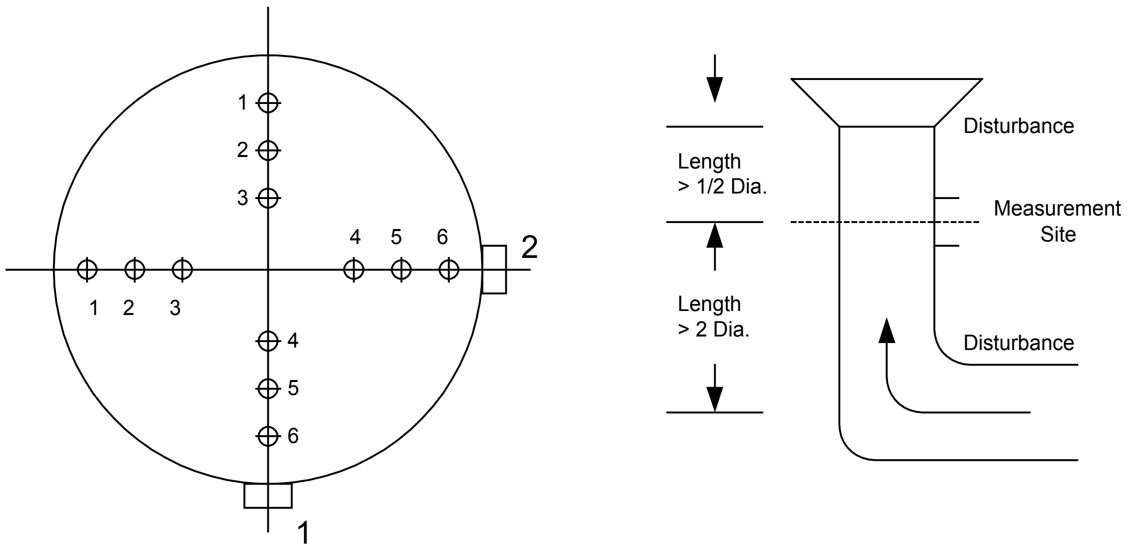


Figure 61. Diagram of equal area traverse for round ducts

Job: NiSource Energy Technologies

Date: Sept. 6 and 7, 2001

Unit No: 1

Duct Diameter: 5 in.

Duct Area: 0.136 ft^2

No. Points Across Diameter: 6

No. of Ports: 2

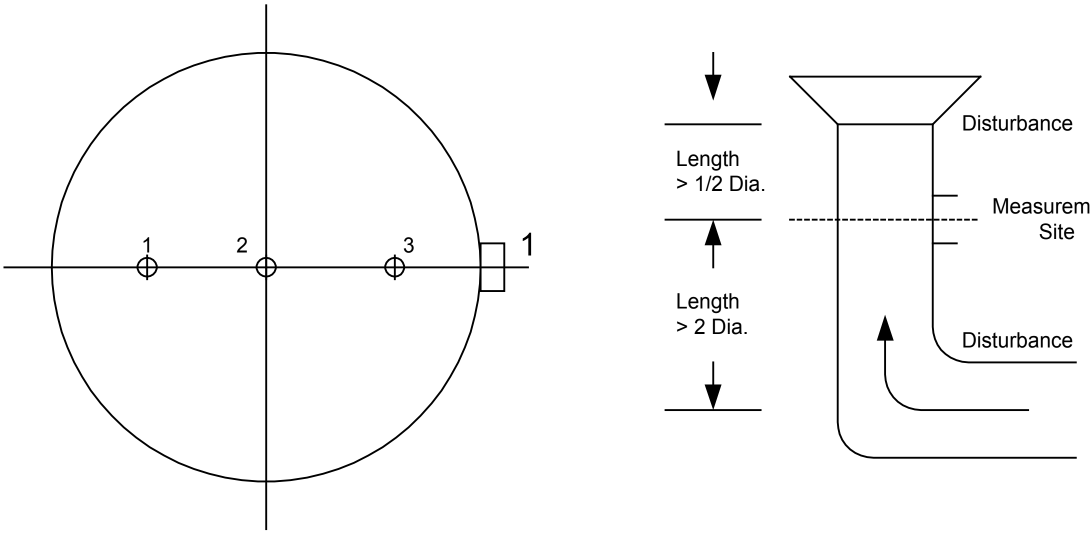


Figure 62. Figure of sampling of the gaseous traverse for round ducts

Job: NiSource Energy Technologies

Date: Sept. 6 and 7, 2001

Unit No: 1

Duct Diameter: 5 in.

Duct Area: 0.136 ft^2

No. Sample Points: 3

Distance from Inside
Wall To Traverse Point:

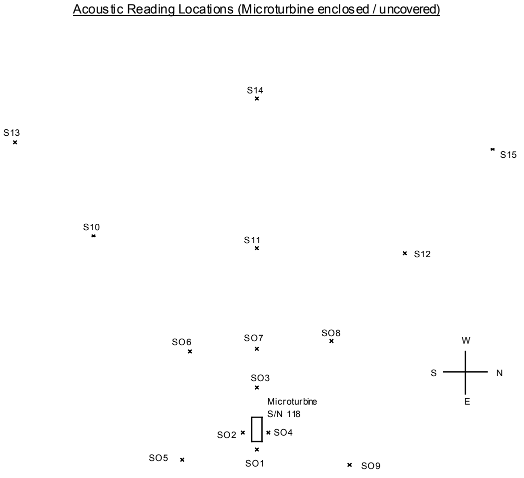
1. 83% of diameter
2. 50% of diameter
3. 17% of diameter

4.5.6 Test 6

Using a Quest model 215 sound level meter in conjunction with a CSI 2120 FFT spectrum analyzer/data collector, sound level readings were recorded for Turbine 1 at load settings ranging from 4 kW to full load capacity. Readings were taken at 15 locations surrounding the microturbine. The described acoustic readings were taken with the meter set to A-weighting, which approximates the frequency sensitivity of the human ear.

General observations regarding the test data include:

- Acoustic readings reflect any road noise or other additional sounds. As load increased, the decibel level increased as expected.
- Figure 63, Figure 64, and Figure 65 show the change in sound level with relation to load. This can be referenced to the table showing various sound levels and exposure time.

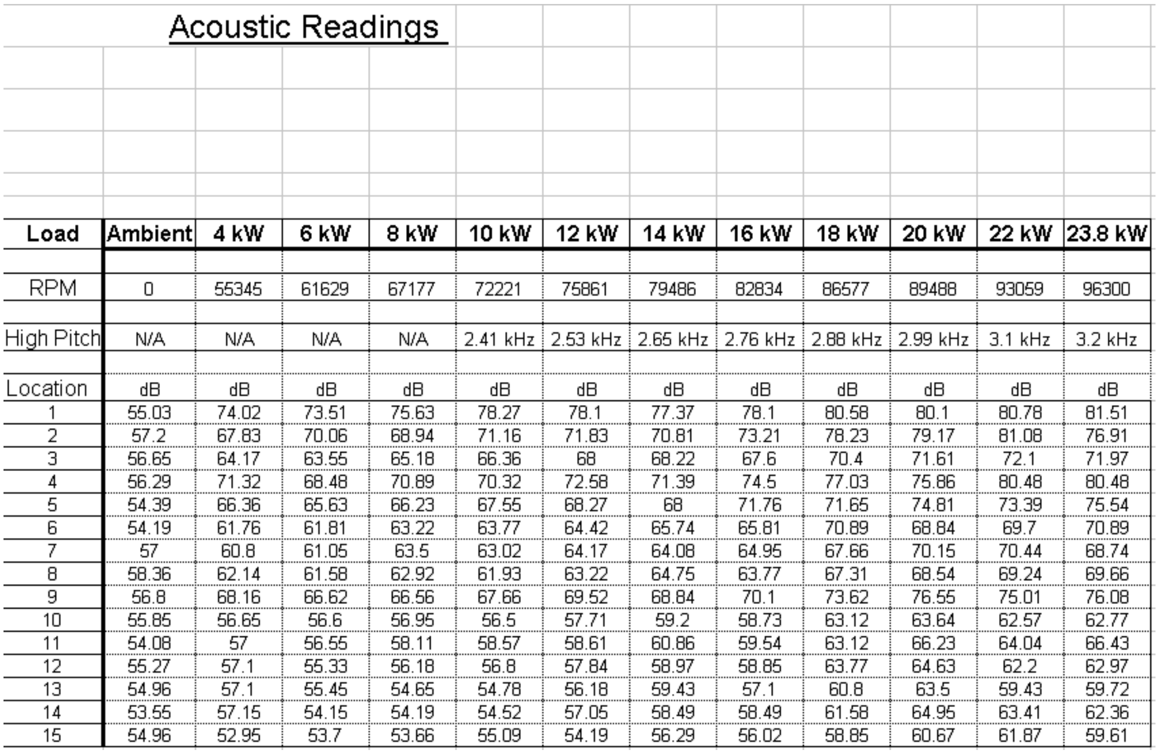


Distances

S01	1' 9"	S09	18'10"
S02	2' 0"	S10	51'1"
S03	6' 0"	S11	35'0"
S04	1' 6"	S12	46'5"
S05	14' 2"	S13	76'4"
S06	19' 10"	S14	65'10"
S07	14' 2"	S15	74'5"
S08	22'7"		

Figure 63. Diagram of the physical measurements for the sound tests

Table 43. Acoustic Readings



Acoustic Readings

Load	Ambient	4 kW	6 kW	8 kW	10 kW	12 kW	14 kW	16 kW	18 kW	20 kW	22 kW	23.8 kW
RPM	0	55345	61629	67177	72221	75861	79486	82834	86577	89488	93059	96300
High Pitch	N/A	N/A	N/A	N/A	2.41 kHz	2.53 kHz	2.65 kHz	2.76 kHz	2.88 kHz	2.99 kHz	3.1 kHz	3.2 kHz
Location	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB	dB
1	55.03	74.02	73.51	75.63	78.27	78.1	77.37	78.1	80.58	80.1	80.78	81.51
2	57.2	67.83	70.06	68.94	71.16	71.83	70.81	73.21	78.23	79.17	81.08	76.91
3	56.65	64.17	63.55	65.18	66.36	68	68.22	67.6	70.4	71.61	72.1	71.97
4	56.29	71.32	68.48	70.89	70.32	72.58	71.39	74.5	77.03	75.86	80.48	80.48
5	54.39	66.36	65.63	66.23	67.55	68.27	68	71.76	71.65	74.81	73.39	75.54
6	54.19	61.76	61.81	63.22	63.77	64.42	65.74	65.81	70.89	68.84	69.7	70.89
7	57	60.8	61.05	63.5	63.02	64.17	64.08	64.95	67.66	70.15	70.44	68.74
8	58.36	62.14	61.58	62.92	61.93	63.22	64.75	63.77	67.31	68.54	69.24	69.66
9	56.8	68.16	66.62	66.56	67.66	69.52	68.84	70.1	73.62	76.55	75.01	76.08
10	55.85	56.65	56.6	56.95	56.5	57.71	59.2	58.73	63.12	63.64	62.57	62.77
11	54.08	57	56.55	58.11	58.57	58.61	60.86	59.54	63.12	66.23	64.04	66.43
12	55.27	57.1	55.33	56.18	56.8	57.84	58.97	58.85	63.77	64.63	62.2	62.97
13	54.96	57.1	55.45	54.65	54.78	56.18	59.43	57.1	60.8	63.5	59.43	59.72
14	53.55	57.15	54.15	54.19	54.52	57.05	58.49	58.49	61.58	64.95	63.41	62.36
15	54.96	52.95	53.7	53.66	55.09	54.19	56.29	56.02	58.85	60.67	61.87	59.61

Figure 64 and Figure 65 illustrate sound spectra at 35 feet from the turbine for various loads ranging from 4 kW to 28 KW at Location 11 (S11 in the previous figure).

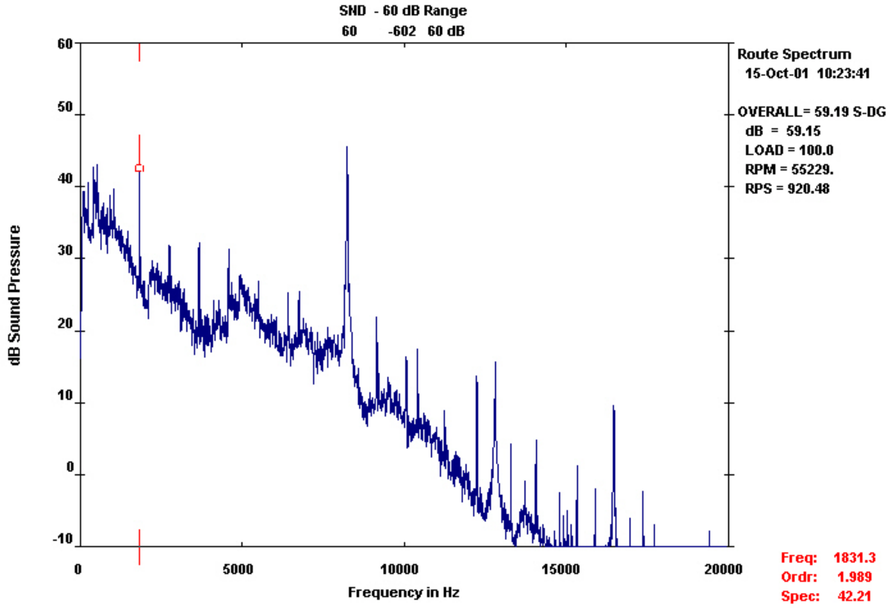


Figure 64. Sound spectra at 35 feet from the turbine for 4 KW at location 11

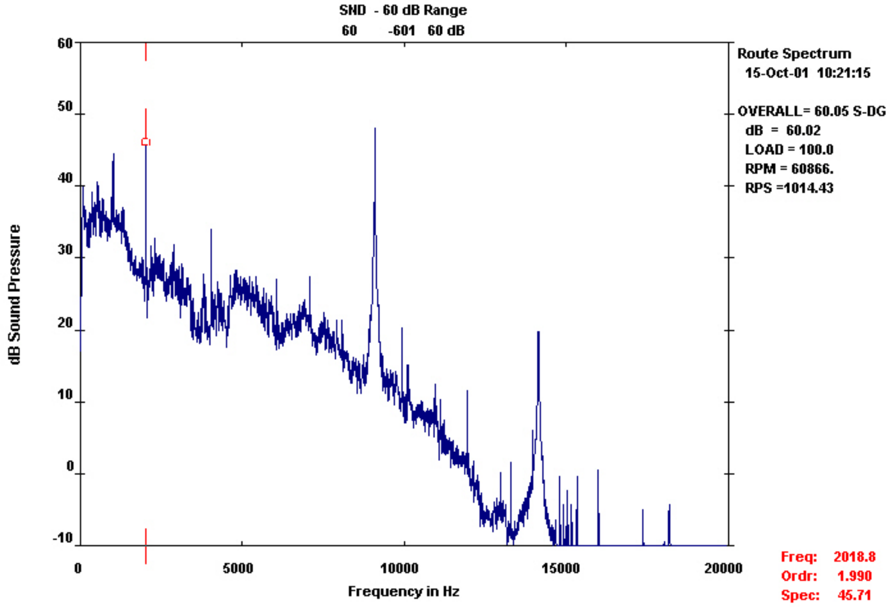


Figure 65. Sound spectra at 35 feet from the turbine for 6 KW at location 11

4.5.7 Test 7

Vibration readings were taken at varying loads on the support structure of Turbine 1 using a CSI 2120 FFT Machinery Analyzer. A review of the 14 vibration monitoring points showed no apparent vibration concern. The following results are the vibration magnitudes and a chart showing various vibration levels. All the readings taken on Turbine 1 were in or around the "very smooth" range.

General conclusions from the tests include:

- The measurements taken are repeatable but not certified.
- Vibration readings taken on the support structure were small in magnitude. Readings fall in the very smooth to very good range, which verifies the statement that the microturbine is "vibration-free."

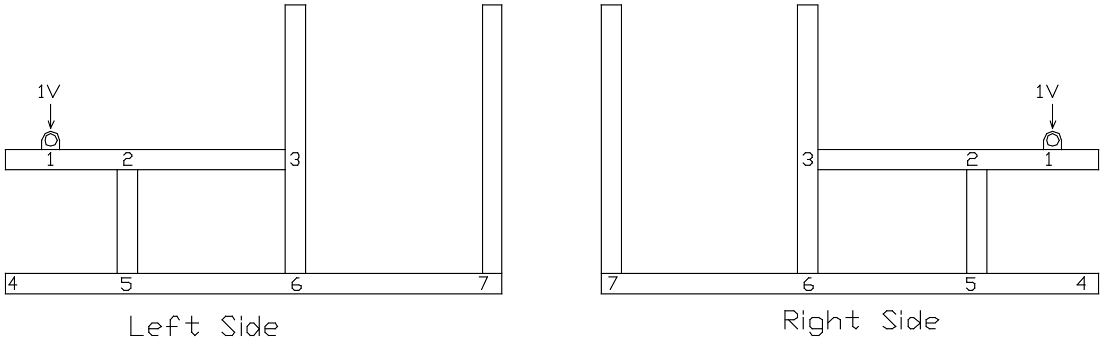


Figure 66. Illustration of vibration data-collection points on microturbine

For each of the locations on the turbine support structure, horizontal and vertical measurements were taken, as illustrated in Figure 66. Table 44 displays the vibration measurements, in units of inches per second squared, at various loading conditions.

Table 44. Vibration Data for Test 7

4 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.02	55822
1VL	1 vertical left	0.015	55822
2HL	2 horizontal left	0.015	55822
3HL	3 horizontal left	0.018	55822
4HL	4 horizontal left	0.0074	55822
5HL	5 horizontal left	0.015	55822
6HL	6 horizontal left	0.023	55822
7HL	7 horizontal left	0.0063	55822
1HR	1 horizontal right	0.016	55822
1VR	1 vertical left	0.015	55822
2HR	2 horizontal right	0.011	55822
3HR	3 horizontal right	0.0086	55822
4HR	4 horizontal right	0.0052	55822
5HR	5 horizontal right	0.012	55822
6HR	6 horizontal right	0.012	55822
7HR	7 horizontal right	0.0058	55822

6 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.018	61400
1VL	1 vertical left	0.0092	61400
2HL	2 horizontal left	0.022	61400
3HL	3 horizontal left	0.026	61400
4HL	4 horizontal left	0.0055	61400
5HL	5 horizontal left	0.0083	61400
6HL	6 horizontal left	0.015	61400
7HL	7 horizontal left	0.016	61400
1HR	1 horizontal right	0.016	61400
1VR	1 vertical left	0.011	61400
2HR	2 horizontal right	0.016	61400
3HR	3 horizontal right	0.017	61400
4HR	4 horizontal right	0.008	61400
5HR	5 horizontal right	0.0075	61400
6HR	6 horizontal right	0.015	61400
7HR	7 horizontal right	0.0091	61400

Vibration readings taken Aug. 21, 2001; Turbine 1

Additional Test 7 results can be found in the appendix.

The vibration spectra and waveforms in Figure 67 and Figure 68 are results obtained from a 10-kW load.

1HR

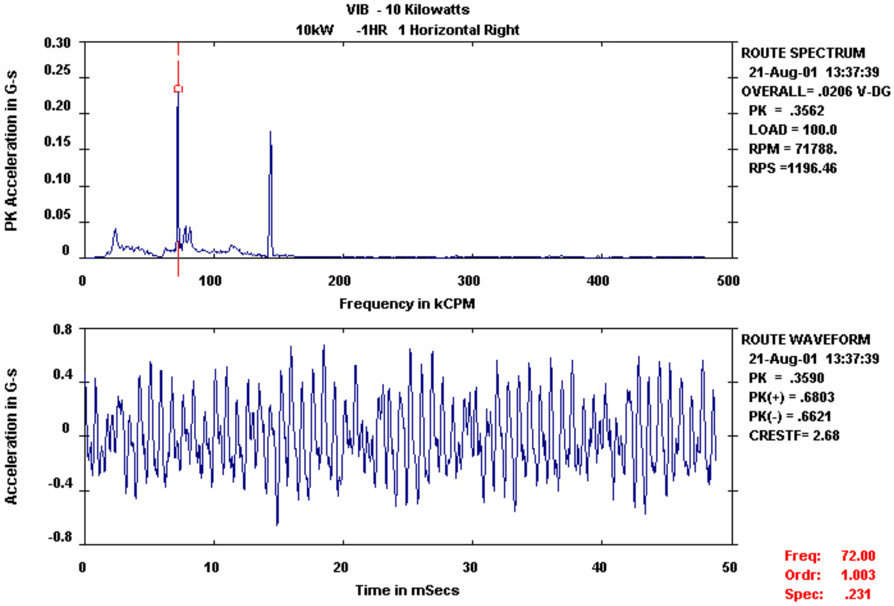


Figure 67. Vibration spectra at 1HR

1HL

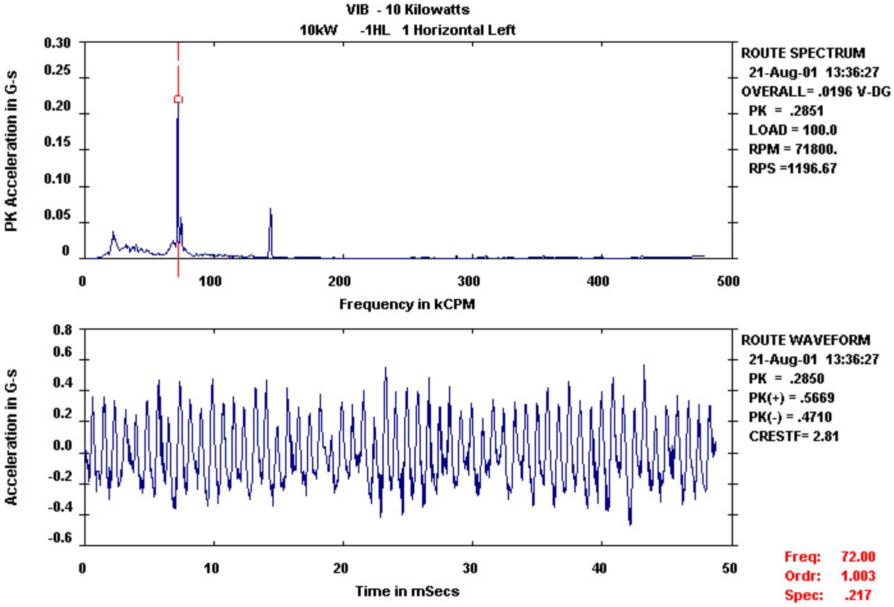


Figure 68. Vibration spectra at 1HL

5 Conclusions and Plans for Next Year

5.1 Interconnection Issues Survey

A survey of the state of the art of interconnection issues associated with DG was completed. Responses were grouped into categories of equipment suppliers, end users, and utilities. More than 100 utilities were contacted as part of the survey. This report provides a basis for assessing the state of agreement among the various parties regarding CHP interconnection.

5.1.1 Conclusions of the Utility Survey

- A widely varying degree of support for DG exists among electric utilities. The degree of support is based on the nature and complexity of the requirements set forth in the standards.
- General consensus exists among utilities regarding the necessity of a disconnect switch between the generator and the utility and the characteristics, placement, and operability of the switch. A few exceptions exist.
- The standards of all participating utilities rely to some degree on pre-existing technical standards such as those of ANSI, IEEE, NEC, NESC, NFPA, and UL (some more than others). The most-referenced standards are ANSI/IEEE 519-1992, 929-2000, and C37.90; NEC; and NESC. Some utilities go to great lengths to reference any standard that might possibly be applicable (for example, utilities 4 and 9).
- Protective relaying requirements among the utilities vary to some degree in nature and complexity. Some are very flexible—giving very little in the way of specific recommendations—while others appear to be very well-defined and sometimes rigid. For example, a number of utilities insist that the more expensive utility-grade relays be used at the point of connection to the utility—even if the same relaying function already exists within the generator installation. All are basically looking to accomplish various goals including utility system protection and employee safety.
- Most of these utilities require a dedicated power transformer for the purpose of isolating the generator from other utility customers.
- Generation power factor specifications are an important ingredient of any comprehensive interconnection standard. Among the utilities, a general consensus is evident regarding the issue of power quality. Most standards heavily rely on the requirements presented in IEEE 519-1992.

5.1.1.1 Recommendations

- Generator classification is based primarily on direction of power flow (one-way or two-way), followed by the power output capability of the unit and the nature of the generator (synchronous, induction, etc.).

- The disconnect switch requirement should be included in any interconnection standard. This switch should exhibit a visible gap between contacts when in open position (visible with case door open), have full load break capability, be accessible to and lockable (in open position) by the utility, and be clearly labeled.
- A standard that coordinates well with existing national standards is desirable. It is important that any DG unit that will operate in parallel with the grid be in compliance with any directly applicable national standards—particularly those of ANSI/IEEE, NEC, and NESC. Occasional references to specific standards can be helpful, when necessary and directly applicable to the issue.
- Reasonable protective relaying requirements are essential to a safe interconnection. However, overkill and redundancy are not necessary to accomplish the basic tasks of isolation and fault protection. At minimum, the standard should include a listing of possible situations that should be cared for through sound protective relaying. Among these would be distribution system faults, abnormal system voltage or frequency, equipment failure, and harmonic voltages. The installation would then be subject to field-testing and verification of system and settings prior to actual interconnection.
- Depending on the size of the generating unit, it is reasonable to require an isolation transformer to confine any undesirable electrical characteristics to the generator. For generators above a certain size threshold, a dedicated utility power transformer is in order. This would prevent the power producer from being fed off a secondary shared with other utility customers.
- Power quality requirements need to address the areas of voltage limits, voltage flicker, harmonic distortion, power factor, abnormal frequency, and fault current levels. Reference to IEEE 519-1992 and the current draft of IEEE 1547 for specific requirements would be helpful in forming a common baseline.

5.1.1.2 General Observations From the Survey

- The level of development of interconnection technology attained is directly proportional to the initiative, effort, and cooperation that the involved entities—utilities, manufacturers, and governmental bodies—are willing to put forth.
- The number of problems related to interconnection at a particular location often is connected to the level of acceptance of DG as a viable energy source by particular utilities. If there is an awareness and acceptance of DG technology and consideration of the benefits it can provide to the system and customers, there are generally fewer interconnection-related issues.
- Most of the utilities that have developed a comprehensive interconnection standard have certain expectations about the quality of power produced by the interconnected power source. A few of the relevant issues pertaining to power quality are voltage limits, voltage flicker, frequency control, harmonics, fault current level, and power factor.

5.1.2 Conclusions of the Manufacturer Survey

- There appears to be reasonable agreement that a fusible disconnect switch or circuit breaker, or both, should exist between the generator and the utility. This affords protection to the utility as well as to the generator.
- Standard references can be useful in directly supporting the legitimacy of a utility-generator interconnection document.
- Basic protective devices such as overvoltage, undervoltage, and over/underfrequency are normally included as part of the generation package. Some packages include additional features such as reverse power flow protection and rate of change of frequency protection.
- Under most circumstances, an intervening transformer is required between the generator and the utility—whether it is internal to the generator package or placed externally in the system.
- While operating parallel to the distribution grid, the generator will attempt to "copy" the electrical characteristics of the grid. This normally provides improved power quality. It is important that a generation source be in conformance with IEEE 519-1992 regarding harmonic distortion.

5.2 State-Related Issues

5.2.1 Regulatory Issues Related to Grid-Connected Distributed Generation Systems

Regulatory activities take place generally on a state-by-state basis in the United States for distribution systems. Should the transmission grid be influenced, there is also the possibility of consideration by the Federal Energy Regulatory Commission.

State governmental bodies can serve as mediators between electric utilities and prospective DG customers, providing a much-needed "check and balance" function in the overall interconnection scenario. A few of the prevailing regulatory issues are:

- Development of interconnection standards
  Several state bodies have already developed comprehensive guidelines upon which utility interconnection standards are to be subject and should be based. Many others have made recommendations and are working toward the development of similar comprehensive guidelines.
- Design of fair and reasonable tariffs
  Utility rate structures should not prohibit or discourage the safe interconnection of distributed energy resources with the electric distribution grid.

- Benefits and costs of DG to the grid
  To ensure proper price signals are given to the marketplace, it is important that the real benefits and costs of DG interconnection be understood prior to any extensive regulatory action.
- Ownership, control, and operation of DG systems
  Various approaches have been proposed based on scale and function.
- Technical processes for connecting to the grid
  Uniform technical guidelines within a state help promote implementation of DG systems.
- Planning processes necessary for grid-parallel DG operation
  Grid-parallel DG installations, depending on their size, require some degree of system planning by the utility.
- Applicability of net metering
  The applicability of net metering should be assessed by the state.
- Identification of barriers to the implementation of DG
  It is important to separate the real technical and economic issues from opinion and localized considerations.
- Determination of the effects of utility regulatory practices on the cost of interconnection
  Different regulatory approaches can result in different costs.

5.2.2 Survey of Local Zoning Requirements for the NiSource Service Territory

This survey provided the basis for assessing the state of knowledge of local municipalities and made recommendations of how to improve to accelerate the penetration of CHP technology into the marketplace.

The scope of this report is to summarize the broad air permitting needs for the installation of end-user DG microturbines on a state-by-state basis in the NiSource Inc. service territory. This is not an exhaustive review of local, county, or regional requirements that may deviate from state or federal regulations. In the event DG devices are proposed for installation in specific locations, a detailed site-specific permit analysis must be conducted to ensure compliance with all laws, regulations, and ordinances.

General recommendations for installing microturbines include:

- Once site locations have been chosen, a comprehensive permit applicability review must be conducted on a site-specific basis to ensure compliance with all applicable laws, regulations, and ordinances.
- Because of the limited review in this study and in the event installation needs to be fast-tracked, exemption letter requests could be sent to select states to obtain an agency determination of exemption prior to final siting.

- Once a “short list” of potential microturbine installation sites has been determined, a detailed air permit applicability review should be conducted to avoid undue delays.
- Installation of microturbines in non-attainment areas could result in additional requirements.

5.3 CHP Test Sites

Two CHP test sites were used to acquire data concerning the operation, reliability, interconnection issues, and performance of CHP systems and components. The test site in Chesterton, Indiana, provided efficiency, reliability, and operating information for a CHP system in an operating commercial business. Efficiency data were gathered for the microturbine. An initial building model was completed for analysis of CHP efficiency for the entire building. These data will be valuable as a basis for designing and implementing future CHP commercial applications.

The test site in Gary, Indiana, provided detailed operating data for two microturbines and a flywheel energy storage device in various grid-connected and isolated configurations. The response and interaction of multiple inverters, a motor generator, and resistive and inductive loads were considered. A statistically based profile of the operating characteristics of a variety of operating configurations was developed. Results were presented for the experimental design in the form of response surfaces and other appropriate representations to facilitate interpretation. In addition, a database of noise, environmental, and vibration information under various conditions was assembled.

One concern is the response of DG devices to the starting of motors and other inductive loads. This behavior was studied both for grid-connected and standalone modes with combinations of DG devices. Various issues associated with standalone operation for inductive transients were identified. This effort provides a database of information that will be valuable for designing both standalone and grid-connected DG systems. Operating issues associated with motor starting were identified, and methods to resolve the issues were suggested.

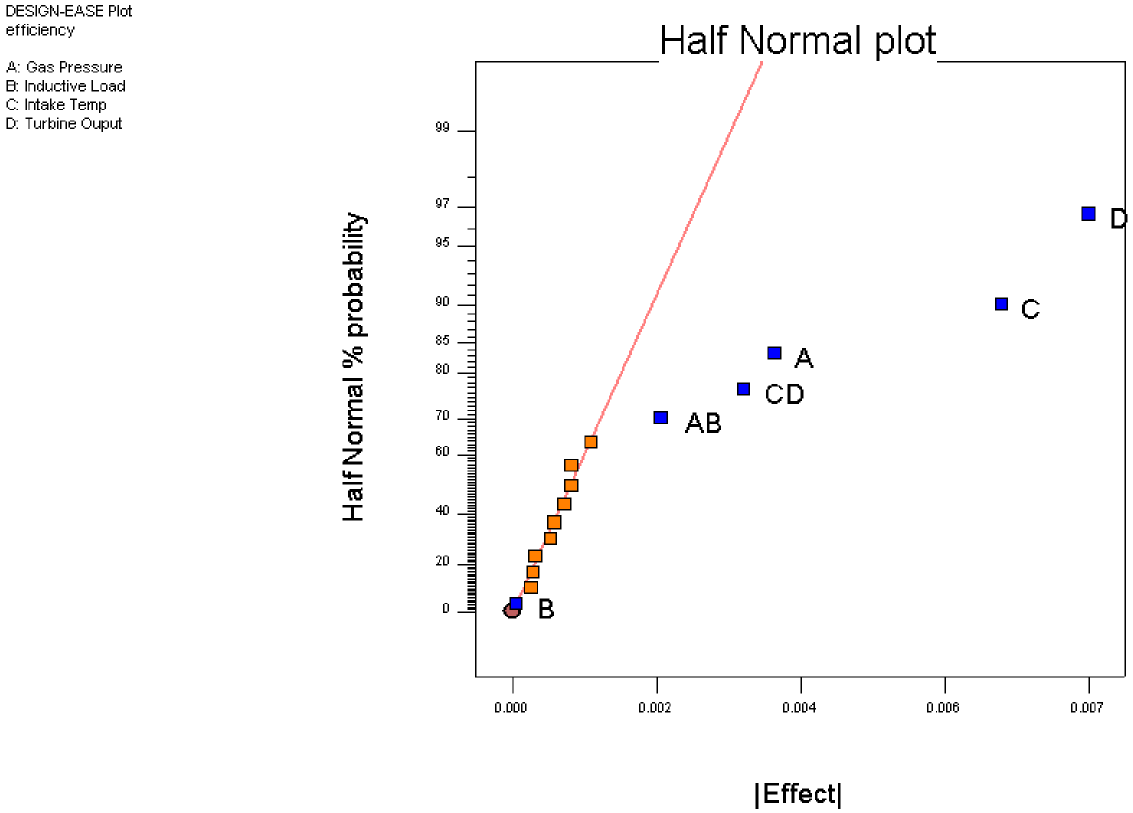
The preceding text provides the results for these tasks. These data were developed as a base line to understand issues associated with the development and implementation of CHP systems.

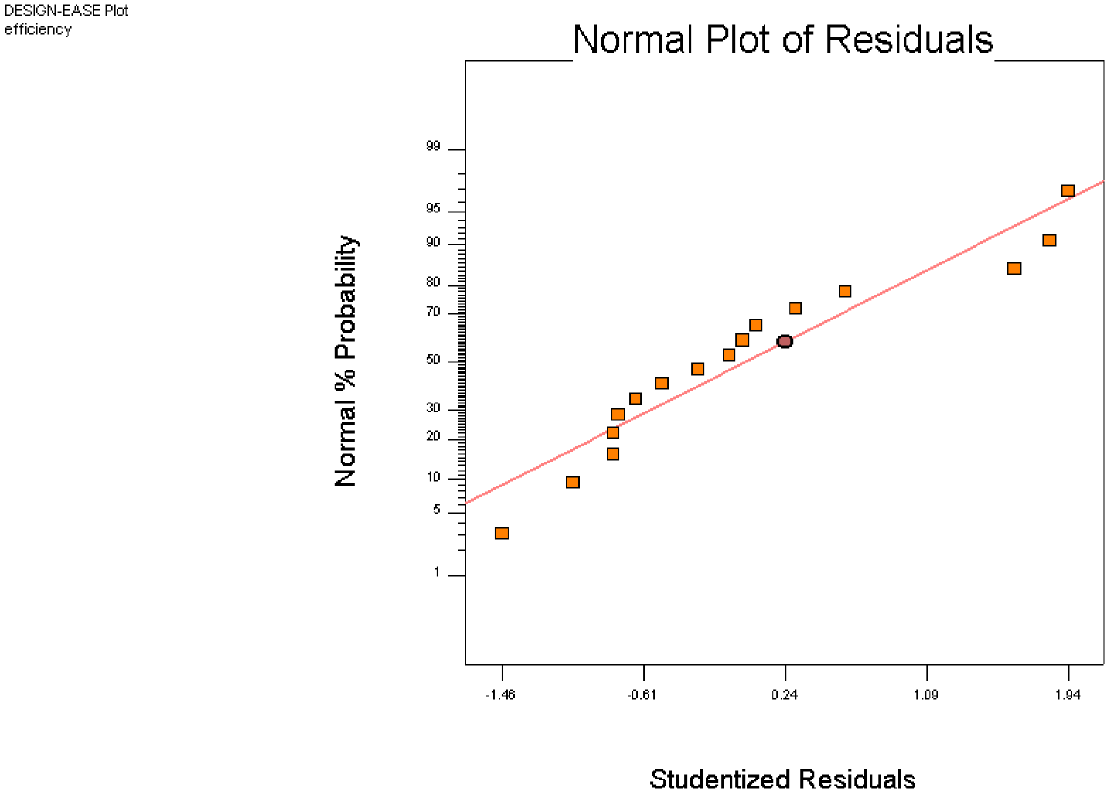
5.4 Plans For Next Year

Next year, this work will be extended to consider the issues described in the initial proposal. These include further consideration of interaction with the electric grid and detailed consideration of CHP systems and how they will integrate into a building to provide improved energy use, efficiency, and reduced net emissions.

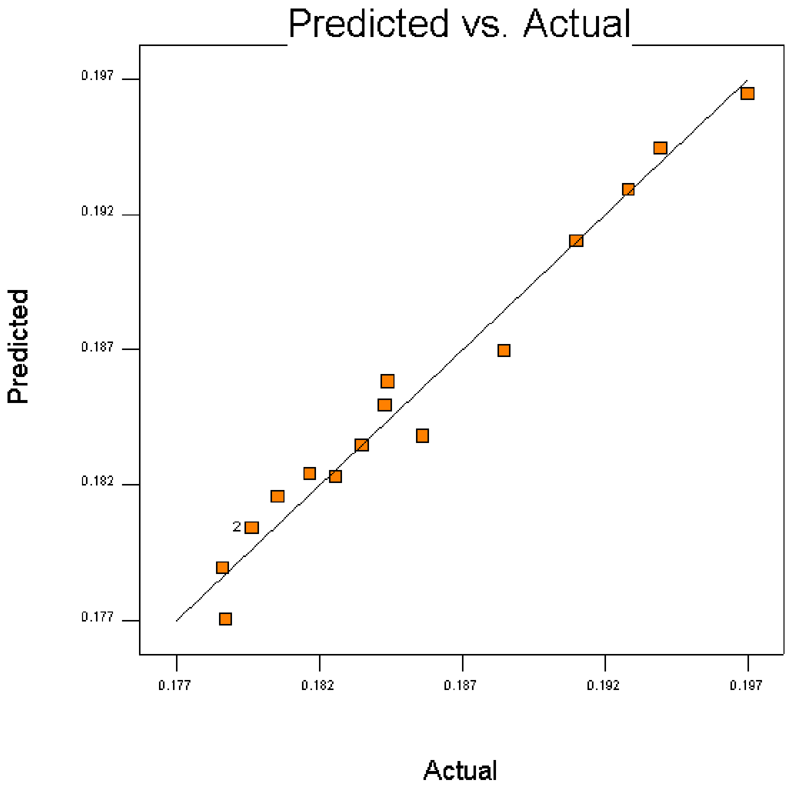
Appendix

A.1 Task 3 - Test 2

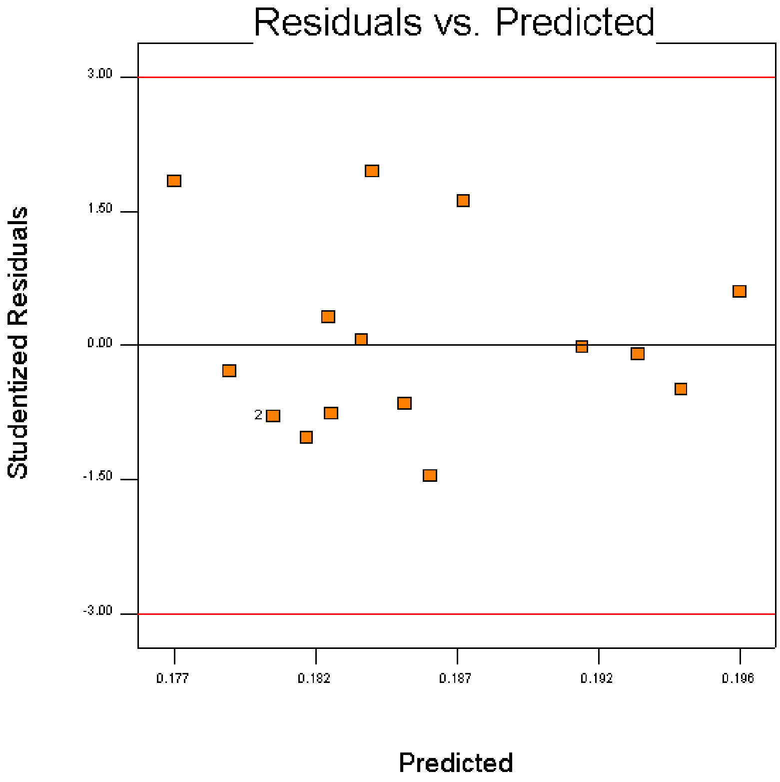




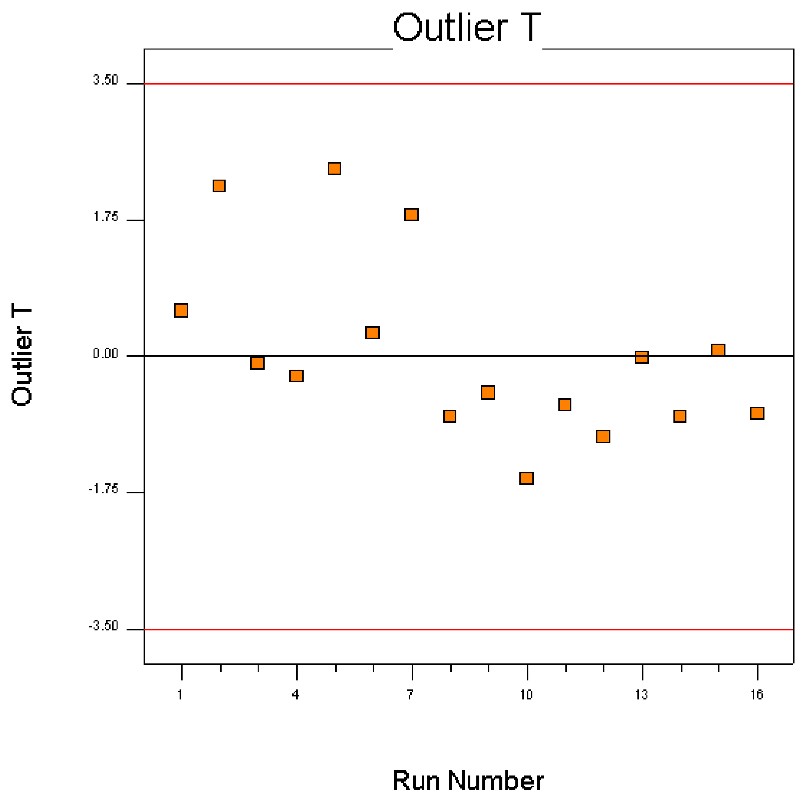
DESIGN-EASE Plot
efficiency



DESIGN-EASE Plot
efficiency



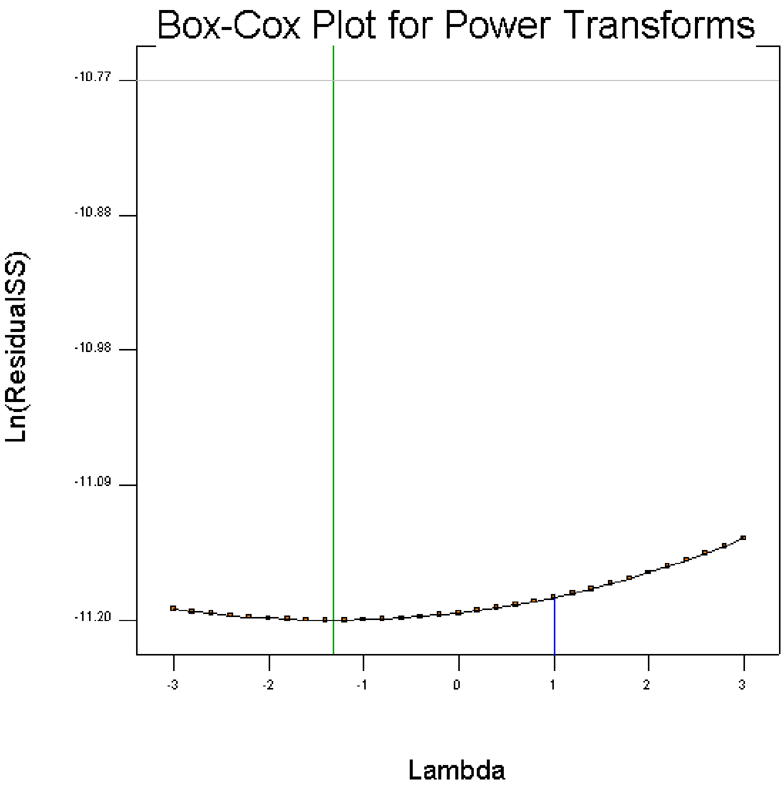
DESIGN-EASE Plot
efficiency

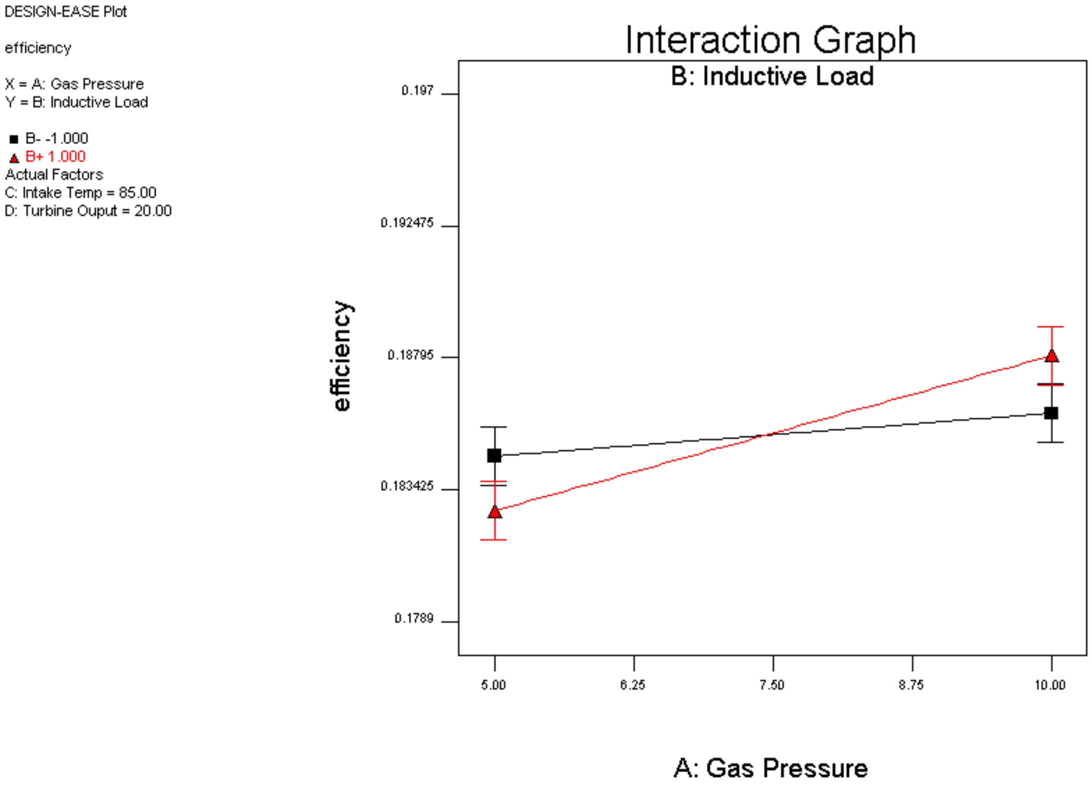


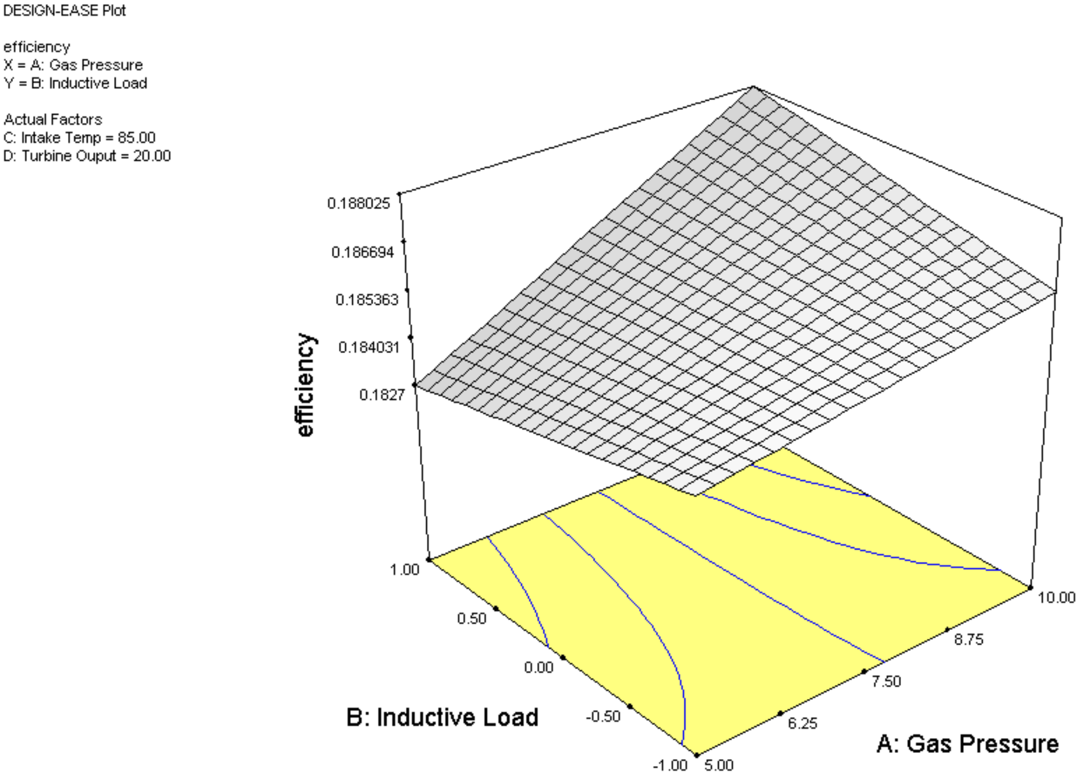
DESIGN-EASE Plot
efficiency

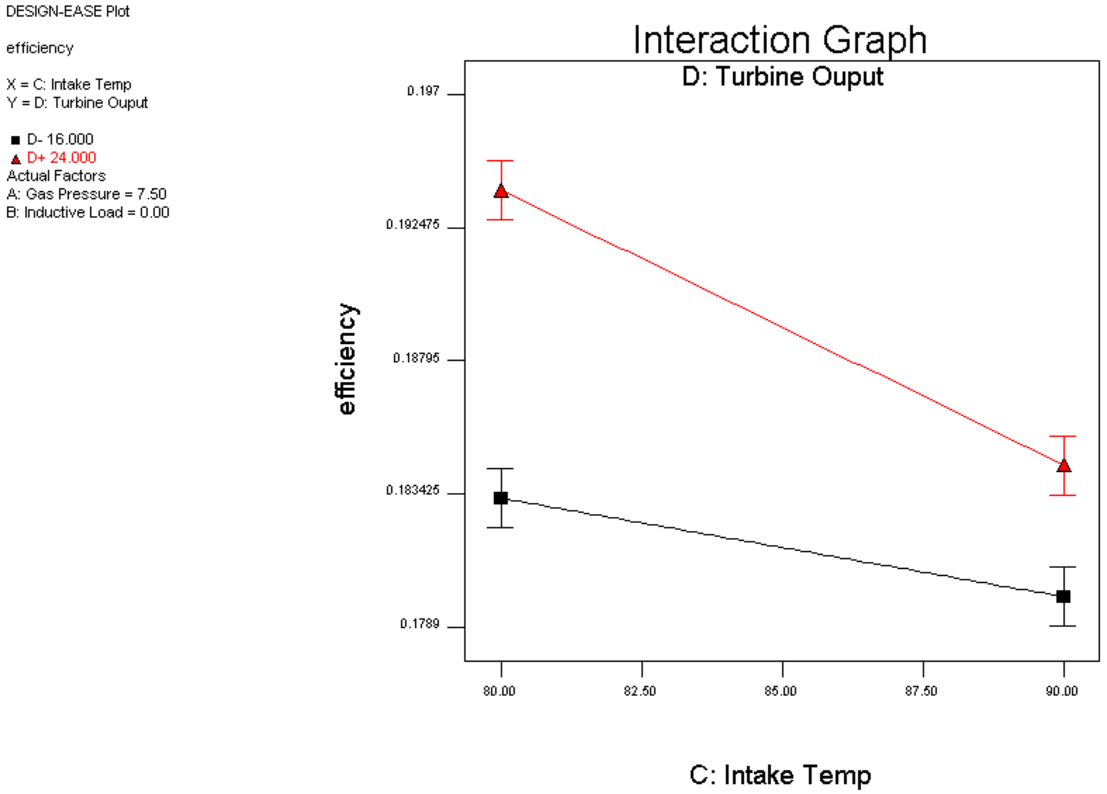
Lambda
Current = 1
Best = -1.31
Low C.I. = -12.98
High C.I. = 10.36

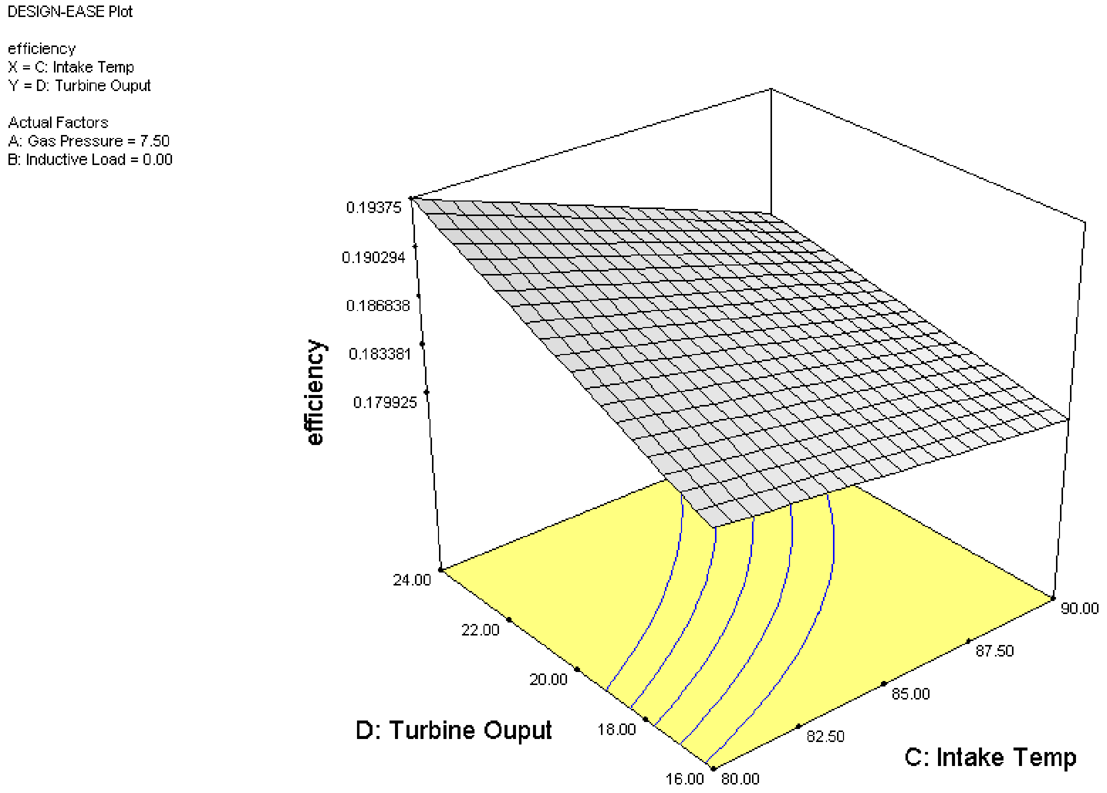
Recommend transform:
None
(Lambda = 1)




DESIGN-EASE Plot
efficiency
X = A: Gas Pressure
Y = B: Inductive Load
■ B- -1.000
▲ B+ 1.000
Actual Factors
C: Intake Temp = 85.00
D: Turbine Ouput = 20.00
Interaction Graph
B: Inductive Load
efficiency
0.197
0.192475
0.18795
0.183425
0.1789
5.00
6.25
7.50
8.75
10.00
A: Gas Pressure


DESIGN-EASE Plot
efficiency
X = A: Gas Pressure
Y = B: Inductive Load
Actual Factors
C: Intake Temp = 85.00
D: Turbine Ouput = 20.00
efficiency
0.188025
0.186694
0.185363
0.184031
0.1827
1.00
0.50
0.00
-0.50
-1.00
B: Inductive Load
5.00
6.25
7.50
8.75
10.00
A: Gas Pressure

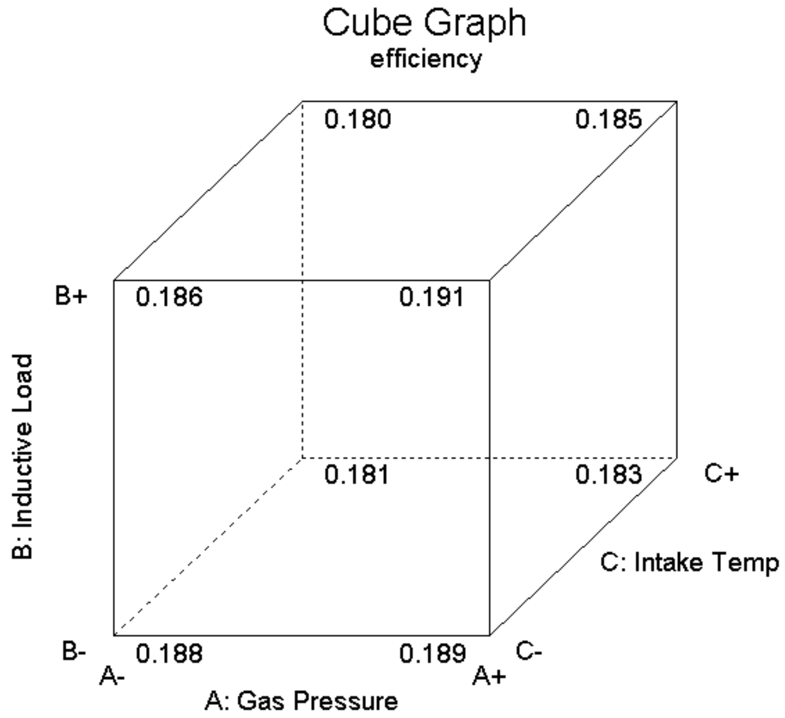

DESIGN-EASE Plot
efficiency
X = C: Intake Temp
Y = D: Turbine Ouput
■ D- 16.000
▲ D+ 24.000
Actual Factors
A: Gas Pressure = 7.50
B: Inductive Load = 0.00
Interaction Graph
D: Turbine Ouput
efficiency
0.197
0.192475
0.18795
0.183425
0.1789
80.00
82.50
85.00
87.50
90.00
C: Intake Temp


DESIGN-EASE Plot
efficiency
X = C: Intake Temp
Y = D: Turbine Ouput
Actual Factors
A: Gas Pressure = 7.50
B: Inductive Load = 0.00
efficiency
0.19375
0.190294
0.186838
0.183381
0.179925
24.00
22.00
20.00
18.00
16.00
D: Turbine Ouput
80.00
82.50
85.00
87.50
90.00
C: Intake Temp

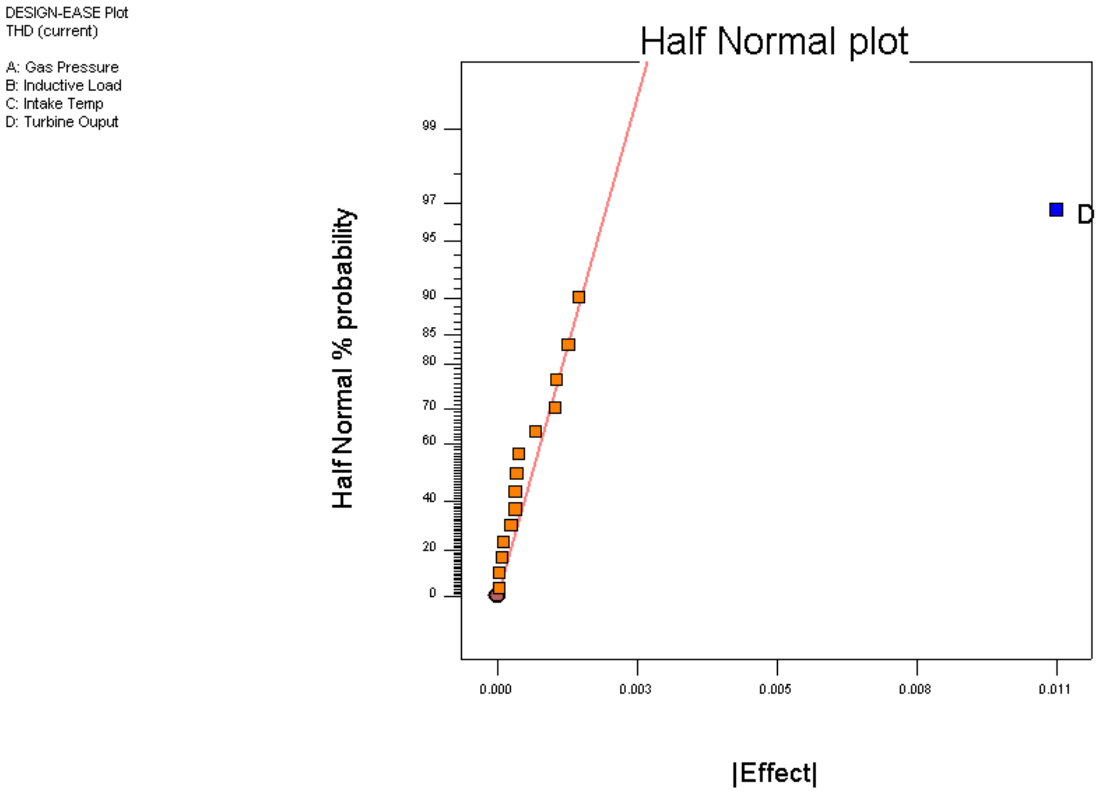
DESIGN-EASE Plot

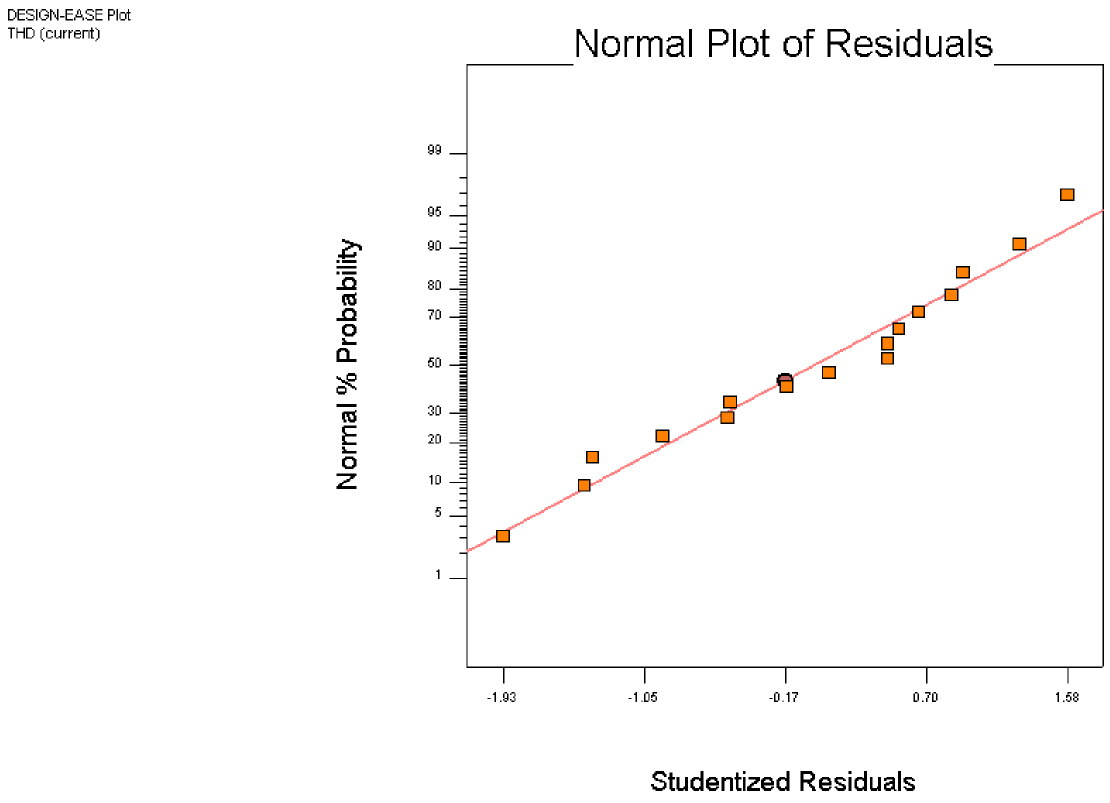
efficiency
X = A: Gas Pressure
Y = B: Inductive Load
Z = C: Intake Temp

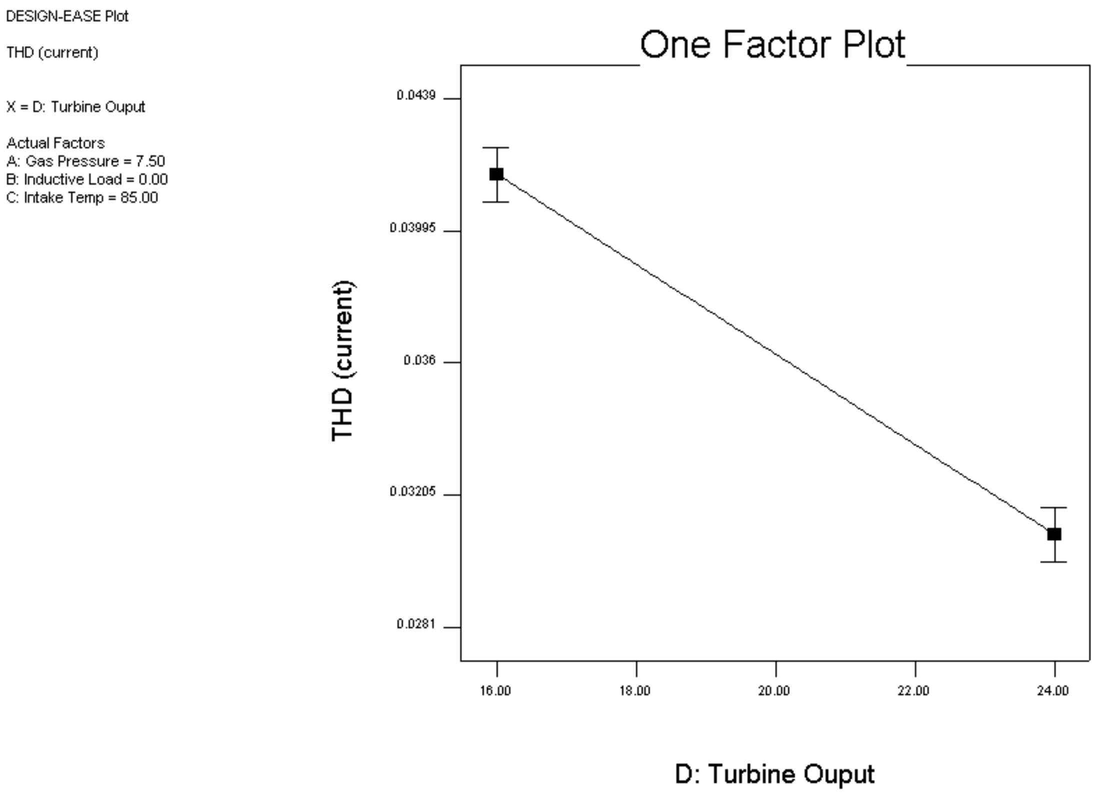
Actual Factor
D: Turbine Ouput = 20.00

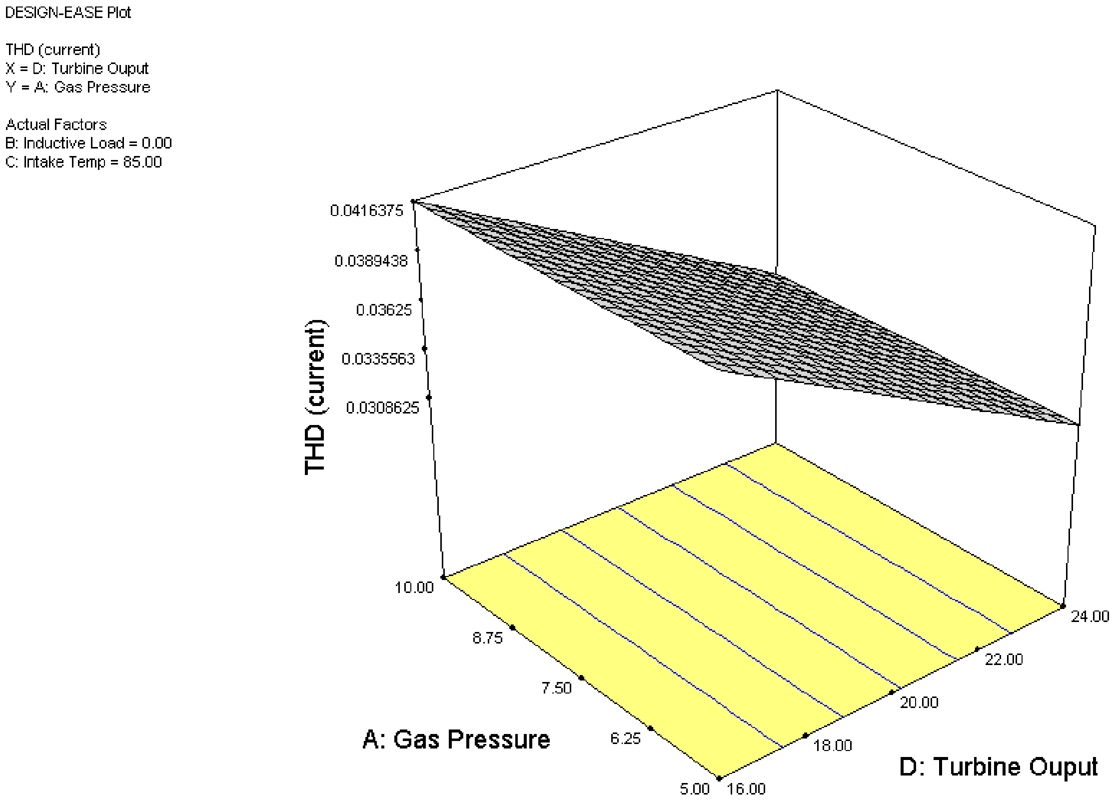


Current THD values



DESIGN-EASE Plot
THD (current)
Normal Plot of Residuals
Normal % Probability
99
95
90
80
70
50
30
20
10
5
1
-1.93
-1.05
-0.17
0.70
1.58
Studentized Residuals

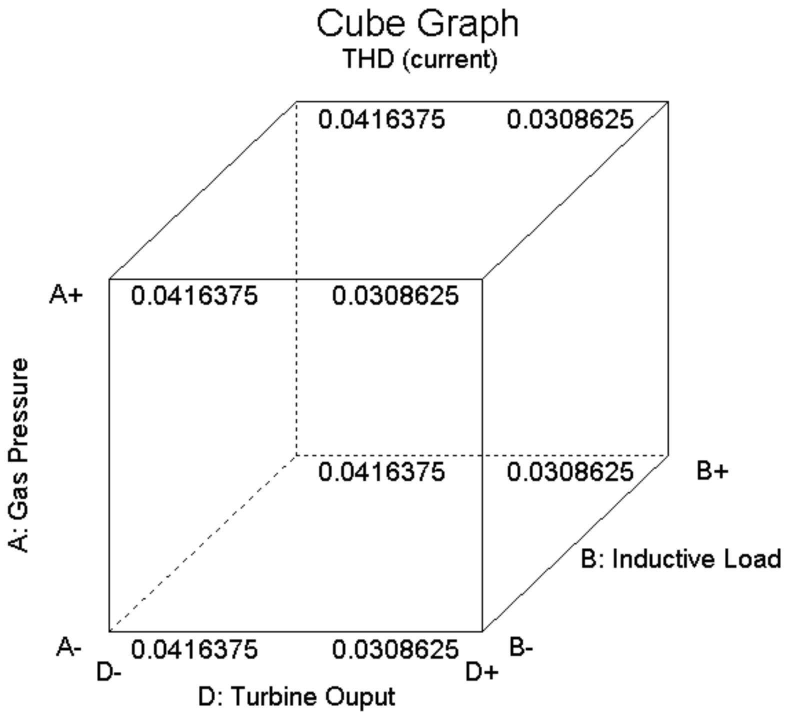

DESIGN-EASE Plot
THD (current)
X = D: Turbine Ouput
Actual Factors
A: Gas Pressure = 7.50
B: Inductive Load = 0.00
C: Intake Temp = 85.00
One Factor Plot
THD (current)
0.0439
0.03995
0.036
0.03205
0.0281
16.00
18.00
20.00
22.00
24.00
D: Turbine Ouput


DESIGN-EASE Plot
THD (current)
X = D: Turbine Ouput
Y = A: Gas Pressure
Actual Factors
B: Inductive Load = 0.00
C: Intake Temp = 85.00
THD (current)
0.0416375
0.0389438
0.03625
0.0335563
0.0308625
A: Gas Pressure
10.00
8.75
7.50
6.25
5.00
D: Turbine Ouput
16.00
18.00
20.00
22.00
24.00

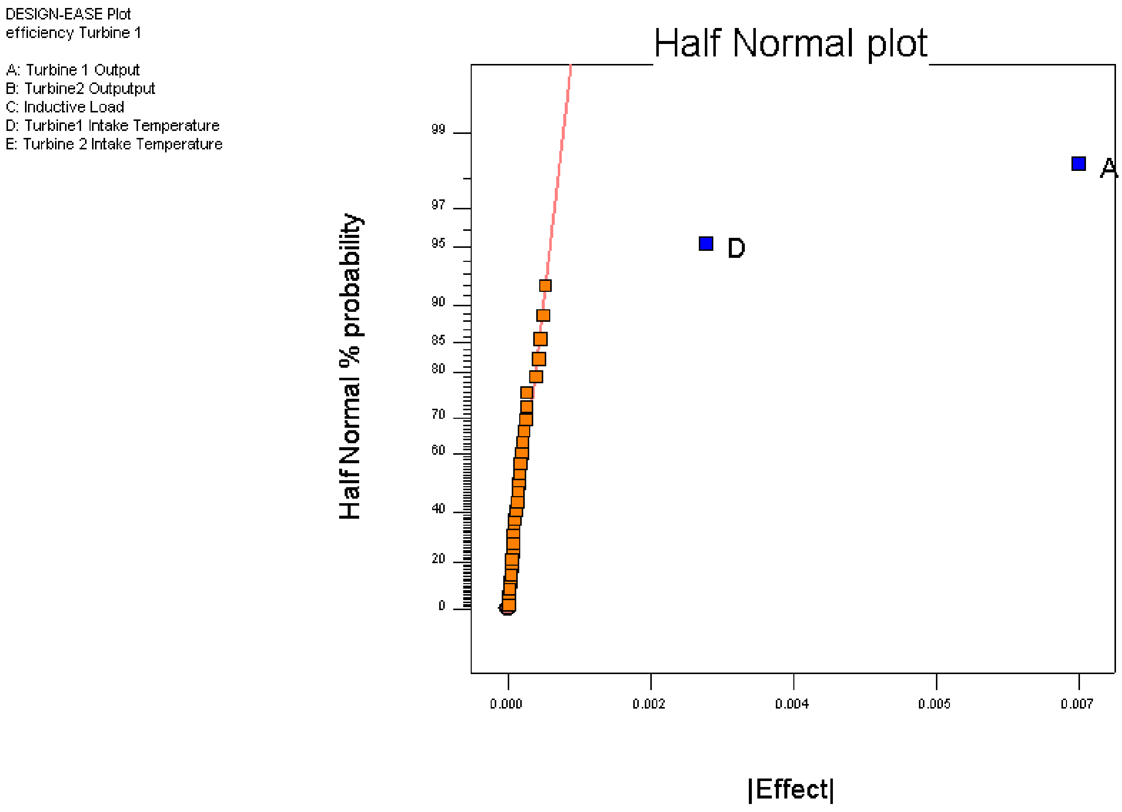
DESIGN-EASE Plot

THD (current)
X = D: Turbine Ouput
Y = A: Gas Pressure
Z = B: Inductive Load

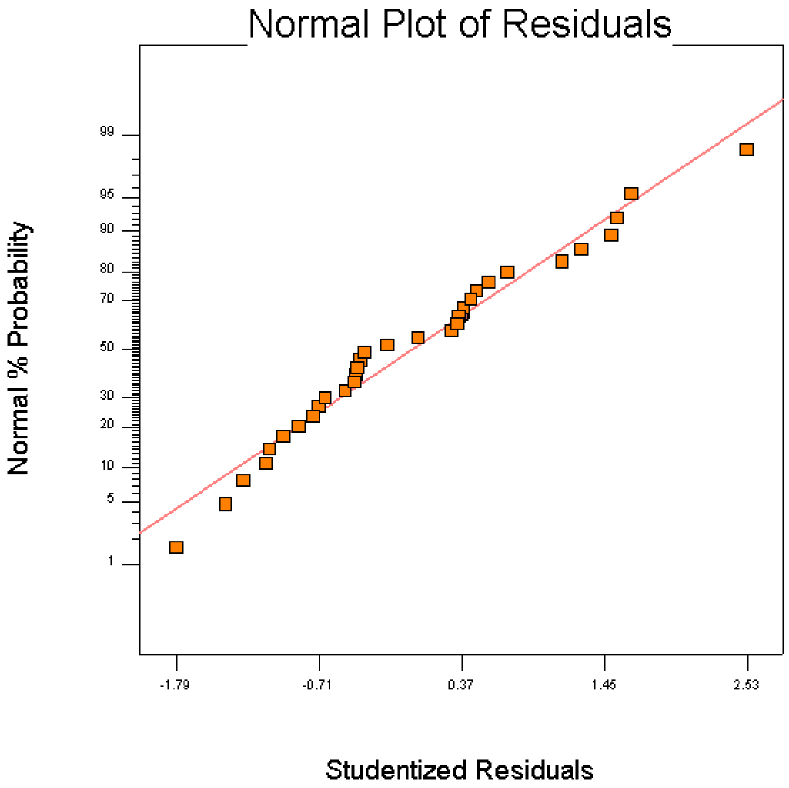
Actual Factor
C: Intake Temp = 85.00



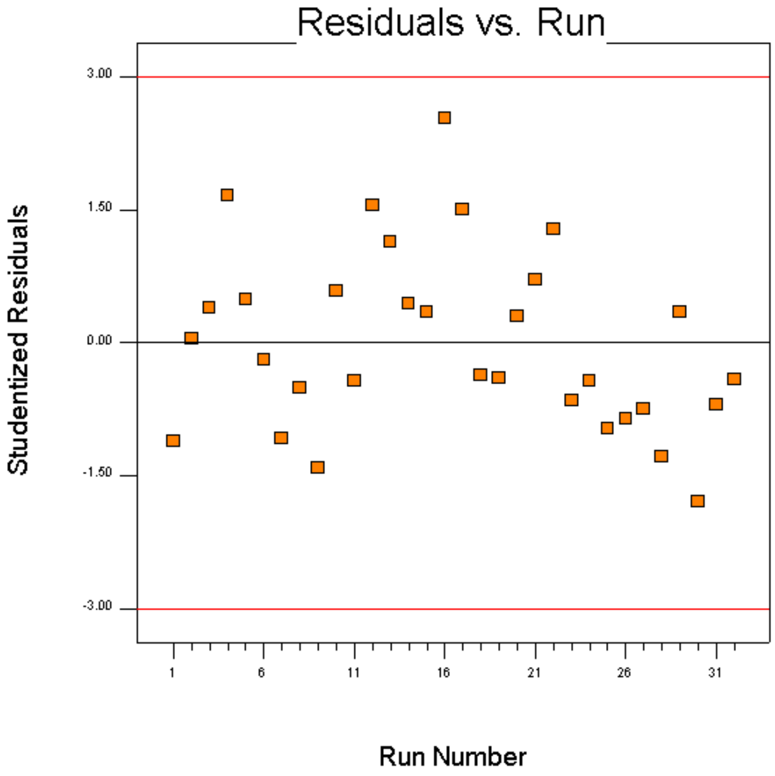
A.2 Task 3 – Test 3



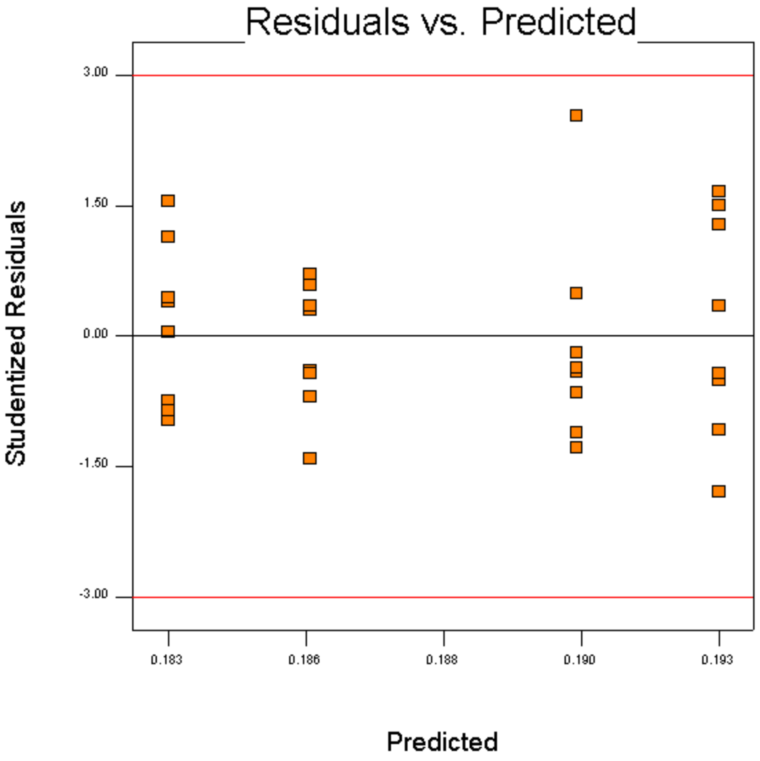
DESIGN-EASE Plot
efficiency Turbine 1



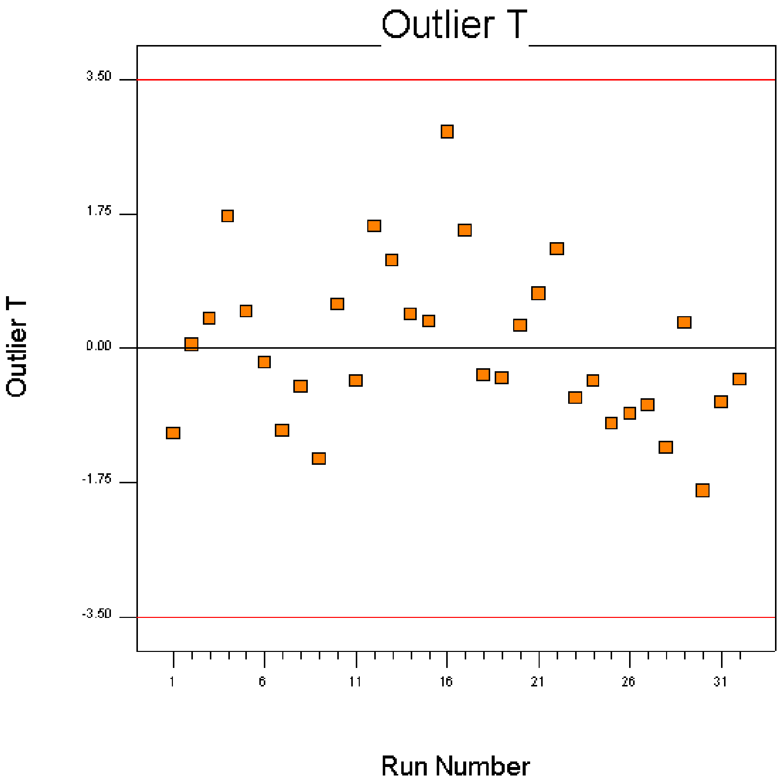
DESIGN-EASE Plot
efficiency Turbine 1



DESIGN-EASE Plot
efficiency Turbine 1



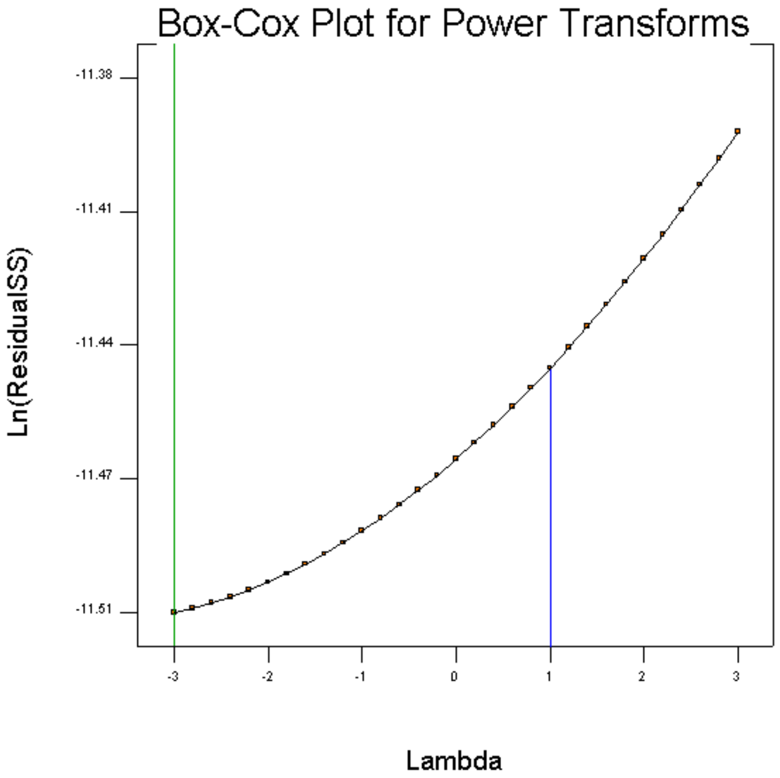
DESIGN-EASE Plot
efficiency Turbine 1

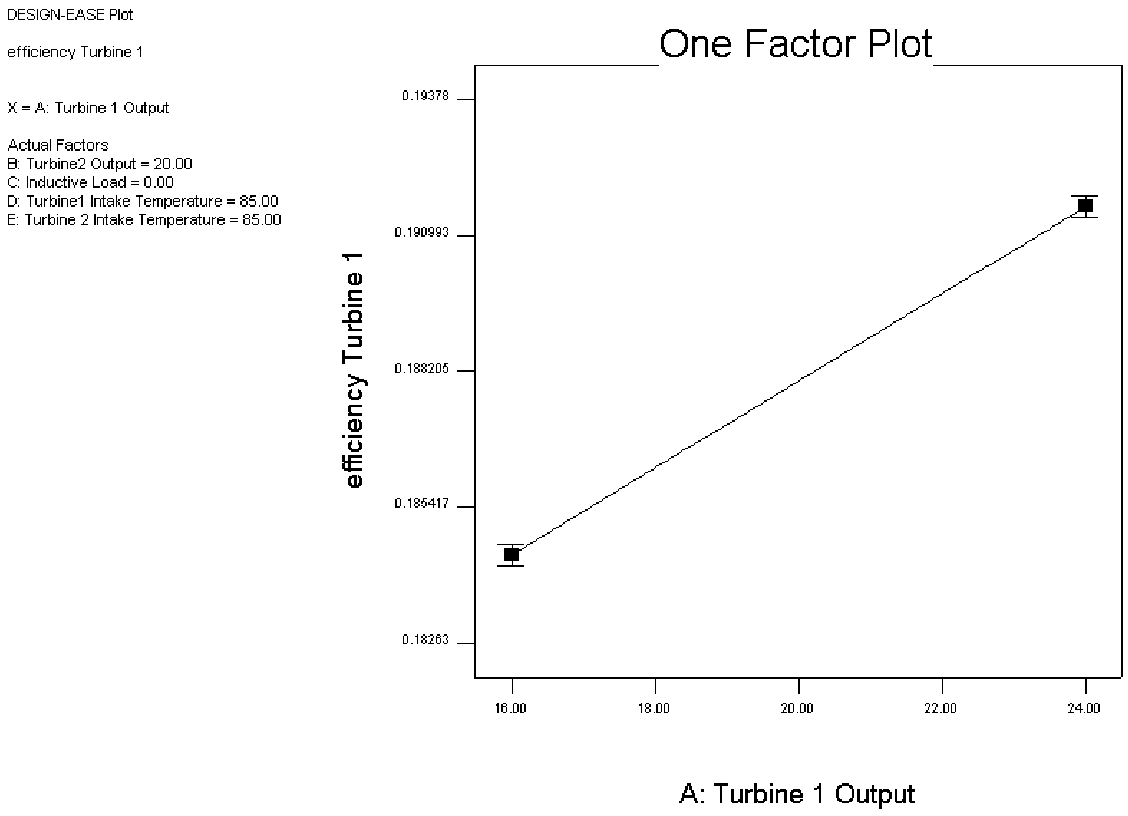


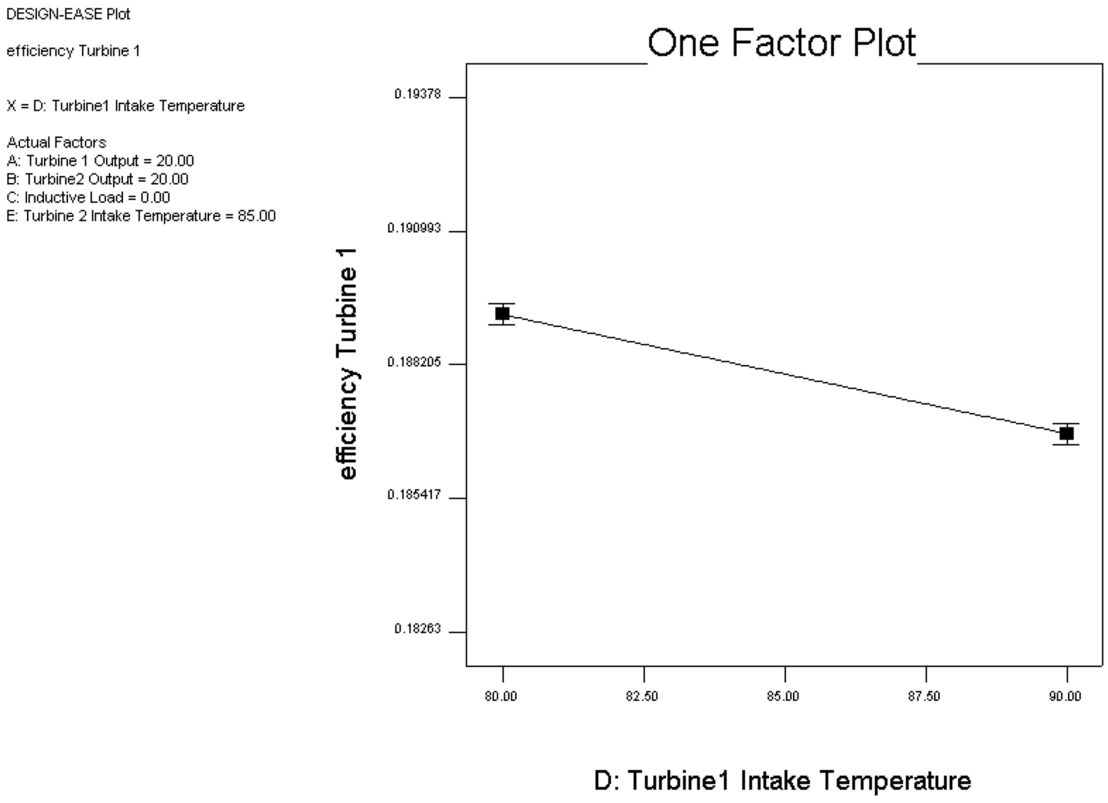
DESIGN-EASE Plot
efficiency Turbine 1

Lambda
Current = 1
Best = -3
Low C.I. =
High C.I. =

Recommend transform:
None
(Lambda = 1)



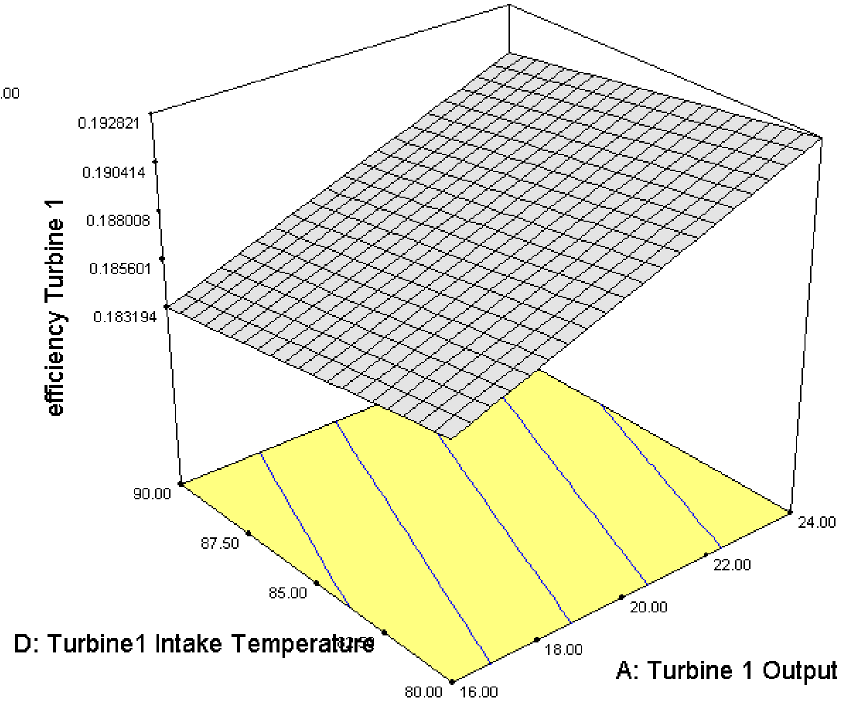

DESIGN-EASE Plot
efficiency Turbine 1
X = A: Turbine 1 Output
Actual Factors
B: Turbine2 Output = 20.00
C: Inductive Load = 0.00
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00
One Factor Plot
efficiency Turbine 1
0.19378
0.190993
0.188205
0.185417
0.18263
16.00
18.00
20.00
22.00
24.00
A: Turbine 1 Output


DESIGN-EASE Plot
efficiency Turbine 1
X = D: Turbine1 Intake Temperature
Actual Factors
A: Turbine 1 Output = 20.00
B: Turbine2 Output = 20.00
C: Inductive Load = 0.00
E: Turbine 2 Intake Temperature = 85.00
One Factor Plot
efficiency Turbine 1
0.19378
0.190993
0.188205
0.185417
0.18263
80.00
82.50
85.00
87.50
90.00
D: Turbine1 Intake Temperature

DESIGN-EASE Plot

efficiency Turbine 1
X = A: Turbine 1 Output
Y = D: Turbine1 Intake Temperature

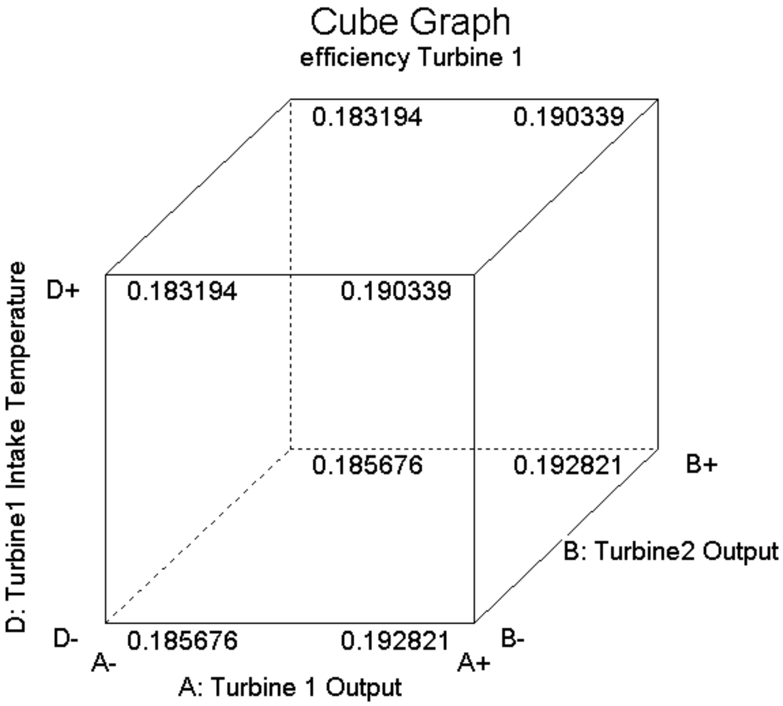
Actual Factors
B: Turbine2 Output = 20.00
C: Inductive Load = 0.00
E: Turbine 2 Intake Temperature = 85.00

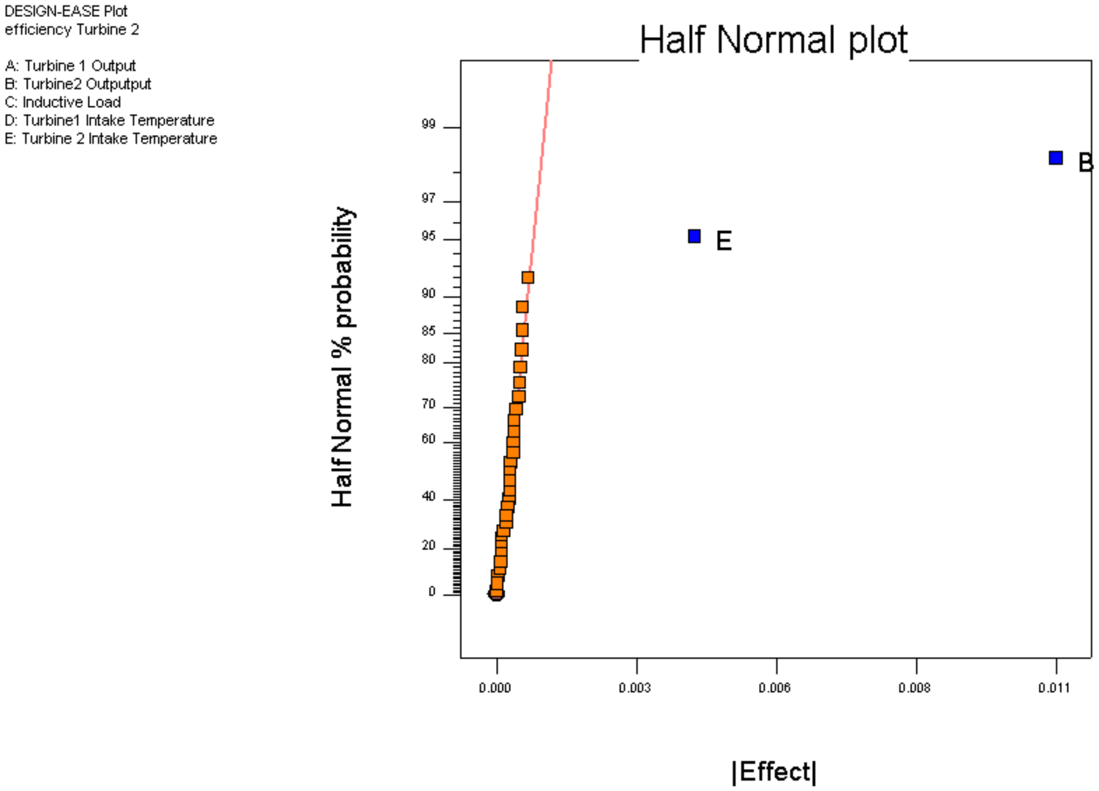


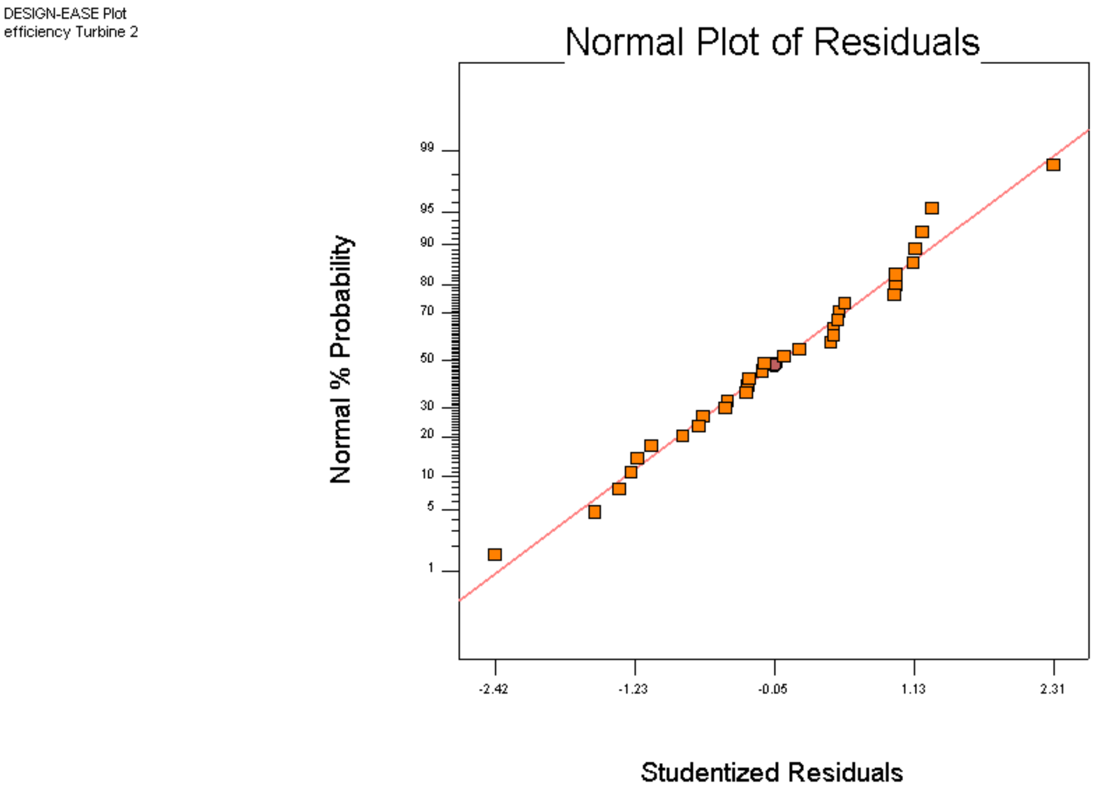
DESIGN-EASE Plot

efficiency Turbine 1
X = A: Turbine 1 Output
Y = D: Turbine1 Intake Temperature
Z = B: Turbine2 Output

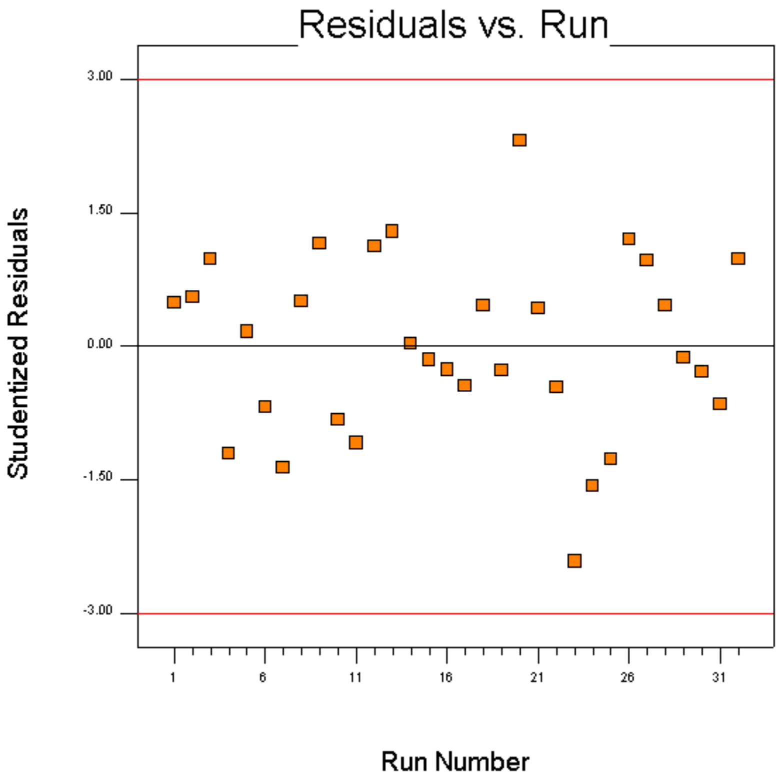
Actual Factors
C: Inductive Load = 0.00
E: Turbine 2 Intake Temperature = 85.00




DESIGN-EASE Plot
efficiency Turbine 2
A: Turbine 1 Output
B: Turbine2 Outputput
C: Inductive Load
D: Turbine1 Intake Temperature
E: Turbine 2 Intake Temperature
Half Normal plot
Half Normal % probability
99
97
95
90
85
80
70
60
40
20
0
B
E
0.000
0.003
0.006
0.008
0.011
|Effect|


DESIGN-EASE Plot
efficiency Turbine 2
Normal Plot of Residuals
Normal % Probability
99
95
90
80
70
50
30
20
10
5
1
-2.42
-1.23
-0.05
1.13
2.31
Studentized Residuals

DESIGN-EASE Plot
efficiency Turbine 2

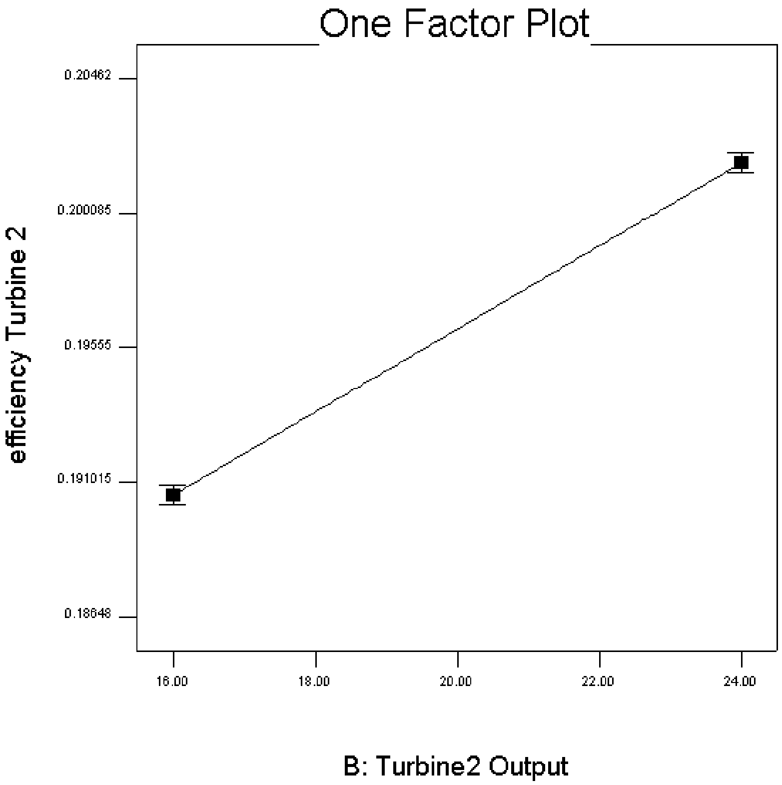


DESIGN-EASE Plot

efficiency Turbine 2

X = B: Turbine2 Output

Actual Factors
A: Turbine 1 Output = 20.00
C: Inductive Load = 0.00
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00

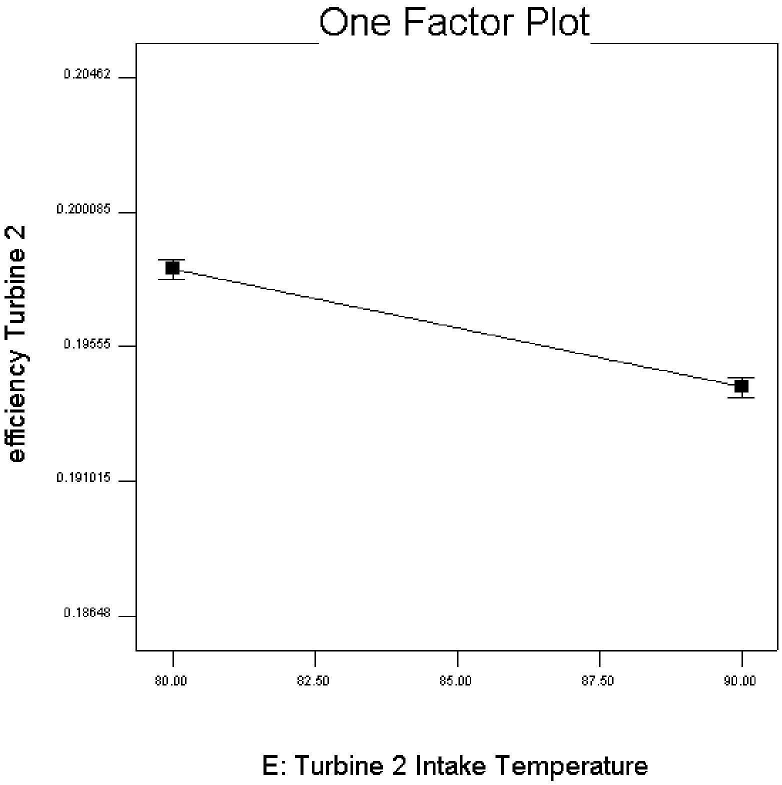


DESIGN-EASE Plot

efficiency Turbine 2

X = E: Turbine 2 Intake Temperature

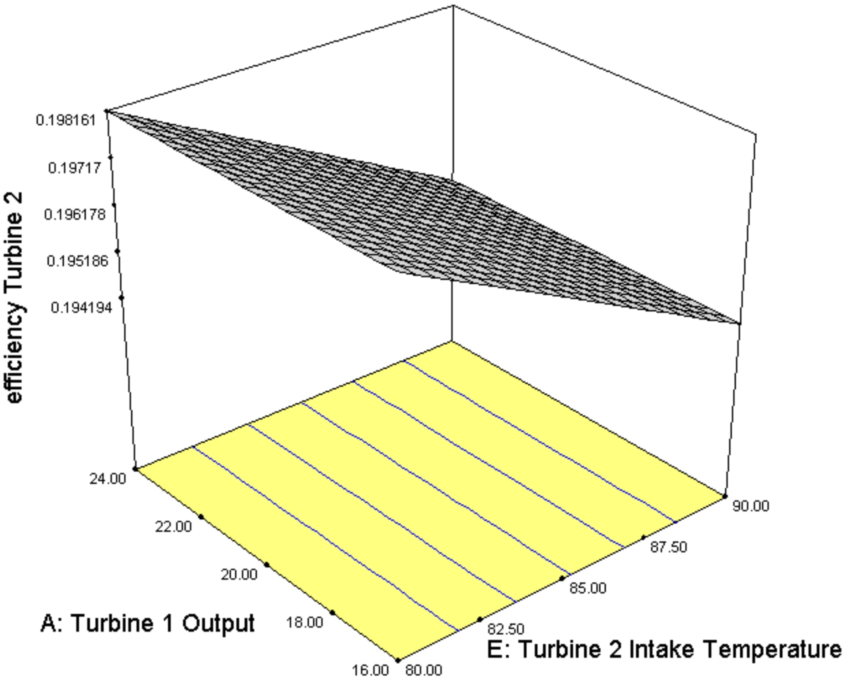
Actual Factors
A: Turbine 1 Output = 20.00
B: Turbine2 Output = 20.00
C: Inductive Load = 0.00
D: Turbine1 Intake Temperature = 85.00



DESIGN-EASE Plot

efficiency Turbine 2
X = E: Turbine 2 Intake Temperature
Y = A: Turbine 1 Output

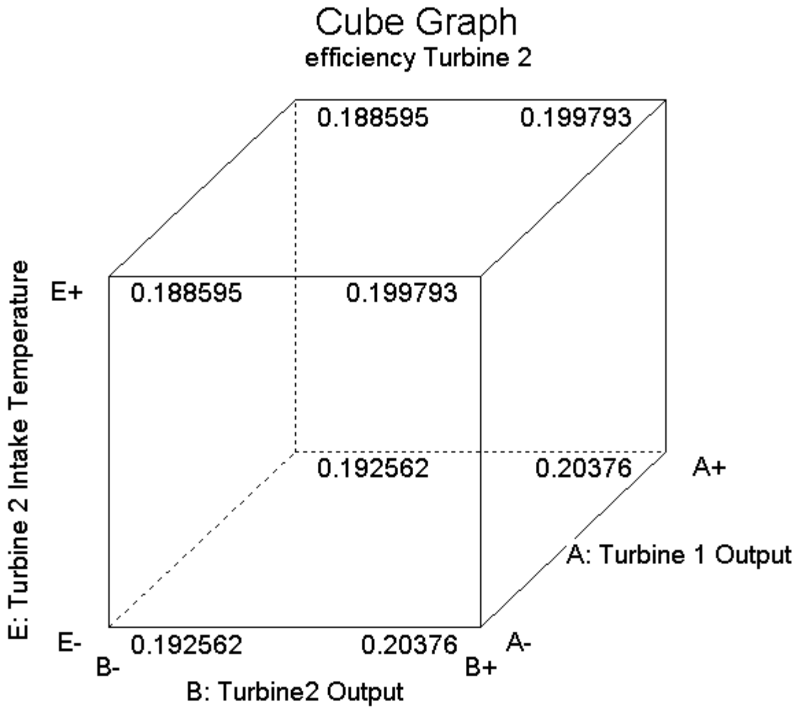
Actual Factors
B: Turbine2 Output = 20.00
C: Inductive Load = 0.00
D: Turbine1 Intake Temperature = 85.00



DESIGN-EASE Plot

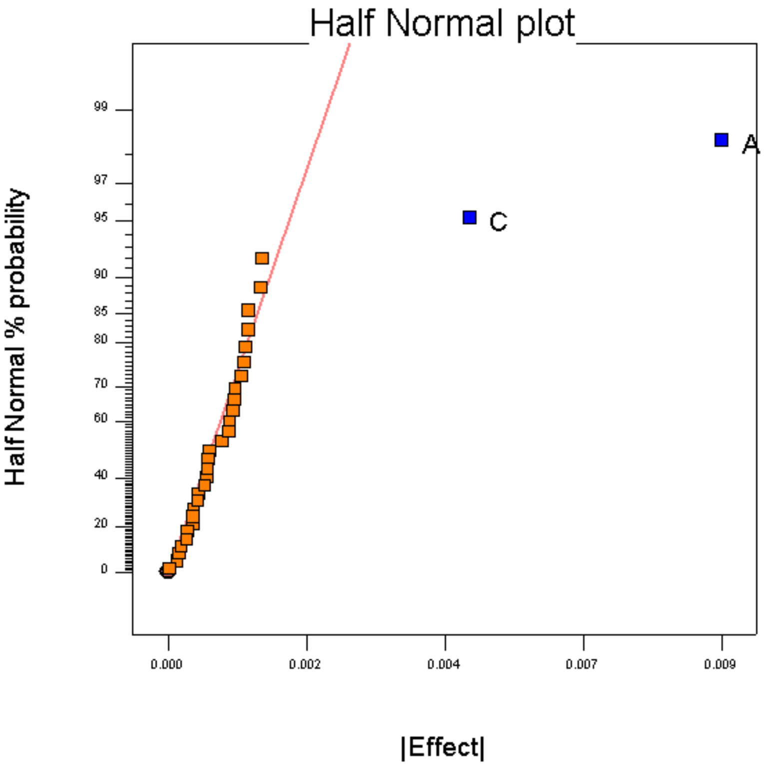
efficiency Turbine 2
X = B: Turbine2 Output
Y = E: Turbine 2 Intake Temperature
Z = A: Turbine 1 Output

Actual Factors
C: Inductive Load = 0.00
D: Turbine1 Intake Temperature = 85.00

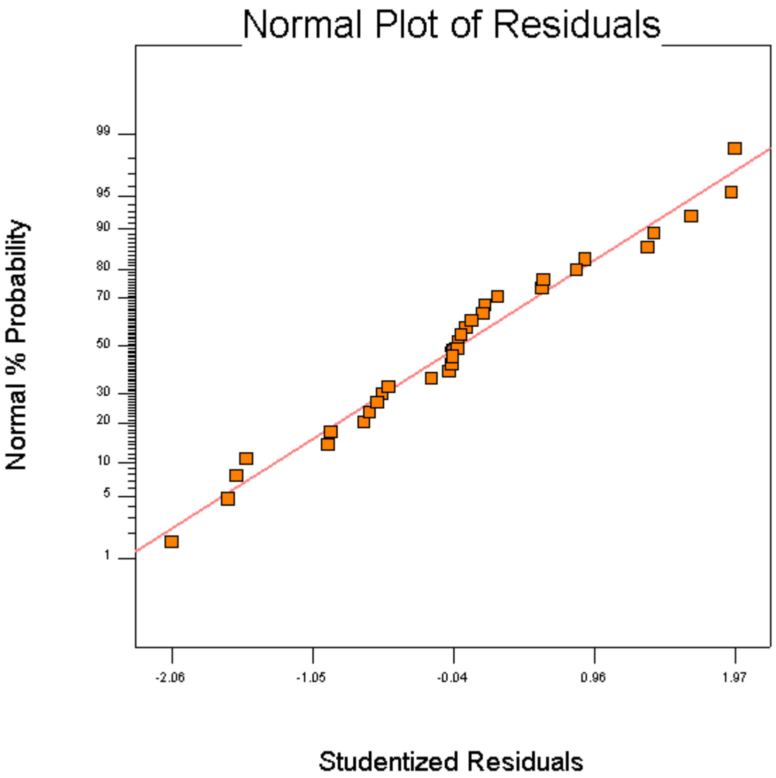


DESIGN-EASE Plot
THD Turbine 1

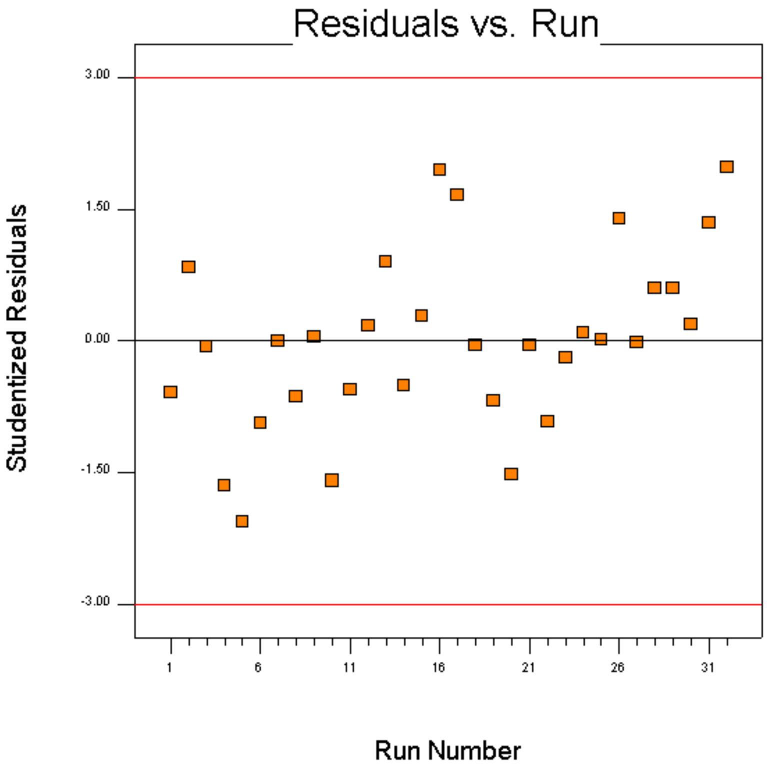
A: Turbine 1 Output
B: Turbine2 Outputput
C: Inductive Load
D: Turbine1 Intake Temperature
E: Turbine 2 Intake Temperature

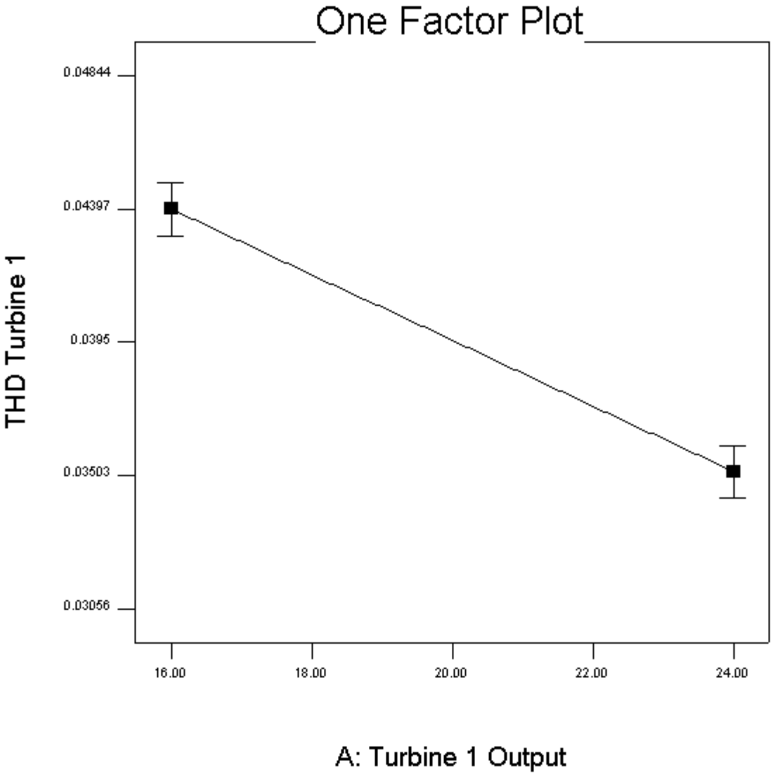


DESIGN-EASE Plot
THD Turbine 1



DESIGN-EASE Plot
THD Turbine 1



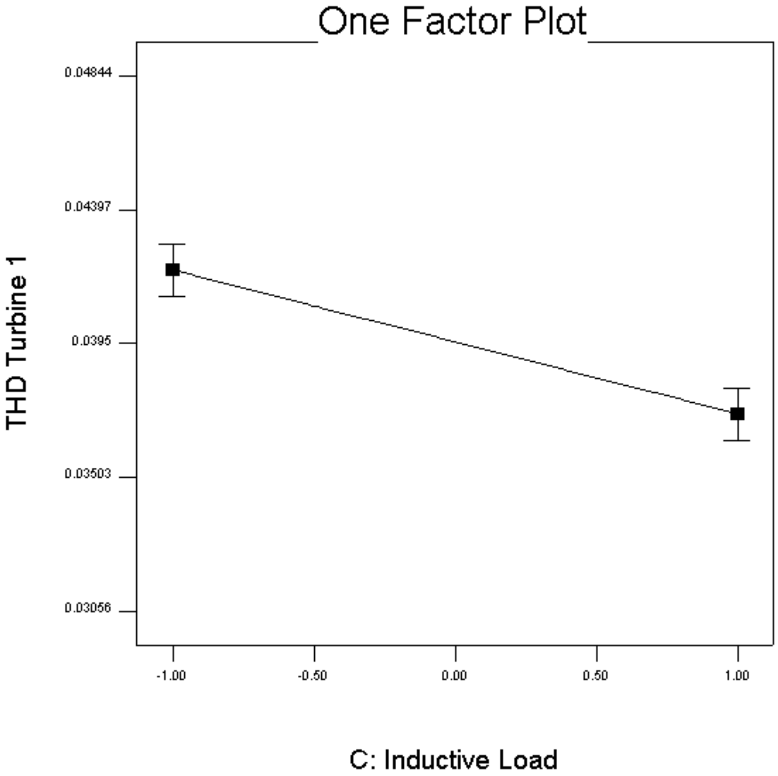


DESIGN-EASE Plot

THD Turbine 1

X = A: Turbine 1 Output

Actual Factors
B: Turbine2 Output = 20.00
C: Inductive Load = 0.00
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00

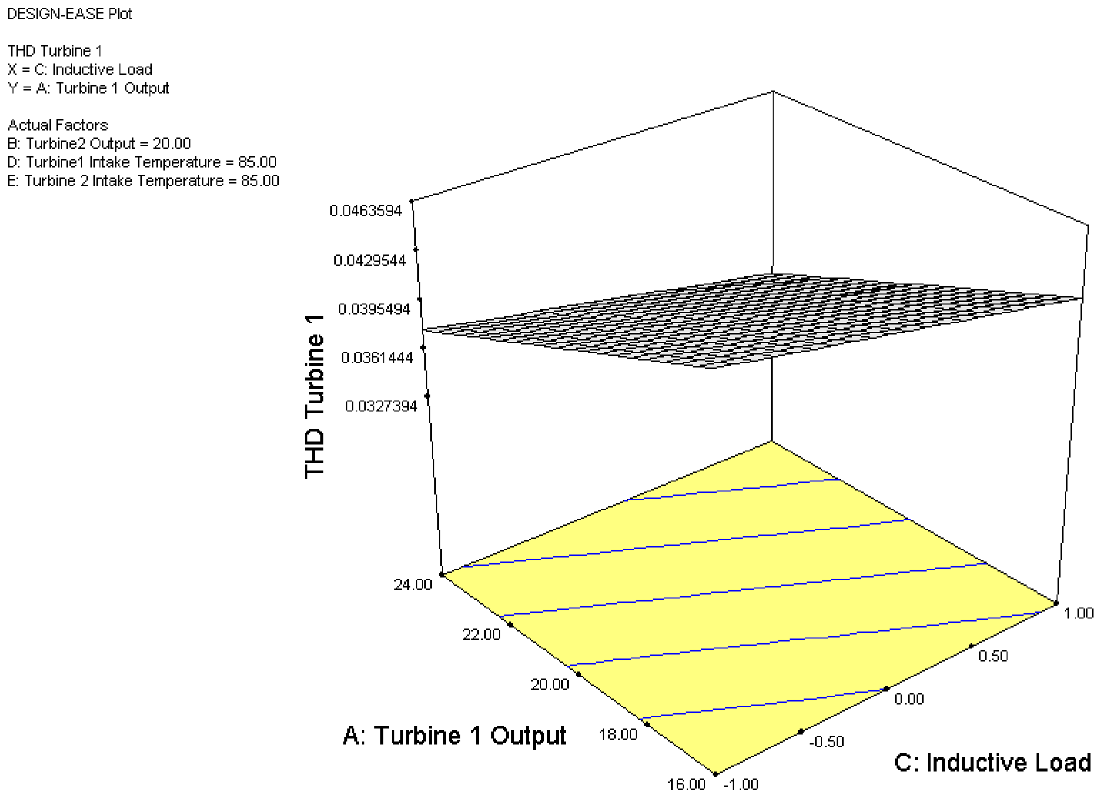


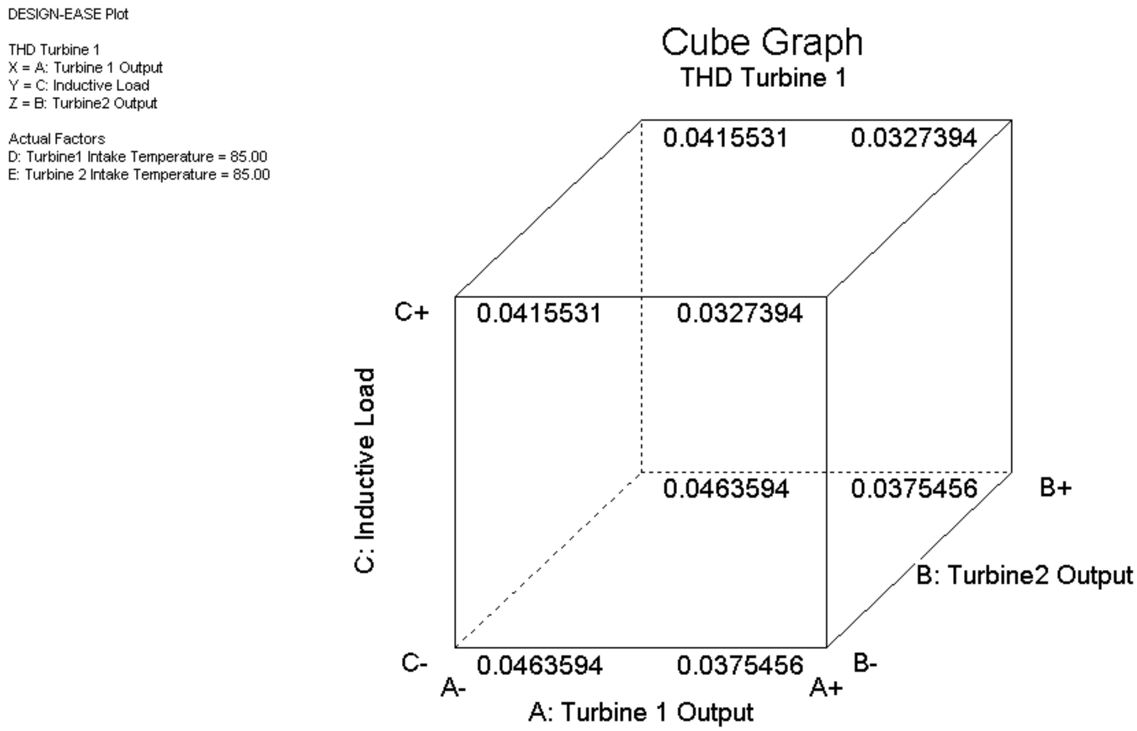
DESIGN-EASE Plot

THD Turbine 1

X = C: Inductive Load

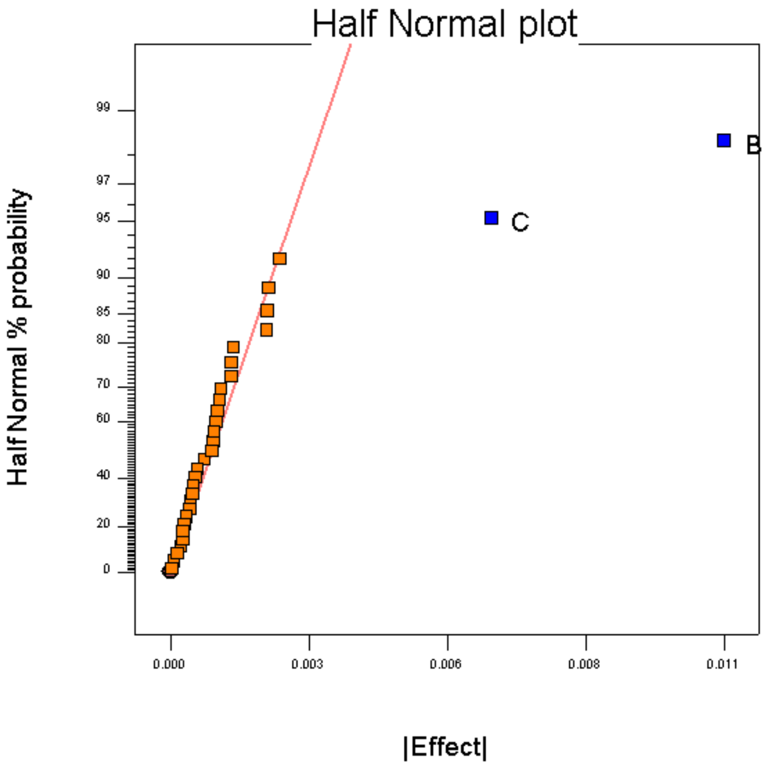
Actual Factors
A: Turbine 1 Output = 20.00
B: Turbine2 Output = 20.00
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00


DESIGN-EASE Plot
THD Turbine 1
X = C: Inductive Load
Y = A: Turbine 1 Output
Actual Factors
B: Turbine2 Output = 20.00
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00
THD Turbine 1
0.0463594
0.0429544
0.0395494
0.0361444
0.0327394
A: Turbine 1 Output
24.00
22.00
20.00
18.00
16.00
C: Inductive Load
-1.00
-0.50
0.00
0.50
1.00

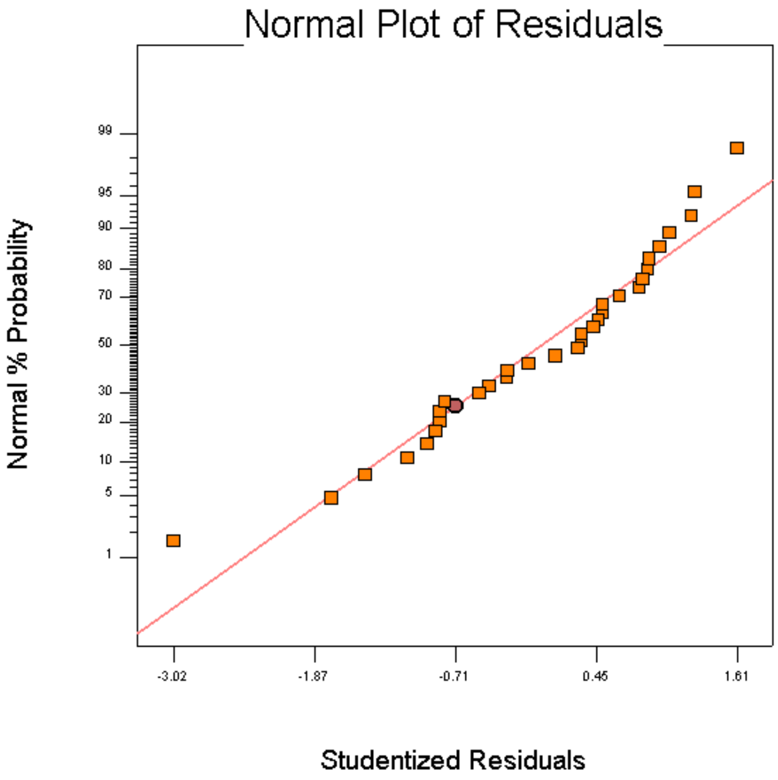

DESIGN-EASE Plot
THD Turbine 1
X = A: Turbine 1 Output
Y = C: Inductive Load
Z = B: Turbine2 Output
Actual Factors
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00
Cube Graph
THD Turbine 1
0.0415531
0.0327394
0.0415531
0.0327394
0.0463594
0.0375456
0.0463594
0.0375456
C+
C-
C: Inductive Load
A-
A+
A: Turbine 1 Output
B-
B+
B: Turbine2 Output

DESIGN-EASE Plot
THD Turbine 2

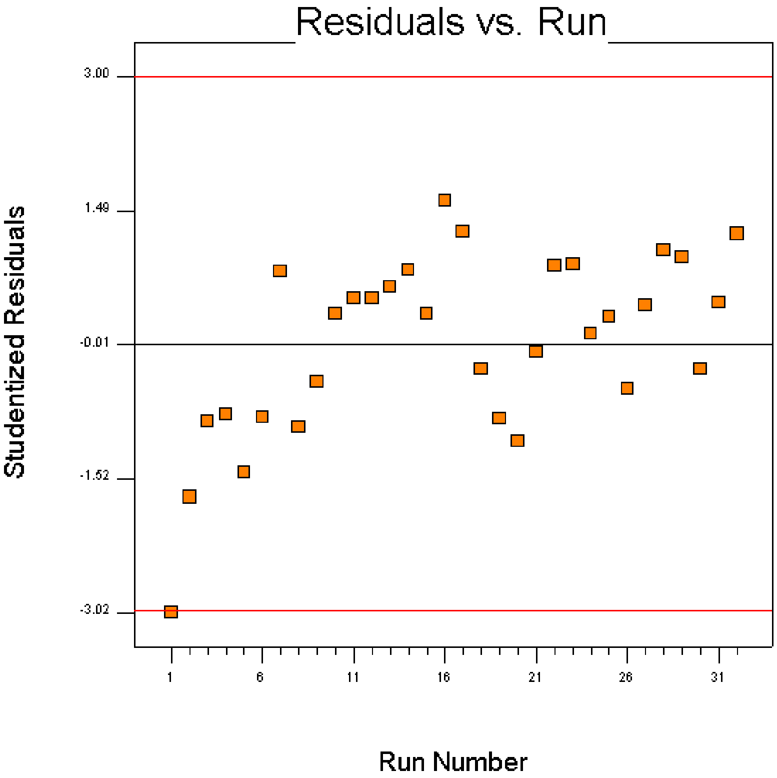
A: Turbine 1 Output
B: Turbine2 Output
C: Inductive Load
D: Turbine1 Intake Temperature
E: Turbine 2 Intake Temperature



DESIGN-EASE Plot
THD Turbine 2



DESIGN-EASE Plot
THD Turbine 2

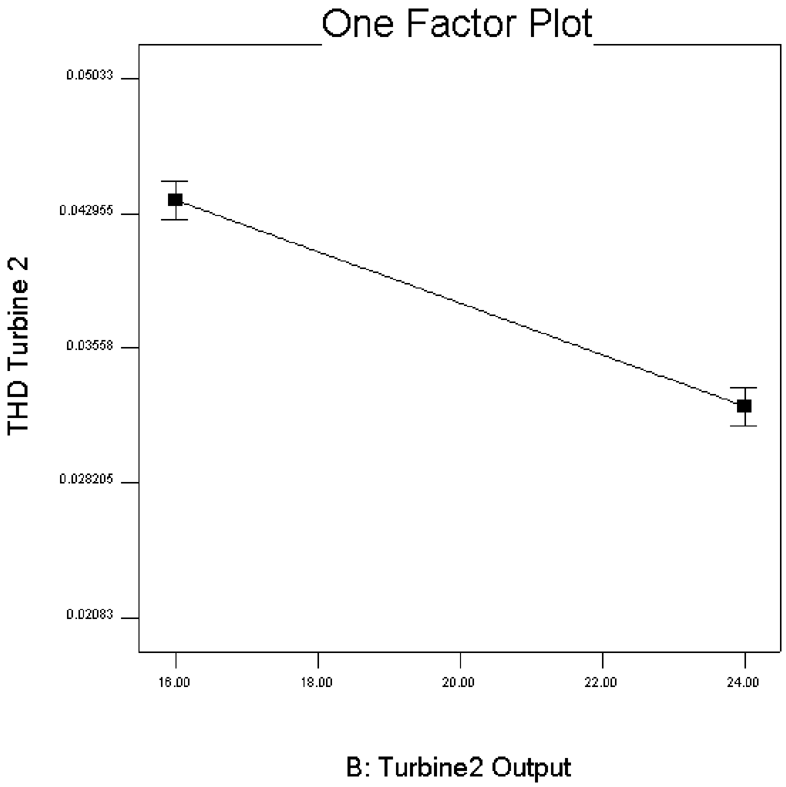


DESIGN-EASE Plot

THD Turbine 2

X = B: Turbine2 Output

Actual Factors
A: Turbine 1 Output = 20.00
C: Inductive Load = 0.00
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00

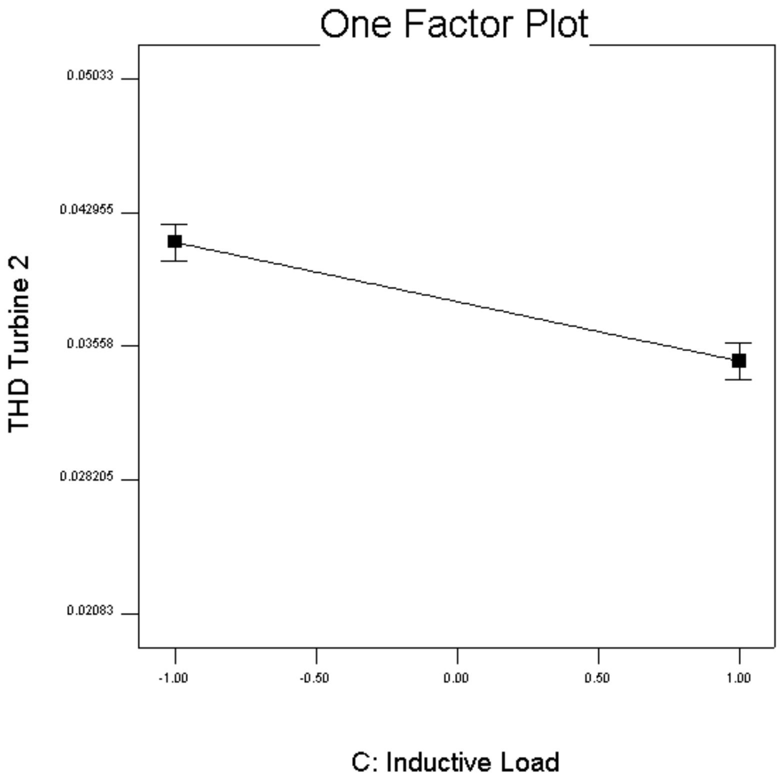


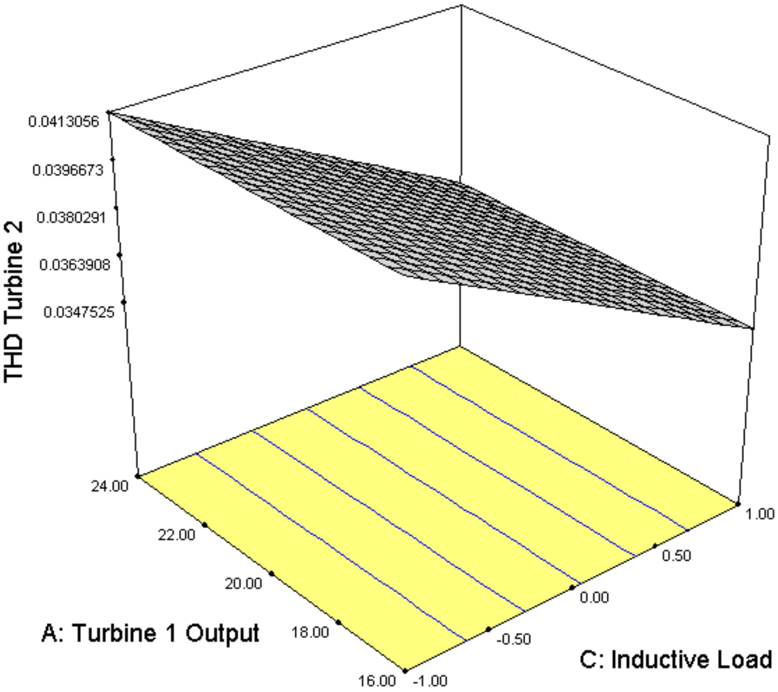
DESIGN-EASE Plot

THD Turbine 2

X = C: Inductive Load

Actual Factors
A: Turbine 1 Output = 20.00
B: Turbine2 Output = 20.00
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00

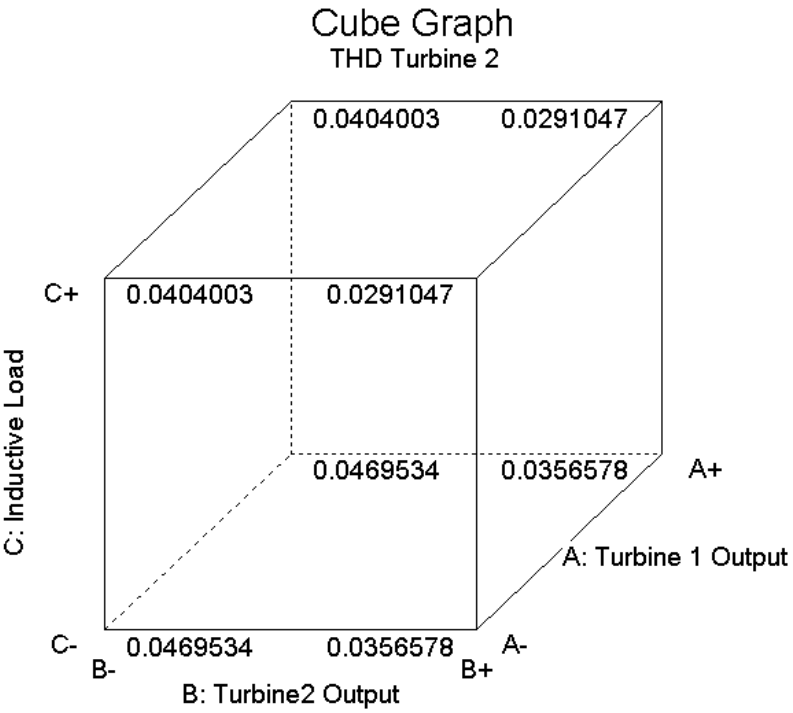




DESIGN-EASE Plot

THD Turbine 2
X = C: Inductive Load
Y = A: Turbine 1 Output

Actual Factors
B: Turbine2 Output = 20.00
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00



DESIGN-EASE Plot

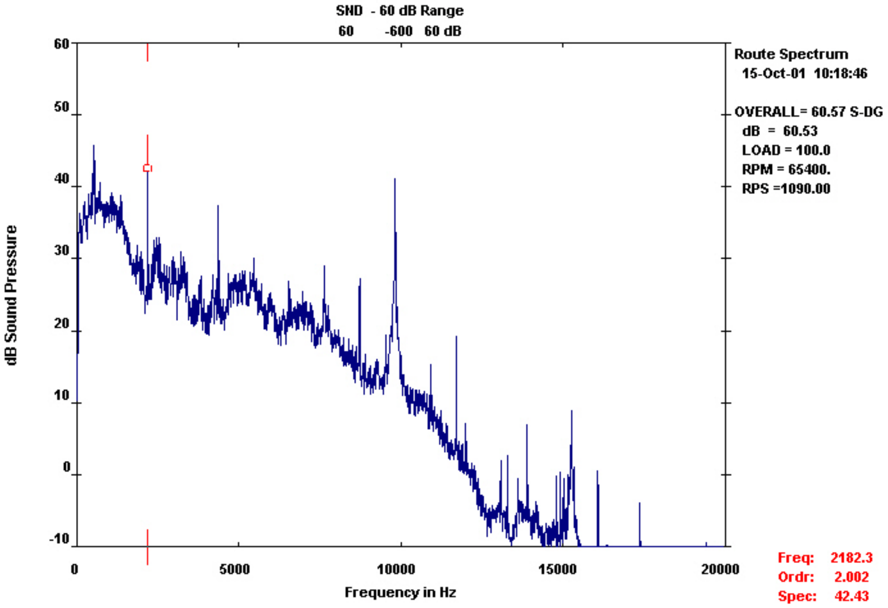
THD Turbine 2
X = B: Turbine2 Output
Y = C: Inductive Load
Z = A: Turbine 1 Output

Actual Factors
D: Turbine1 Intake Temperature = 85.00
E: Turbine 2 Intake Temperature = 85.00

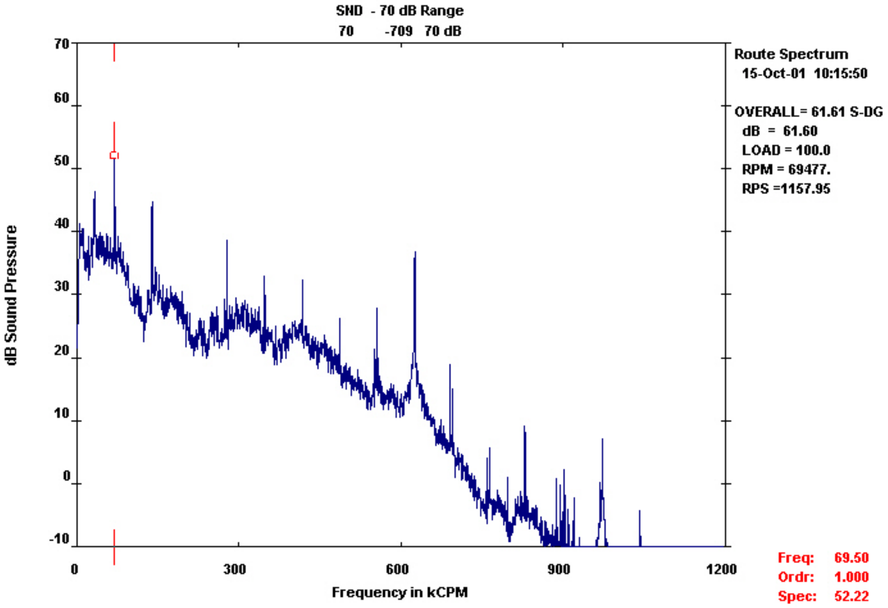
Cube Graph
THD Turbine 2

A.3 Task 3 – Test 6

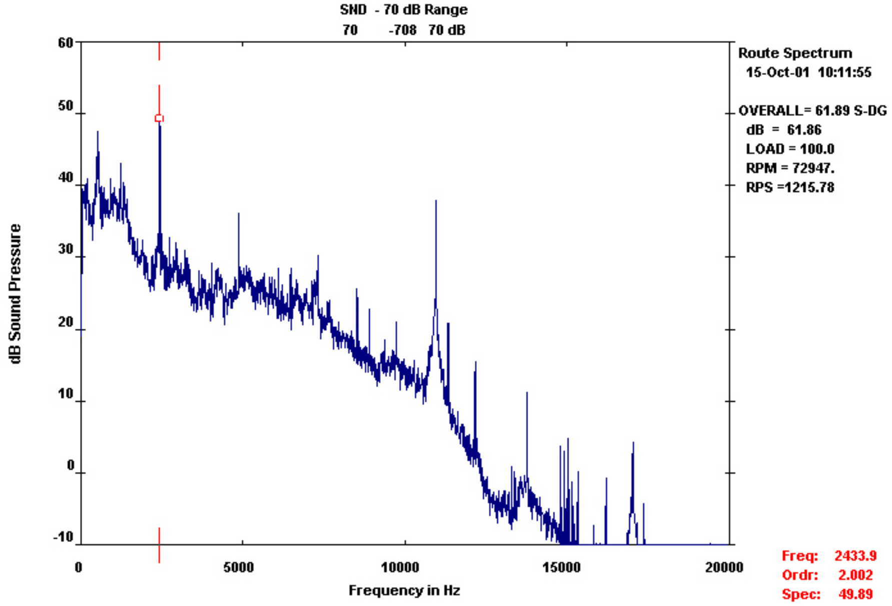
8 KW



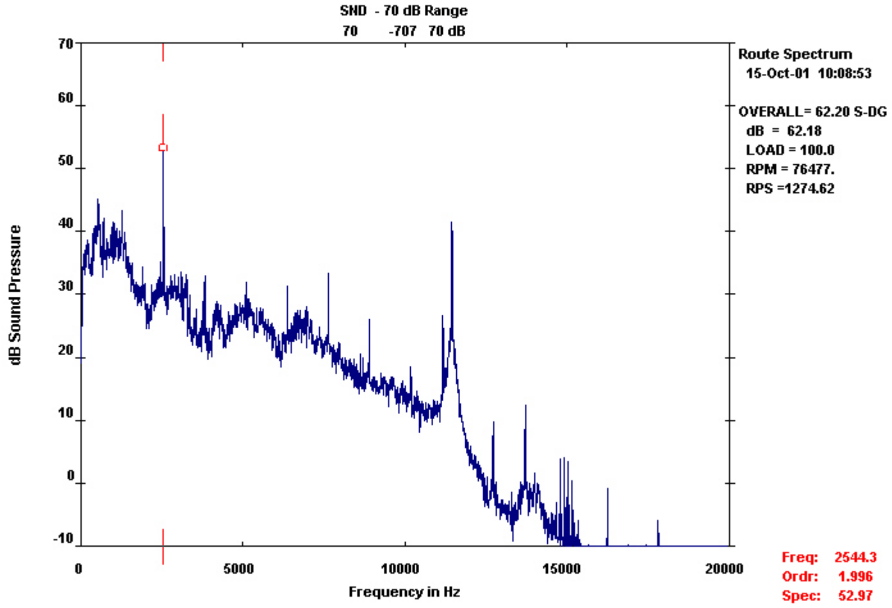
10 KW



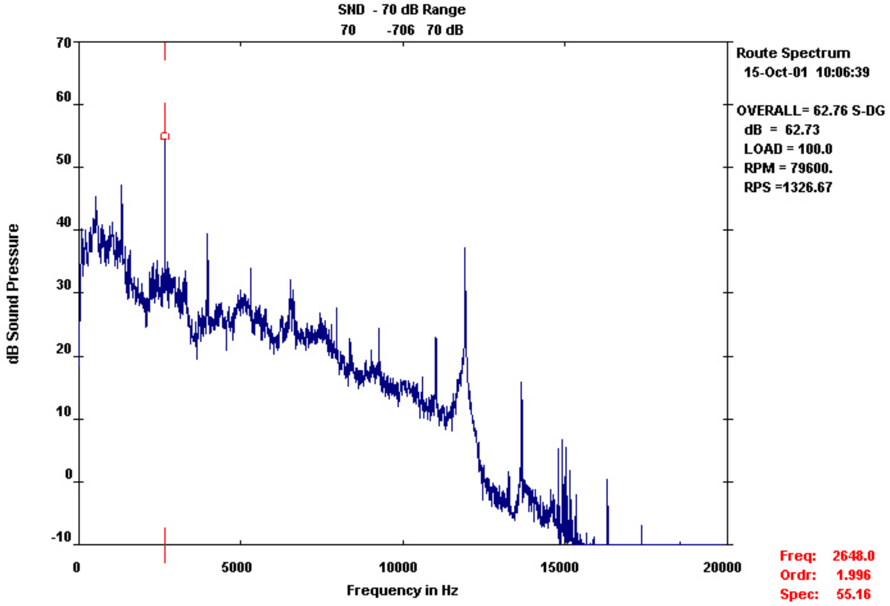
12 KW


SND - 70 dB Range
70 -708 70 dB
Route Spectrum
15-Oct-01 10:11:55
OVERALL= 61.89 S-DG
dB = 61.86
LOAD = 100.0
RPM = 72947.
RPS =1215.78
dB Sound Pressure
60
50
40
30
20
10
0
-10
0
5000
10000
15000
20000
Frequency in Hz
Freq: 2433.9
Ordr: 2.002
Spec: 49.89

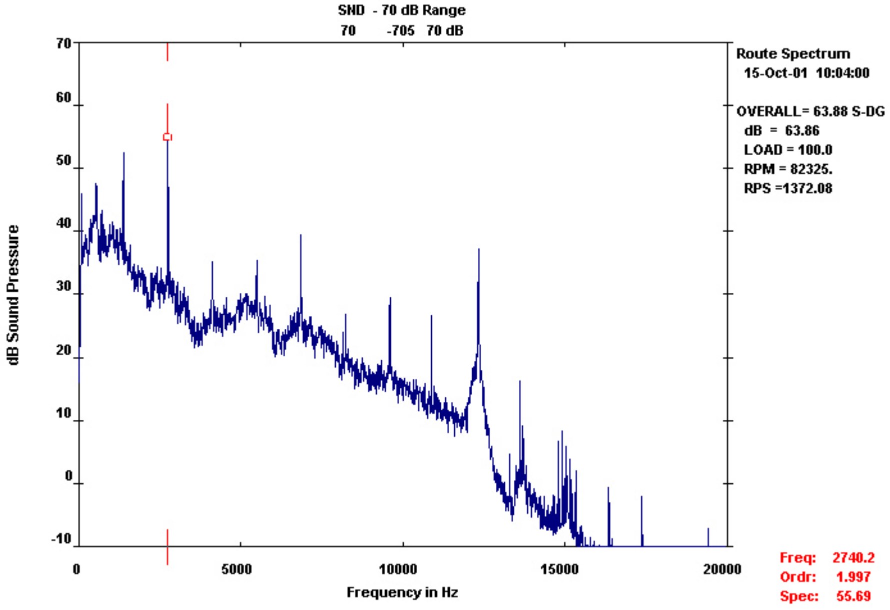
14 KW


SND - 70 dB Range
70 -707 70 dB
Route Spectrum
15-Oct-01 10:08:53
OVERALL= 62.20 S-DG
dB = 62.18
LOAD = 100.0
RPM = 76477.
RPS =1274.62
dB Sound Pressure
70
60
50
40
30
20
10
0
-10
0
5000
10000
15000
20000
Frequency in Hz
Freq: 2544.3
Ordr: 1.996
Spec: 52.97

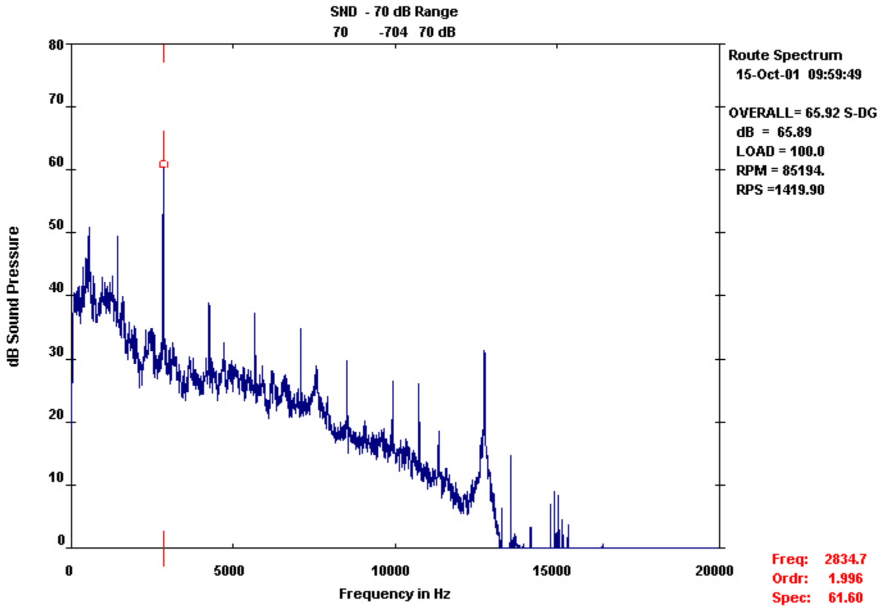
16 KW


SND - 70 dB Range
70 -706 70 dB
70
60
50
40
30
20
10
0
-10
dB Sound Pressure
0
5000
10000
15000
20000
Frequency in Hz
Route Spectrum
15-Oct-01 10:06:39
OVERALL= 62.76 S-DG
dB = 62.73
LOAD = 100.0
RPM = 79600.
RPS =1326.67
Freq: 2648.0
Ordr: 1.996
Spec: 55.16

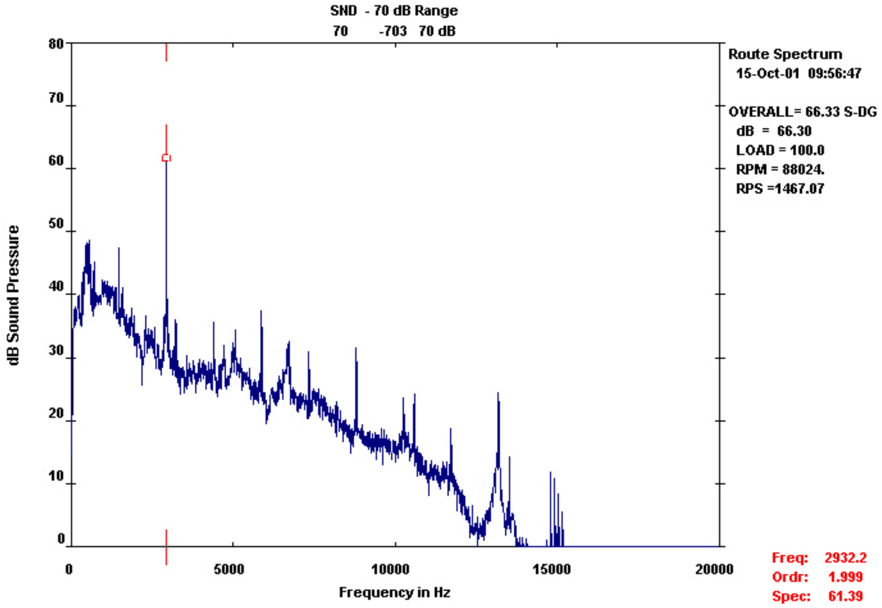
18 KW


SND - 70 dB Range
70 -705 70 dB
70
60
50
40
30
20
10
0
-10
dB Sound Pressure
0
5000
10000
15000
20000
Frequency in Hz
Route Spectrum
15-Oct-01 10:04:00
OVERALL= 63.88 S-DG
dB = 63.86
LOAD = 100.0
RPM = 82325.
RPS =1372.08
Freq: 2740.2
Ordr: 1.997
Spec: 55.69

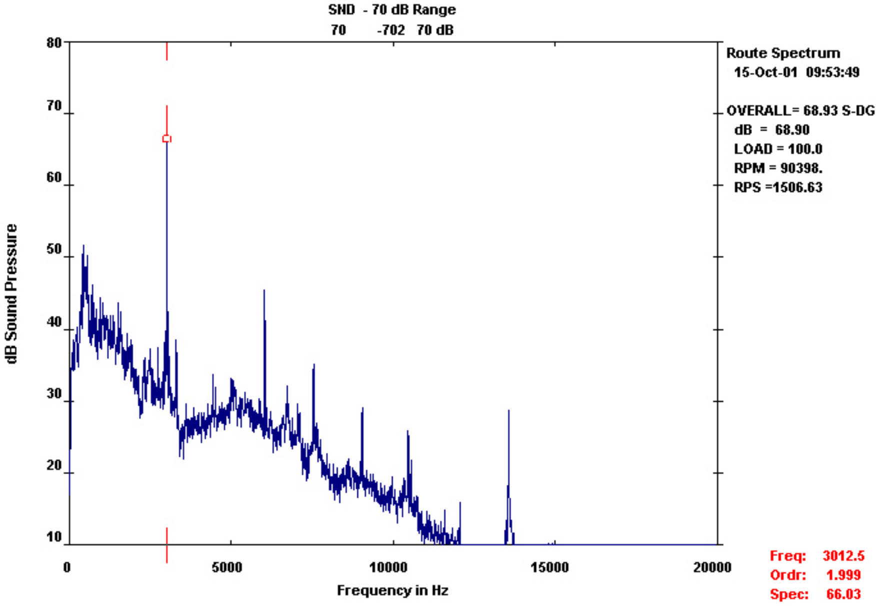
20 KW


SND - 70 dB Range
70 -704 70 dB
80
70
60
50
40
30
20
10
0
dB Sound Pressure
0
5000
10000
15000
20000
Frequency in Hz
Route Spectrum
15-Oct-01 09:59:49
OVERALL= 65.92 S-DG
dB = 65.89
LOAD = 100.0
RPM = 85194.
RPS =1419.90
Freq: 2834.7
Ordr: 1.996
Spec: 61.60

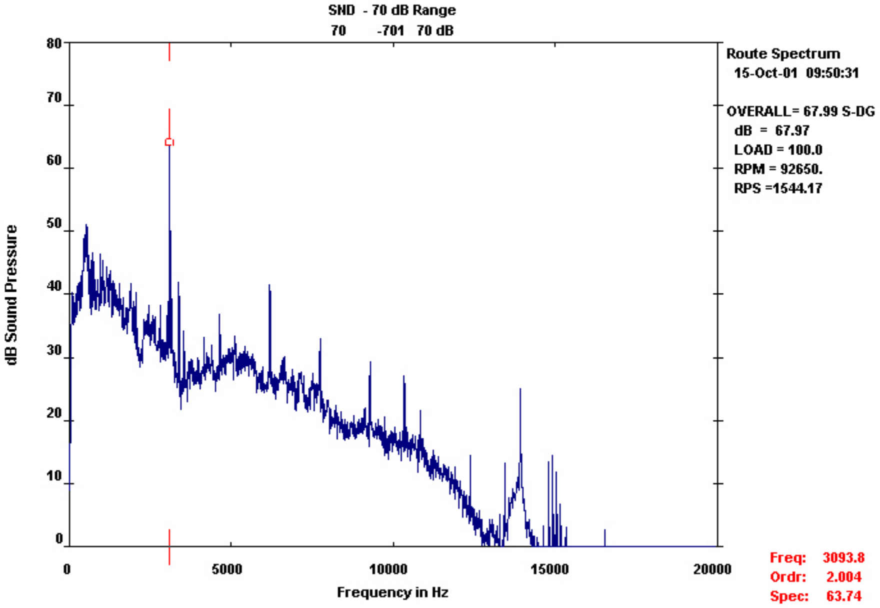
22 KW


SND - 70 dB Range
70 -703 70 dB
80
70
60
50
40
30
20
10
0
dB Sound Pressure
0
5000
10000
15000
20000
Frequency in Hz
Route Spectrum
15-Oct-01 09:56:47
OVERALL= 66.33 S-DG
dB = 66.30
LOAD = 100.0
RPM = 88024.
RPS =1467.07
Freq: 2932.2
Ordr: 1.999
Spec: 61.39

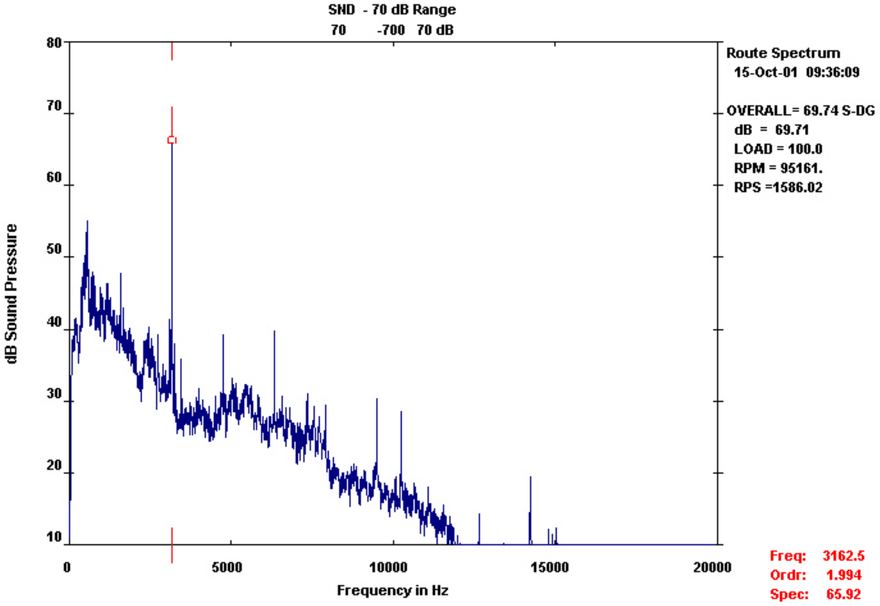
24 KW


SND - 70 dB Range
70 -702 70 dB
80
70
60
50
40
30
20
10
dB Sound Pressure
0
5000
10000
15000
20000
Frequency in Hz
Route Spectrum
15-Oct-01 09:53:49
OVERALL= 68.93 S-DG
dB = 68.90
LOAD = 100.0
RPM = 90398.
RPS =1506.63
Freq: 3012.5
Ordr: 1.999
Spec: 66.03

26 KW

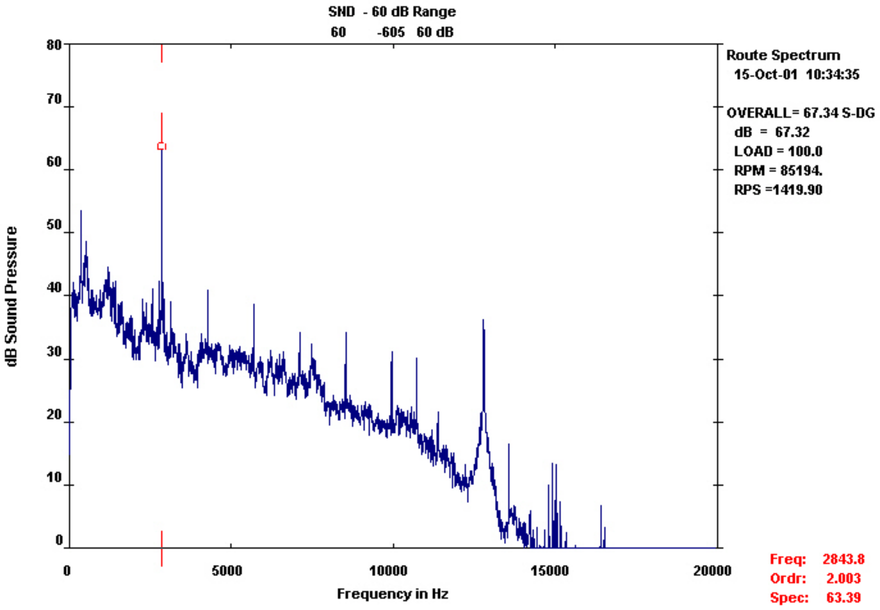

SND - 70 dB Range
70 -701 70 dB
80
70
60
50
40
30
20
10
0
dB Sound Pressure
0
5000
10000
15000
20000
Frequency in Hz
Route Spectrum
15-Oct-01 09:50:31
OVERALL= 67.99 S-DG
dB = 67.97
LOAD = 100.0
RPM = 92650.
RPS =1544.17
Freq: 3093.8
Ordr: 2.004
Spec: 63.74

Full load: 27 KW

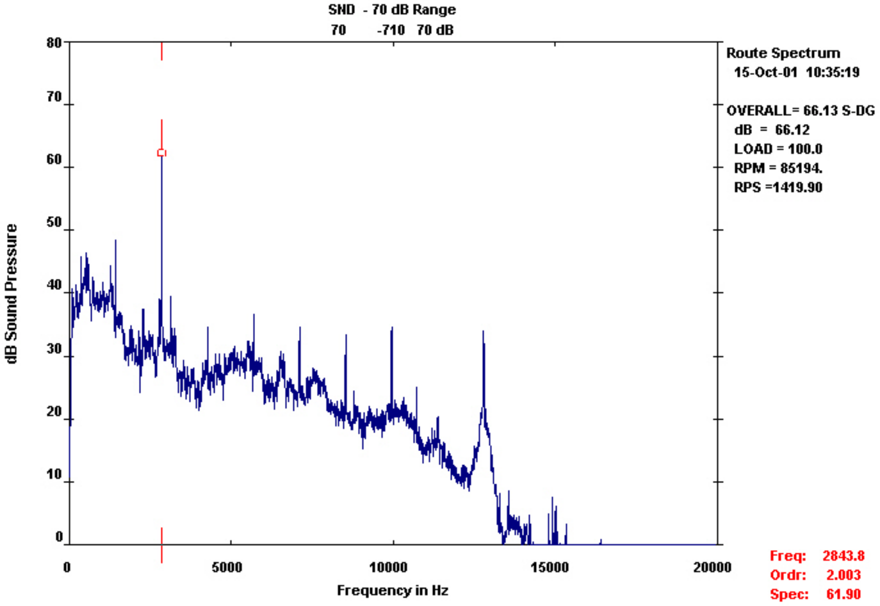


Additional readings were taken to the right and left of S11 from the turbine to ensure uniformity of the data and recognize any local acoustic effects.

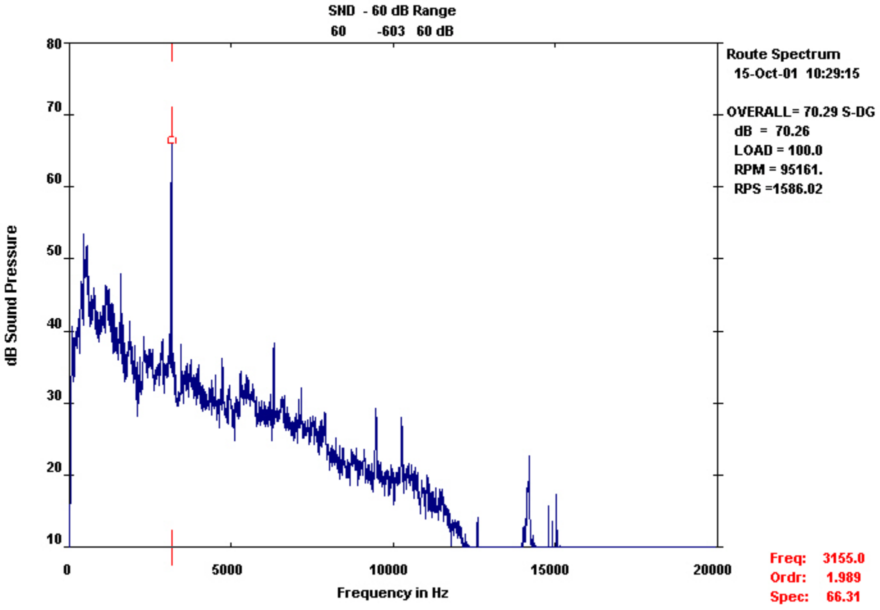
Left side 20 kW



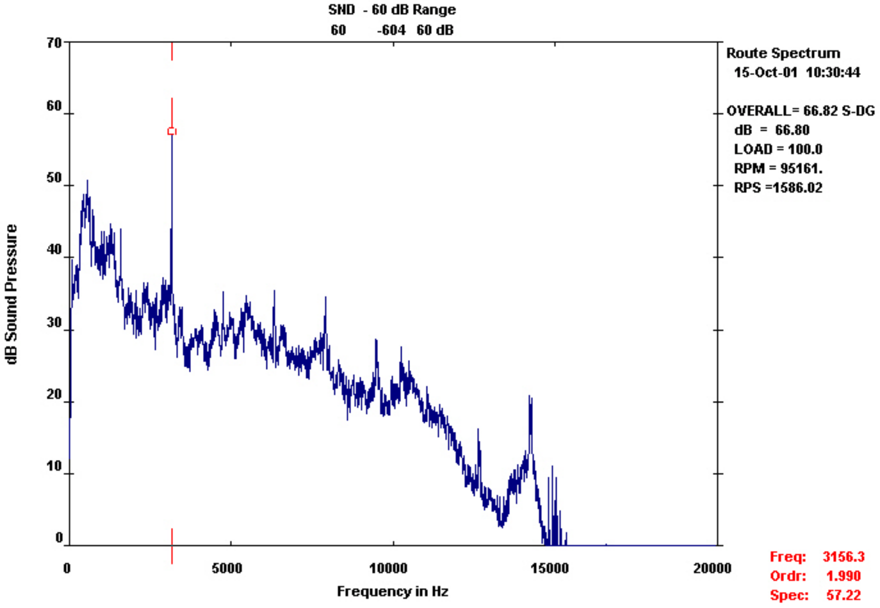
Right side 20 kW



Left side 27 kW



Right side 27 kW



A. 4 Task 3 – Test 7

8 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.019	67650
1VL	1 vertical left	0.0098	67650
2HL	2 horizontal left	0.015	67650
3HL	3 horizontal left	0.014	67650
4HL	4 horizontal left	0.008	67650
5HL	5 horizontal left	0.012	67650
6HL	6 horizontal left	0.01	67650
7HL	7 horizontal left	0.012	67650
1HR	1 horizontal right	0.033	67650
1VR	1 vertical left	0.011	67650
2HR	2 horizontal right	0.038	67650
3HR	3 horizontal right	0.025	67650
4HR	4 horizontal right	0.0057	67650
5HR	5 horizontal right	0.021	67650
6HR	6 horizontal right	0.027	67650
7HR	7 horizontal right	0.0062	67650

10 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.02	71786
1VL	1 vertical left	0.012	71786
2HL	2 horizontal left	0.014	71786
3HL	3 horizontal left	0.011	71786
4HL	4 horizontal left	0.0076	71786
5HL	5 horizontal left	0.0081	71786
6HL	6 horizontal left	0.0079	71786
7HL	7 horizontal left	0.0076	71786
1HR	1 horizontal right	0.021	71786
1VR	1 vertical left	0.018	71786
2HR	2 horizontal right	0.022	71786
3HR	3 horizontal right	0.011	71786
4HR	4 horizontal right	0.008	71786
5HR	5 horizontal right	0.0068	71786
6HR	6 horizontal right	0.0084	71786
7HR	7 horizontal right	0.0067	71786

12 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.017	75628
1VL	1 vertical left	0.025	75628
2HL	2 horizontal left	0.022	75628
3HL	3 horizontal left	0.016	75628
4HL	4 horizontal left	0.0098	75628
5HL	5 horizontal left	0.008	75628
6HL	6 horizontal left	0.011	75628
7HL	7 horizontal left	0.0098	75628
1HR	1 horizontal right	0.017	75628
1VR	1 vertical left	0.031	75628
2HR	2 horizontal right	0.025	75628
3HR	3 horizontal right	0.015	75628
4HR	4 horizontal right	0.0056	75628
5HR	5 horizontal right	0.0079	75628
6HR	6 horizontal right	0.0085	75628
7HR	7 horizontal right	0.0077	75628

14 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.017	78946
1VL	1 vertical left	0.013	78946
2HL	2 horizontal left	0.021	78946
3HL	3 horizontal left	0.013	78946
4HL	4 horizontal left	0.0067	78946
5HL	5 horizontal left	0.0072	78946
6HL	6 horizontal left	0.0084	78946
7HL	7 horizontal left	0.0063	78946
1HR	1 horizontal right	0.02	78946
1VR	1 vertical left	0.023	78946
2HR	2 horizontal right	0.022	78946
3HR	3 horizontal right	0.01	78946
4HR	4 horizontal right	0.0062	78946
5HR	5 horizontal right	0.0099	78946
6HR	6 horizontal right	0.0092	78946
7HR	7 horizontal right	0.0063	78946

16 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.018	82324
1VL	1 vertical left	0.016	82324
2HL	2 horizontal left	0.02	82324
3HL	3 horizontal left	0.012	82324
4HL	4 horizontal left	0.0073	82324
5HL	5 horizontal left	0.01	82324
6HL	6 horizontal left	0.0083	82324
7HL	7 horizontal left	0.0063	82324
1HR	1 horizontal right	0.02	82324
1VR	1 vertical left	0.019	82324
2HR	2 horizontal right	0.019	82324
3HR	3 horizontal right	0.014	82324
4HR	4 horizontal right	0.0058	82324
5HR	5 horizontal right	0.011	82324
6HR	6 horizontal right	0.011	82324
7HR	7 horizontal right	0.006	82324

18 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.021	85344
1VL	1 vertical left	0.016	85344
2HL	2 horizontal left	0.022	85344
3HL	3 horizontal left	0.027	85344
4HL	4 horizontal left	0.011	85344
5HL	5 horizontal left	0.026	85344
6HL	6 horizontal left	0.025	85344
7HL	7 horizontal left	0.011	85344
1HR	1 horizontal right	0.024	85344
1VR	1 vertical left	0.026	85344
2HR	2 horizontal right	0.024	85344
3HR	3 horizontal right	0.019	85344
4HR	4 horizontal right	0.0061	85344
5HR	5 horizontal right	0.029	85344
6HR	6 horizontal right	0.022	85344
7HR	7 horizontal right	0.012	85344

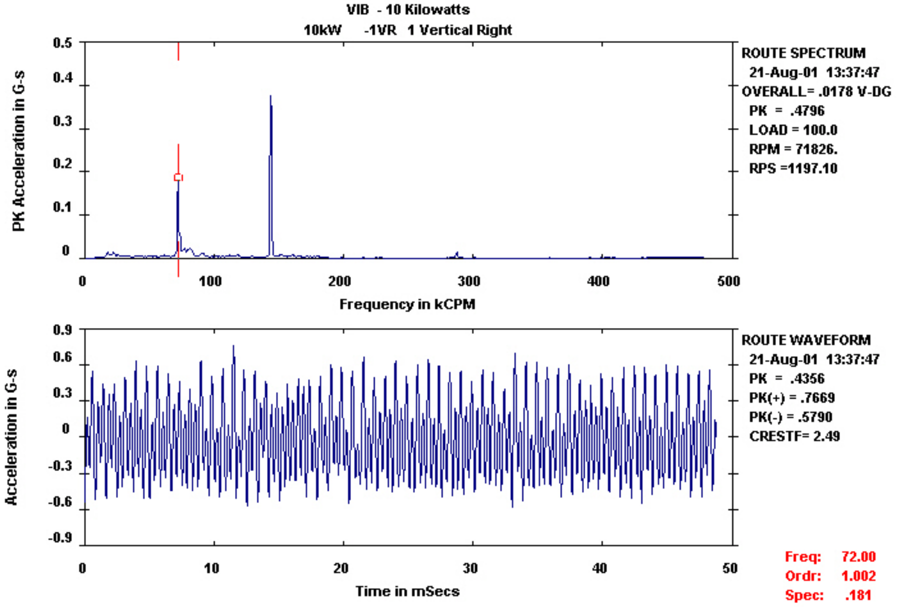
20 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.023	88464
1VL	1 vertical left	0.017	88464
2HL	2 horizontal left	0.025	88464
3HL	3 horizontal left	0.027	88464
4HL	4 horizontal left	0.0093	88464
5HL	5 horizontal left	0.024	88464
6HL	6 horizontal left	0.019	88464
7HL	7 horizontal left	0.0075	88464
1HR	1 horizontal right	0.025	88464
1VR	1 vertical left	0.024	88464
2HR	2 horizontal right	0.03	88464
3HR	3 horizontal right	0.036	88464
4HR	4 horizontal right	0.0091	88464
5HR	5 horizontal right	0.011	88464
6HR	6 horizontal right	0.017	88464
7HR	7 horizontal right	0.0072	88464

22 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.029	91784
1VL	1 vertical left	0.019	91784
2HL	2 horizontal left	0.025	91784
3HL	3 horizontal left	0.021	91784
4HL	4 horizontal left	0.015	91784
5HL	5 horizontal left	0.012	91784
6HL	6 horizontal left	0.0084	91784
7HL	7 horizontal left	0.0089	91784
1HR	1 horizontal right	0.028	91784
1VR	1 vertical left	0.022	91784
2HR	2 horizontal right	0.039	91784
3HR	3 horizontal right	0.018	91784
4HR	4 horizontal right	0.013	91784
5HR	5 horizontal right	0.017	91784
6HR	6 horizontal right	0.011	91784
7HR	7 horizontal right	0.0086	91784

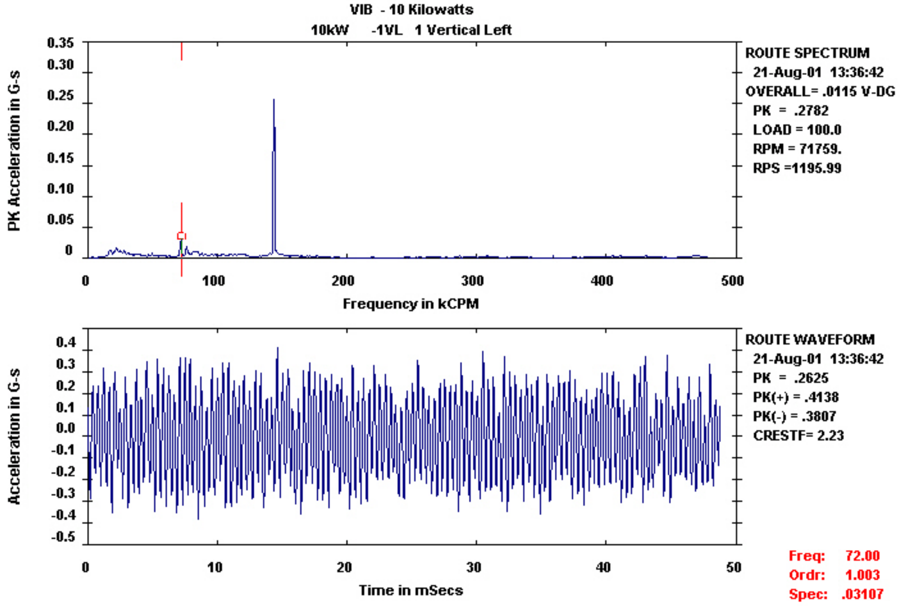
24 kW	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.026	94348
1VL	1 vertical left	0.019	94348
2HL	2 horizontal left	0.025	94348
3HL	3 horizontal left	0.017	94348
4HL	4 horizontal left	0.0071	94348
5HL	5 horizontal left	0.011	94348
6HL	6 horizontal left	0.01	94348
7HL	7 horizontal left	0.0074	94348
1HR	1 horizontal right	0.029	94348
1VR	1 vertical left	0.034	94348
2HR	2 horizontal right	0.031	94348
3HR	3 horizontal right	0.024	94348
4HR	4 horizontal right	0.0059	94348
5HR	5 horizontal right	0.014	94348
6HR	6 horizontal right	0.01	94348
7HR	7 horizontal right	0.0085	94348

26 kW Full Load	Measurement Point	Overall Level	Machine Speed
1HL	1 horizontal left	0.027	96300
1VL	1 vertical left	0.026	96300
2HL	2 horizontal left	0.032	96300
3HL	3 horizontal left	0.02	96300
4HL	4 horizontal left	0.0089	96300
5HL	5 horizontal left	0.013	96300
6HL	6 horizontal left	0.012	96300
7HL	7 horizontal left	0.0094	96300
1HR	1 horizontal right	0.03	96300
1VR	1 vertical left	0.027	96300
2HR	2 horizontal right	0.035	96300
3HR	3 horizontal right	0.019	96300
4HR	4 horizontal right	0.0064	96300
5HR	5 horizontal right	0.013	96300
6HR	6 horizontal right	0.015	96300
7HR	7 horizontal right	0.0096	96300

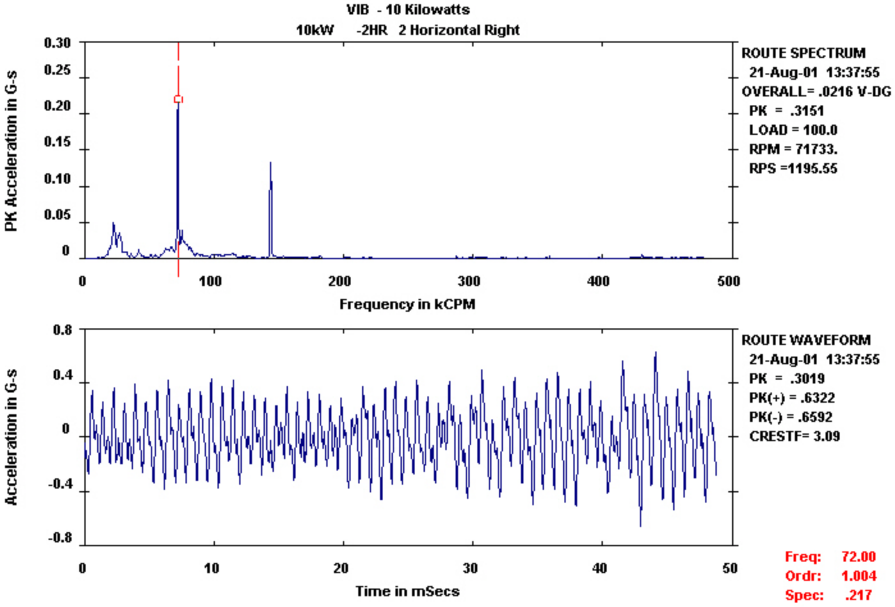
1VR


VIB - 10 Kilowatts
10kW -1VR 1 Vertical Right
PK Acceleration in G-s
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:37:47
OVERALL= .0178 V-DG
PK = .4796
LOAD = 100.0
RPM = 71826.
RPS =1197.10
Acceleration in G-s
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:37:47
PK = .4356
PK(+) = .7669
PK(-) = .5790
CRESTF= 2.49
Freq: 72.00
Ordr: 1.002
Spec: .181

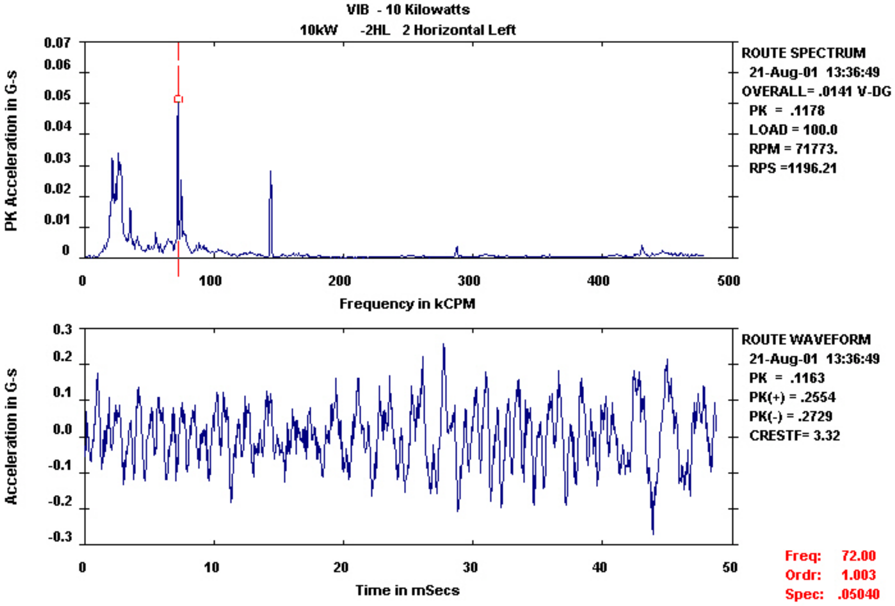
1VL


VIB - 10 Kilowatts
10kW -1VL 1 Vertical Left
PK Acceleration in G-s
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:36:42
OVERALL= .0115 V-DG
PK = .2782
LOAD = 100.0
RPM = 71759.
RPS =1195.99
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:36:42
PK = .2625
PK(+) = .4138
PK(-) = .3807
CRESTF= 2.23
Freq: 72.00
Ordr: 1.003
Spec: .03107

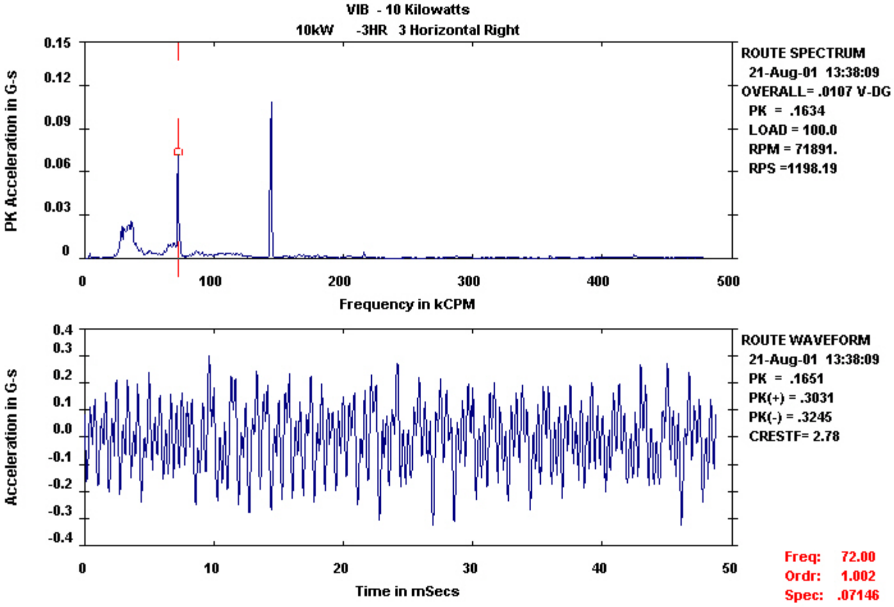
2HR


VIB - 10 Kilowatts
10kW -2HR 2 Horizontal Right
PK Acceleration in G-s
0.30
0.25
0.20
0.15
0.10
0.05
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:37:55
OVERALL= .0216 V-DG
PK = .3151
LOAD = 100.0
RPM = 71733.
RPS =1195.55
Acceleration in G-s
0.8
0.4
0
-0.4
-0.8
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:37:55
PK = .3019
PK(+) = .6322
PK(-) = .6592
CRESTF= 3.09
Freq: 72.00
Ordr: 1.004
Spec: .217

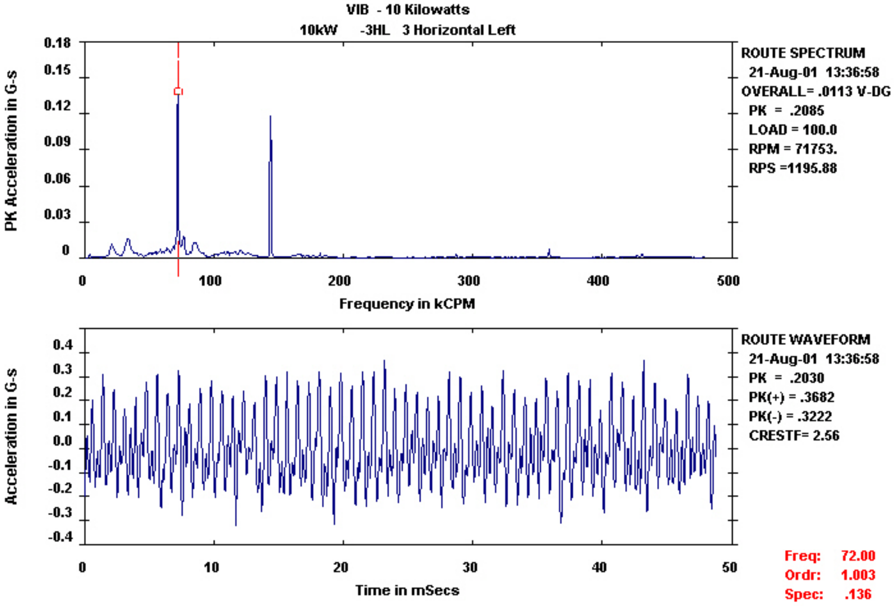
2HL


VIB - 10 Kilowatts
10kW -2HL 2 Horizontal Left
PK Acceleration in G-s
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:36:49
OVERALL= .0141 V-DG
PK = .1178
LOAD = 100.0
RPM = 71773.
RPS =1196.21
Acceleration in G-s
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:36:49
PK = .1163
PK(+) = .2554
PK(-) = .2729
CRESTF= 3.32
Freq: 72.00
Ordr: 1.003
Spec: .05040

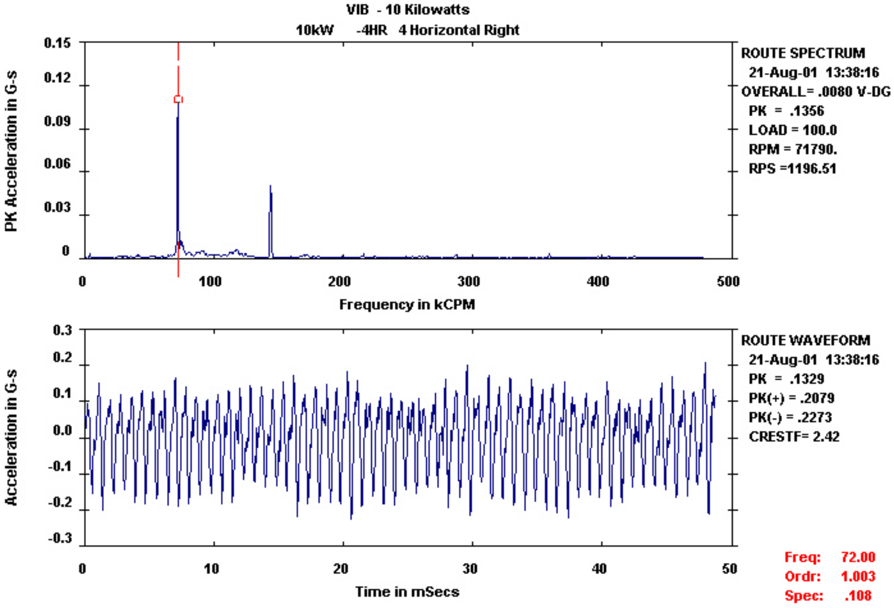
3HR


VIB - 10 Kilowatts
10kW -3HR 3 Horizontal Right
PK Acceleration in G-s
0.15
0.12
0.09
0.06
0.03
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:38:09
OVERALL= .0107 V-DG
PK = .1634
LOAD = 100.0
RPM = 71891.
RPS =1198.19
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:38:09
PK = .1651
PK(+) = .3031
PK(-) = .3245
CRESTF= 2.78
Freq: 72.00
Ordr: 1.002
Spec: .07146

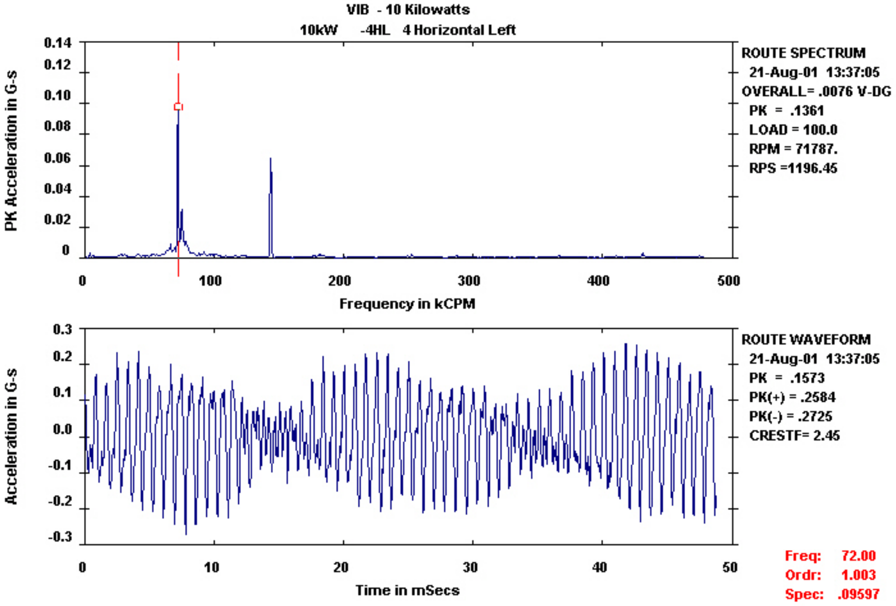
3HL


VIB - 10 Kilowatts
10kW -3HL 3 Horizontal Left
PK Acceleration in G-s
0.18
0.15
0.12
0.09
0.06
0.03
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:36:58
OVERALL= .0113 V-DG
PK = .2085
LOAD = 100.0
RPM = 71753.
RPS =1195.88
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:36:58
PK = .2030
PK(+) = .3682
PK(-) = .3222
CRESTF= 2.56
Freq: 72.00
Ordr: 1.003
Spec: .136

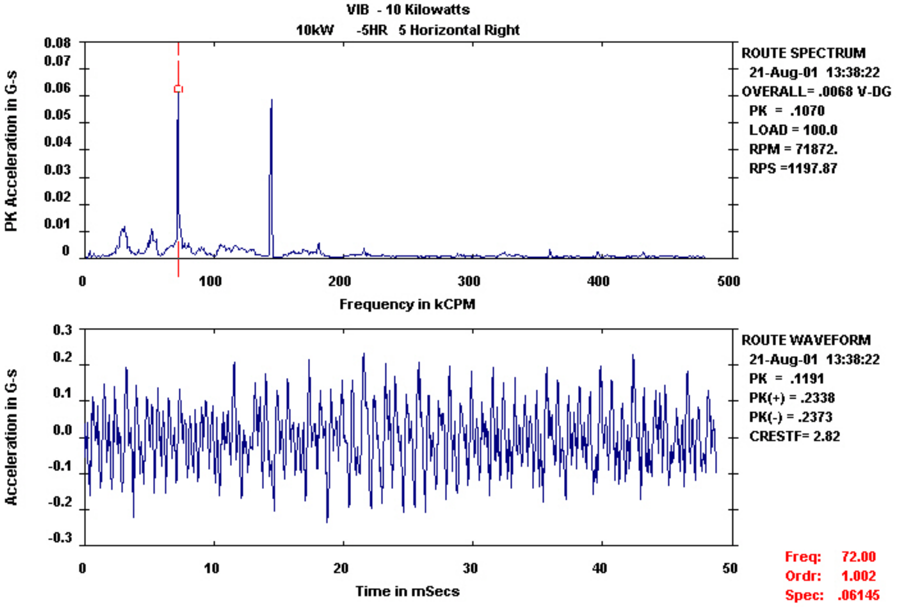
4HR


VIB - 10 Kilowatts
10kW -4HR 4 Horizontal Right
PK Acceleration in G-s
0.15
0.12
0.09
0.06
0.03
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:38:16
OVERALL= .0080 V-DG
PK = .1356
LOAD = 100.0
RPM = 71790.
RPS =1196.51
Acceleration in G-s
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:38:16
PK = .1329
PK(+) = .2079
PK(-) = .2273
CRESTF= 2.42
Freq: 72.00
Ordr: 1.003
Spec: .108

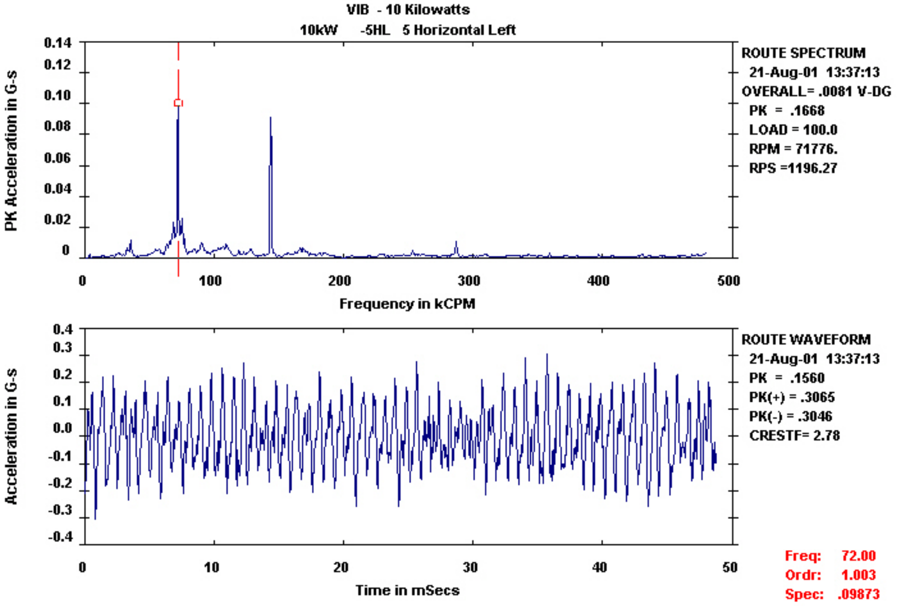
4HL


VIB - 10 Kilowatts
10kW -4HL 4 Horizontal Left
PK Acceleration in G-s
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:37:05
OVERALL= .0076 V-DG
PK = .1361
LOAD = 100.0
RPM = 71787.
RPS =1196.45
Acceleration in G-s
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:37:05
PK = .1573
PK(+) = .2584
PK(-) = .2725
CRESTF= 2.45
Freq: 72.00
Ordr: 1.003
Spec: .09597

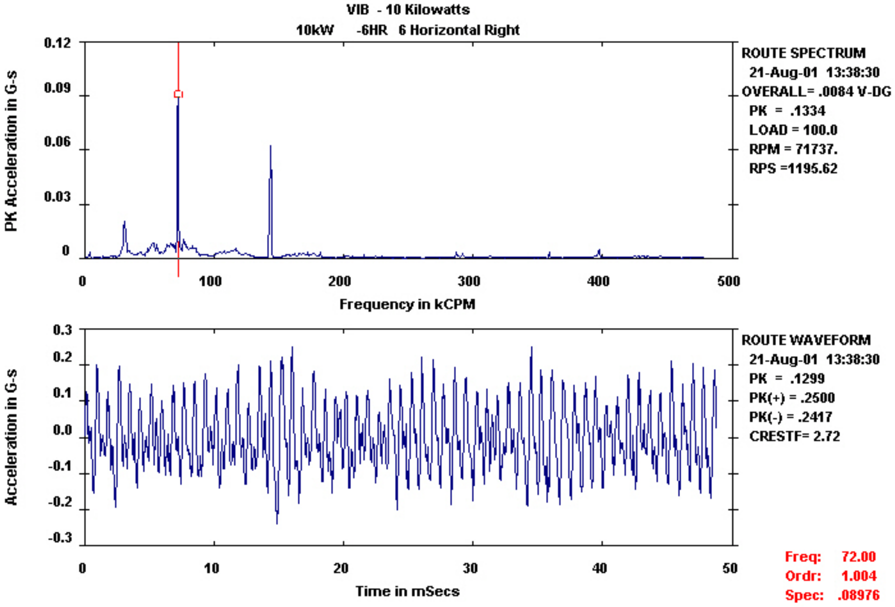
5HR


VIB - 10 Kilowatts
10kW -5HR 5 Horizontal Right
PK Acceleration in G-s
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:38:22
OVERALL= .0068 V-DG
PK = .1070
LOAD = 100.0
RPM = 71872.
RPS =1197.87
Acceleration in G-s
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:38:22
PK = .1191
PK(+) = .2338
PK(-) = .2373
CRESTF= 2.82
Freq: 72.00
Ordr: 1.002
Spec: .06145

5HL


VIB - 10 Kilowatts
10kW -5HL 5 Horizontal Left
PK Acceleration in G-s
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:37:13
OVERALL= .0081 V-DG
PK = .1668
LOAD = 100.0
RPM = 71776.
RPS =1196.27
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:37:13
PK = .1560
PK(+) = .3065
PK(-) = .3046
CRESTF= 2.78
Freq: 72.00
Ordr: 1.003
Spec: .09873

6HR

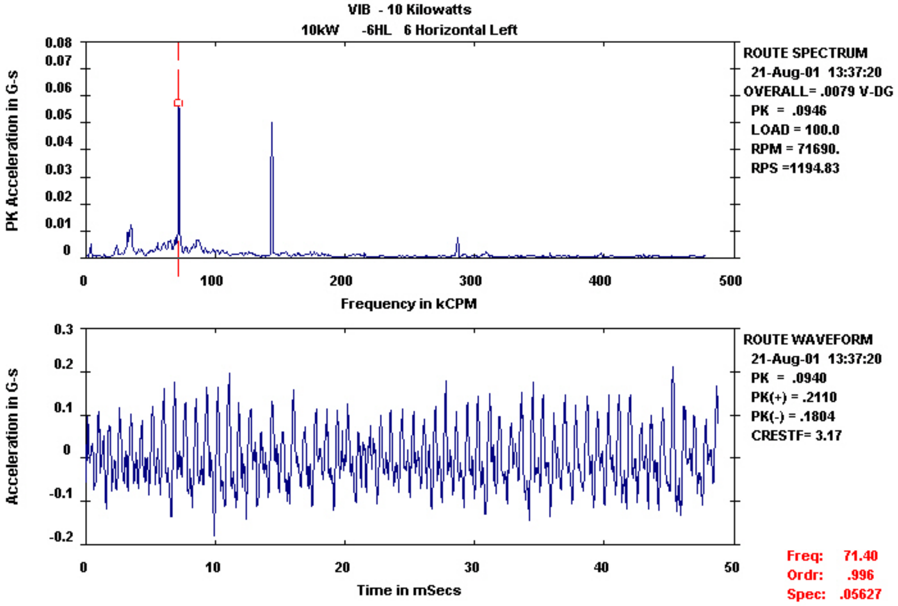

VIB - 10 Kilowatts
10kW -6HR 6 Horizontal Right

ROUTE SPECTRUM
21-Aug-01 13:38:30
OVERALL= .0084 V-DG
PK = .1334
LOAD = 100.0
RPM = 71737.
RPS =1195.62

ROUTE WAVEFORM
21-Aug-01 13:38:30
PK = .1299
PK(+) = .2500
PK(-) = .2417
CRESTF= 2.72

Freq: 72.00
Ordr: 1.004
Spec: .08976

6HL

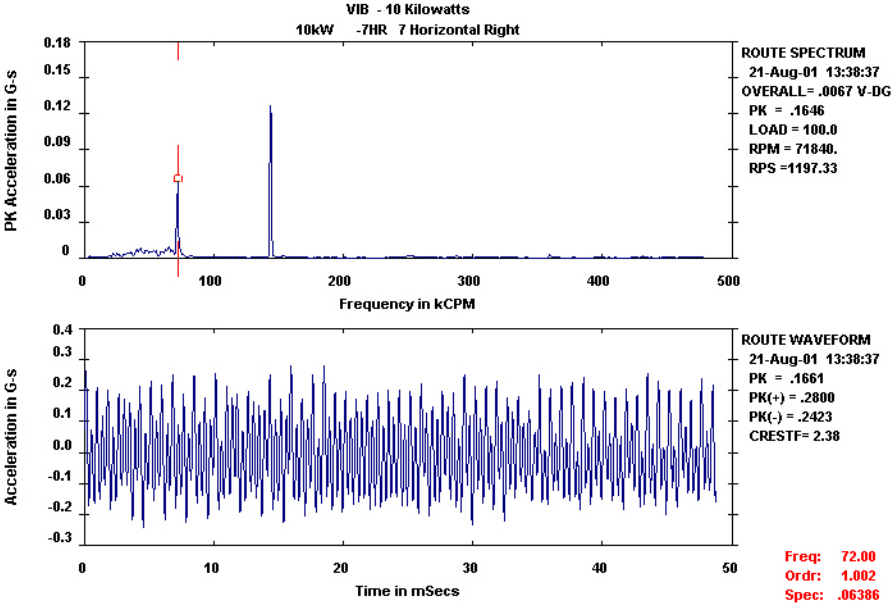

VIB - 10 Kilowatts
10kW -6HL 6 Horizontal Left

ROUTE SPECTRUM
21-Aug-01 13:37:20
OVERALL= .0079 V-DG
PK = .0946
LOAD = 100.0
RPM = 71690.
RPS =1194.83

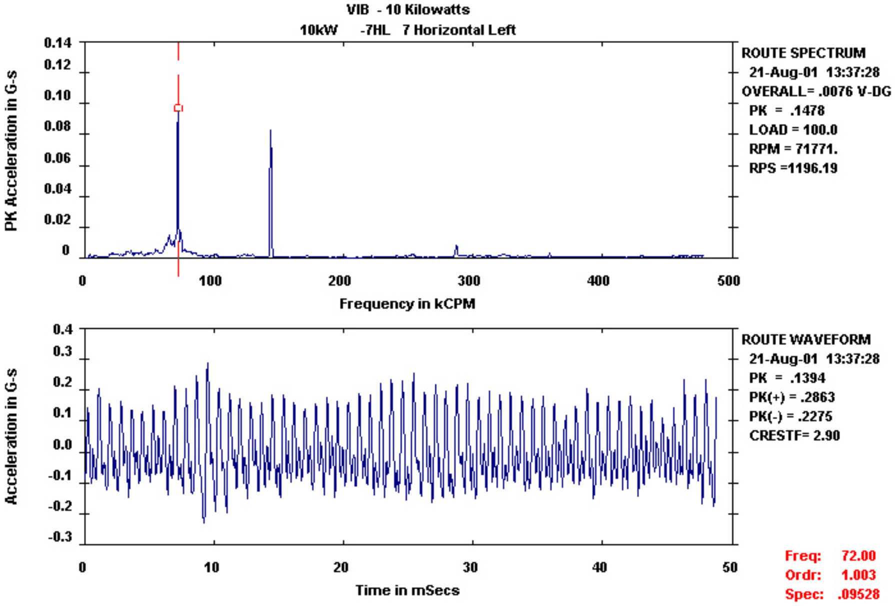
ROUTE WAVEFORM
21-Aug-01 13:37:20
PK = .0940
PK(+) = .2110
PK(-) = .1804
CRESTF= 3.17

Freq: 71.40
Ordr: .996
Spec: .05627

7HR

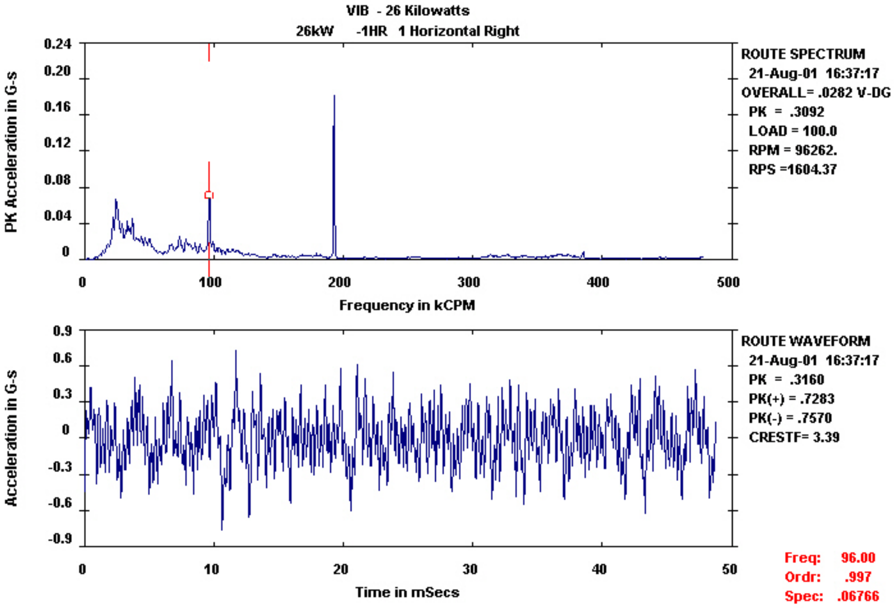

VIB - 10 Kilowatts
10kW -7HR 7 Horizontal Right
PK Acceleration in G-s
0.18
0.15
0.12
0.09
0.06
0.03
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:38:37
OVERALL= .0067 V-DG
PK = .1646
LOAD = 100.0
RPM = 71840.
RPS =1197.33
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:38:37
PK = .1661
PK(+) = .2800
PK(-) = .2423
CRESTF= 2.38
Freq: 72.00
Ordr: 1.002
Spec: .06386

7HL

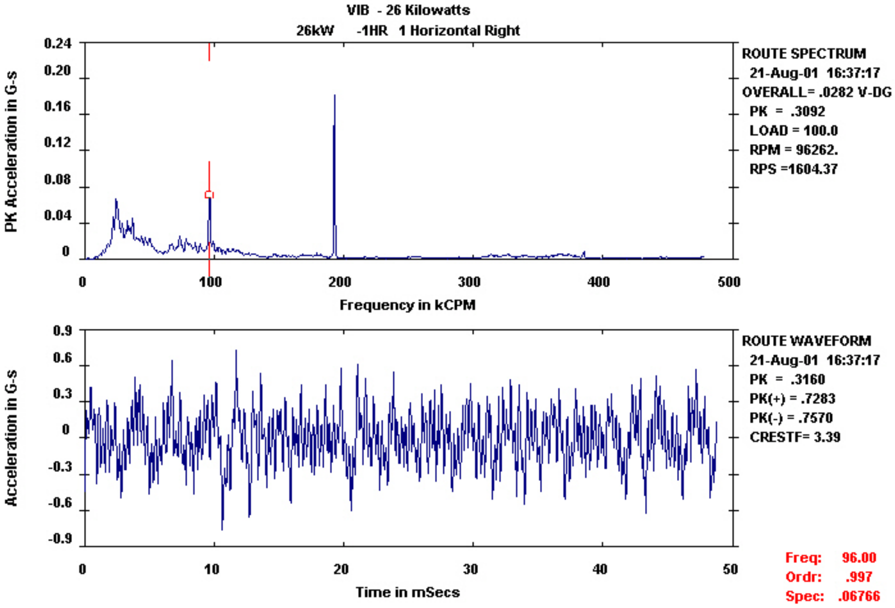

VIB - 10 Kilowatts
10kW -7HL 7 Horizontal Left
PK Acceleration in G-s
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 13:37:28
OVERALL= .0076 V-DG
PK = .1478
LOAD = 100.0
RPM = 71771.
RPS =1196.19
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 13:37:28
PK = .1394
PK(+) = .2863
PK(-) = .2275
CRESTF= 2.90
Freq: 72.00
Ordr: 1.003
Spec: .09528

The following waveforms and spectrums are for full load conditions, 26 kW.

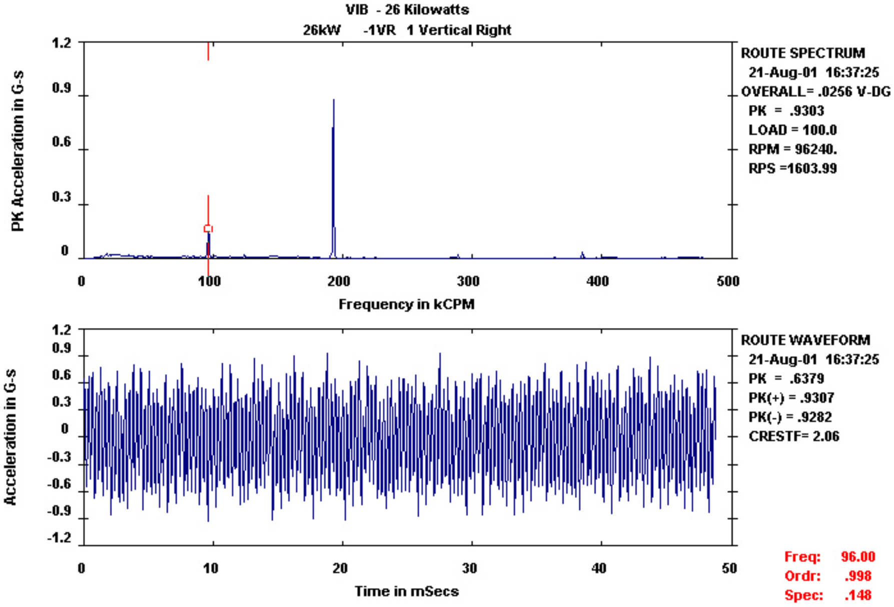
1HR



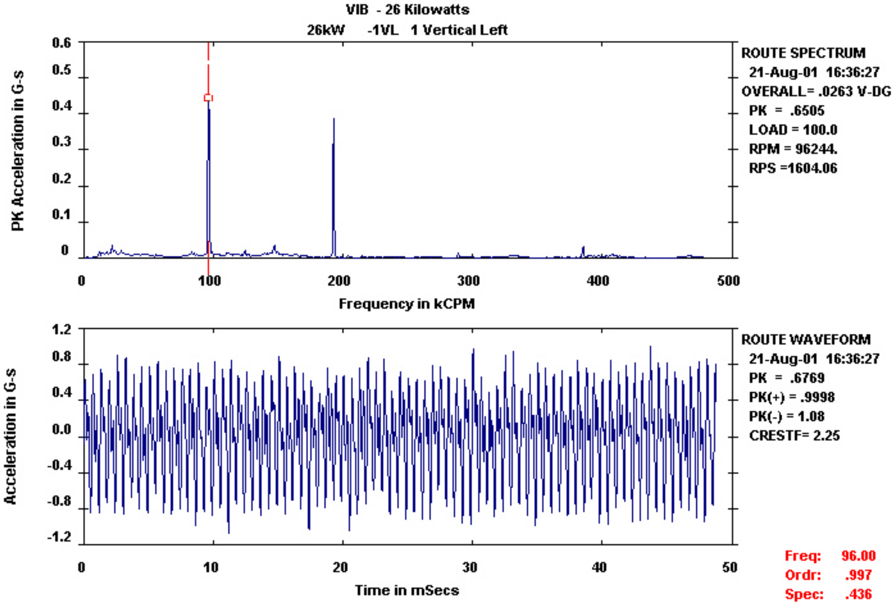
1HL



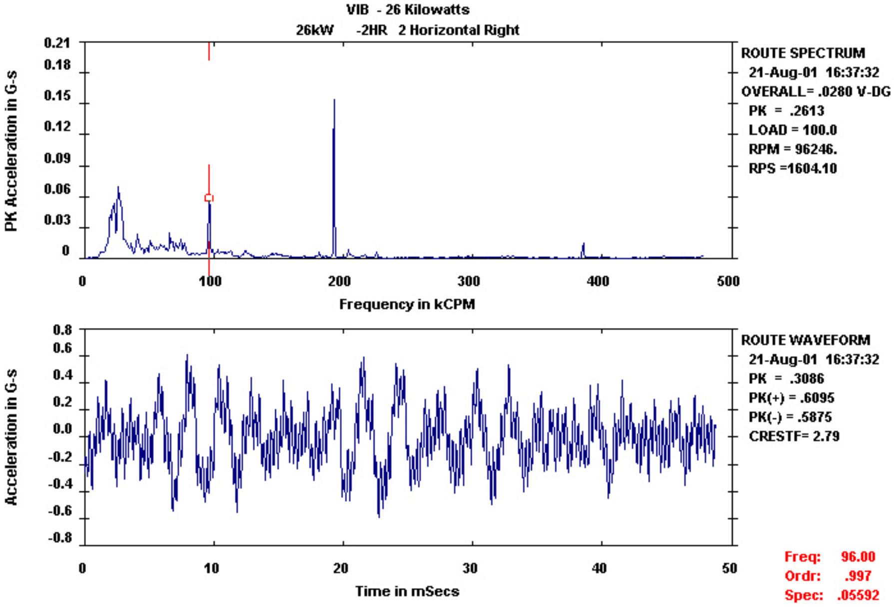
1VR


VIB - 26 Kilowatts
26kW -1VR 1 Vertical Right
PK Acceleration in G-s
1.2
0.9
0.6
0.3
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:37:25
OVERALL= .0256 V-DG
PK = .9303
LOAD = 100.0
RPM = 96240.
RPS =1603.99
Acceleration in G-s
1.2
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
-1.2
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:37:25
PK = .6379
PK(+) = .9307
PK(-) = .9282
CRESTF= 2.06
Freq: 96.00
Ordr: .998
Spec: .148

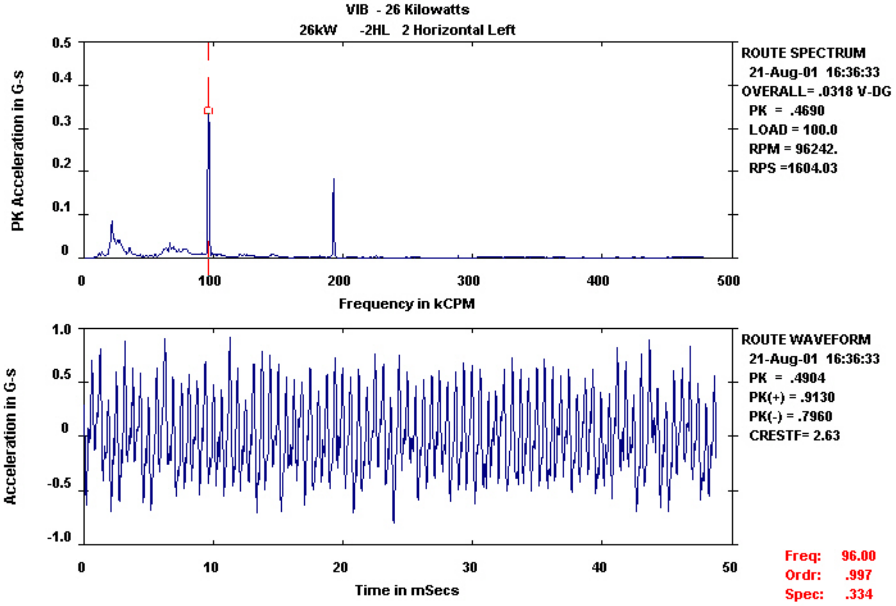
1VL


VIB - 26 Kilowatts
26kW -1VL 1 Vertical Left
PK Acceleration in G-s
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:36:27
OVERALL= .0263 V-DG
PK = .6505
LOAD = 100.0
RPM = 96244.
RPS =1604.06
Acceleration in G-s
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:36:27
PK = .6769
PK(+) = .9998
PK(-) = 1.08
CRESTF= 2.25
Freq: 96.00
Ordr: .997
Spec: .436

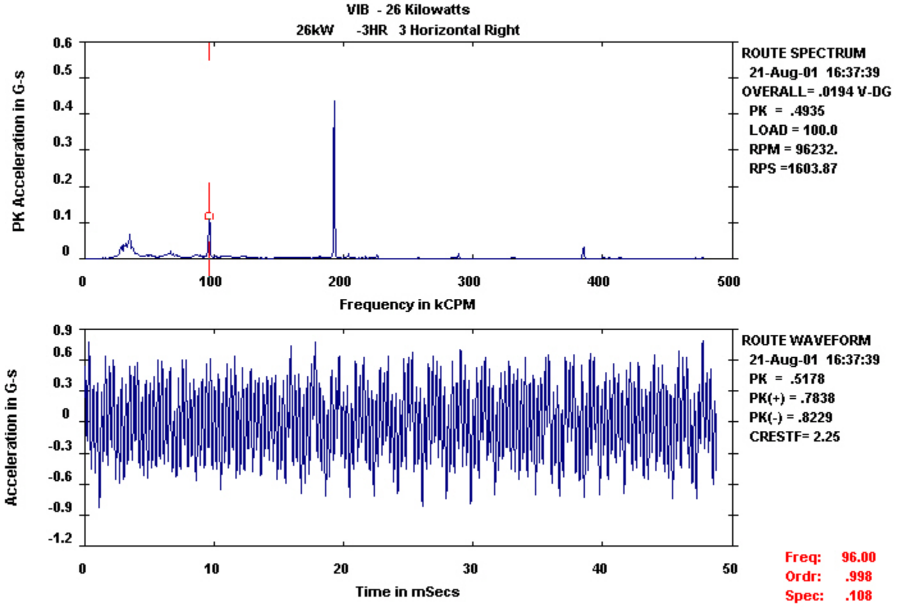
2HR


VIB - 26 Kilowatts
26kW -2HR 2 Horizontal Right
PK Acceleration in G-s
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:37:32
OVERALL= .0280 V-DG
PK = .2613
LOAD = 100.0
RPM = 96246.
RPS =1604.10
Acceleration in G-s
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:37:32
PK = .3086
PK(+) = .6095
PK(-) = .5875
CRESTF= 2.79
Freq: 96.00
Ordr: .997
Spec: .05592

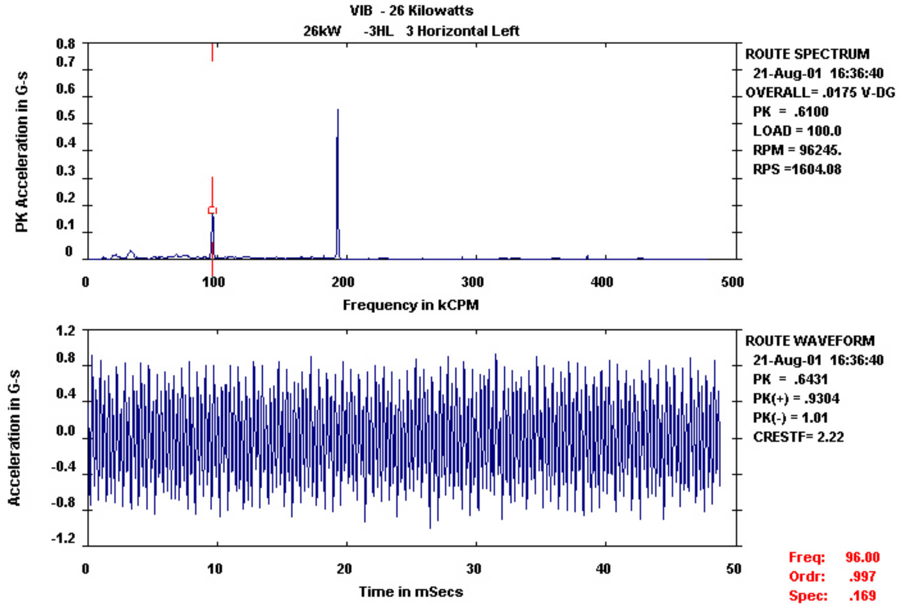
2HL


VIB - 26 Kilowatts
26kW -2HL 2 Horizontal Left
PK Acceleration in G-s
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:36:33
OVERALL= .0318 V-DG
PK = .4690
LOAD = 100.0
RPM = 96242.
RPS =1604.03
Acceleration in G-s
1.0
0.5
0
-0.5
-1.0
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:36:33
PK = .4904
PK(+) = .9130
PK(-) = .7960
CRESTF= 2.63
Freq: 96.00
Ordr: .997
Spec: .334

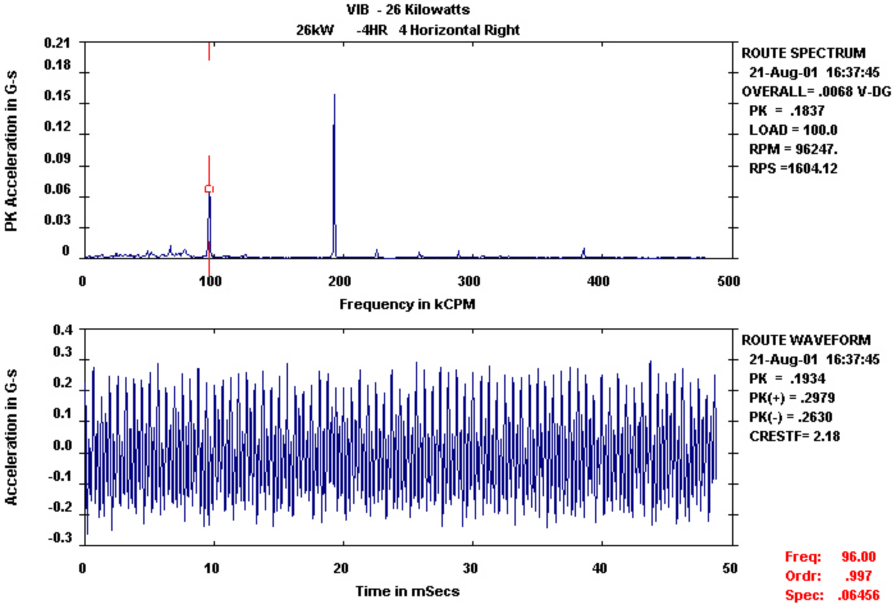
3HR


VIB - 26 Kilowatts
26kW -3HR 3 Horizontal Right
PK Acceleration in G-s
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:37:39
OVERALL= .0194 V-DG
PK = .4935
LOAD = 100.0
RPM = 96232.
RPS =1603.87
Acceleration in G-s
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
-1.2
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:37:39
PK = .5178
PK(+) = .7838
PK(-) = .8229
CRESTF= 2.25
Freq: 96.00
Ordr: .998
Spec: .108

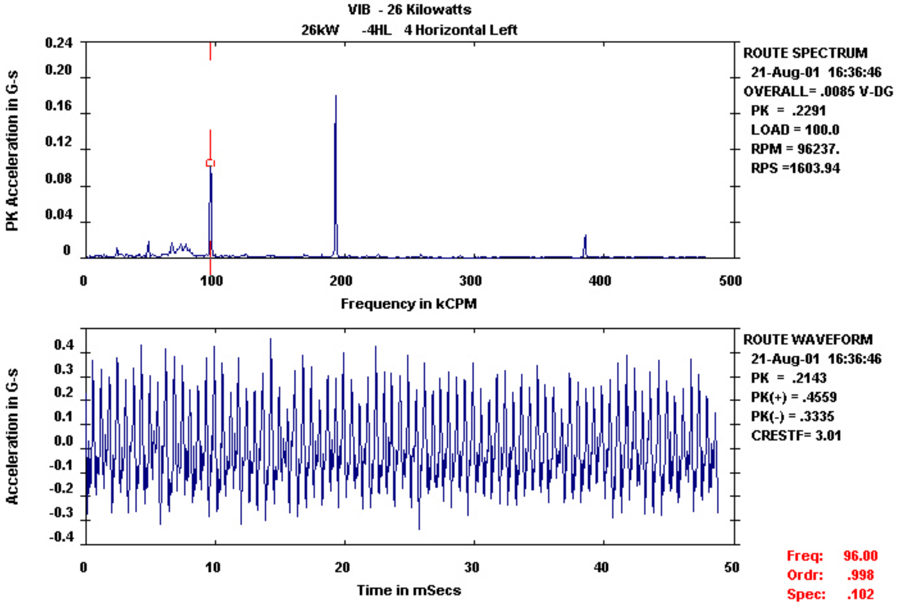
3HL


VIB - 26 Kilowatts
26kW -3HL 3 Horizontal Left
PK Acceleration in G-s
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:36:40
OVERALL= .0175 V-DG
PK = .6100
LOAD = 100.0
RPM = 96245.
RPS =1604.08
Acceleration in G-s
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:36:40
PK = .6431
PK(+) = .9304
PK(-) = 1.01
CRESTF= 2.22
Freq: 96.00
Ordr: .997
Spec: .169

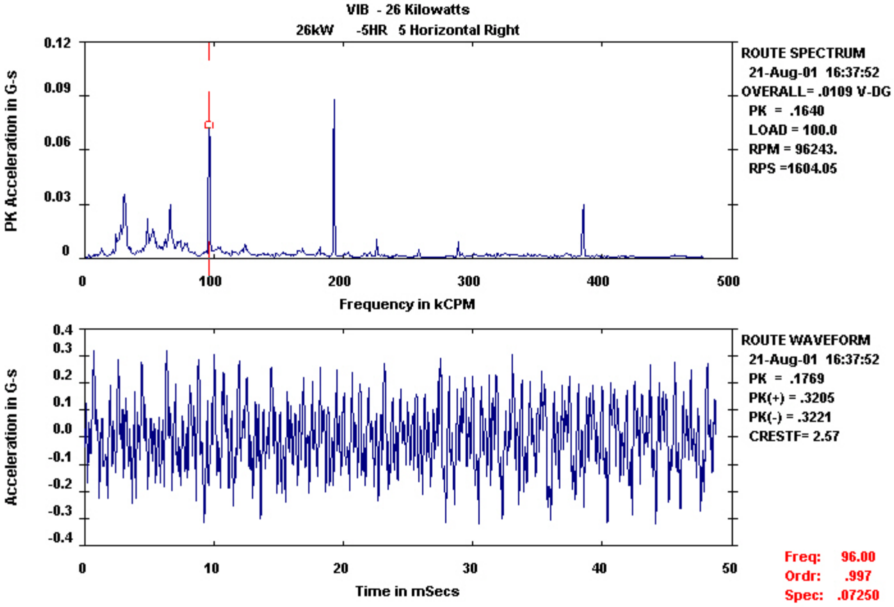
4HR


VIB - 26 Kilowatts
26kW -4HR 4 Horizontal Right
PK Acceleration in G-s
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:37:45
OVERALL= .0068 V-DG
PK = .1837
LOAD = 100.0
RPM = 96247.
RPS =1604.12
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:37:45
PK = .1934
PK(+) = .2979
PK(-) = .2630
CRESTF= 2.18
Freq: 96.00
Ordr: .997
Spec: .06456

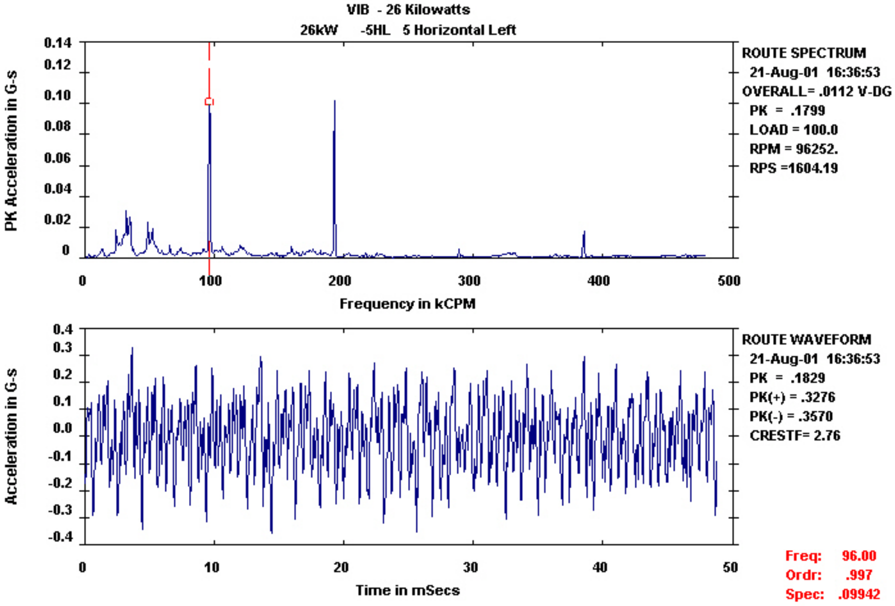
4HL


VIB - 26 Kilowatts
26kW -4HL 4 Horizontal Left
PK Acceleration in G-s
0.24
0.20
0.16
0.12
0.08
0.04
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:36:46
OVERALL= .0085 V-DG
PK = .2291
LOAD = 100.0
RPM = 96237.
RPS =1603.94
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:36:46
PK = .2143
PK(+) = .4559
PK(-) = .3335
CRESTF= 3.01
Freq: 96.00
Ordr: .998
Spec: .102

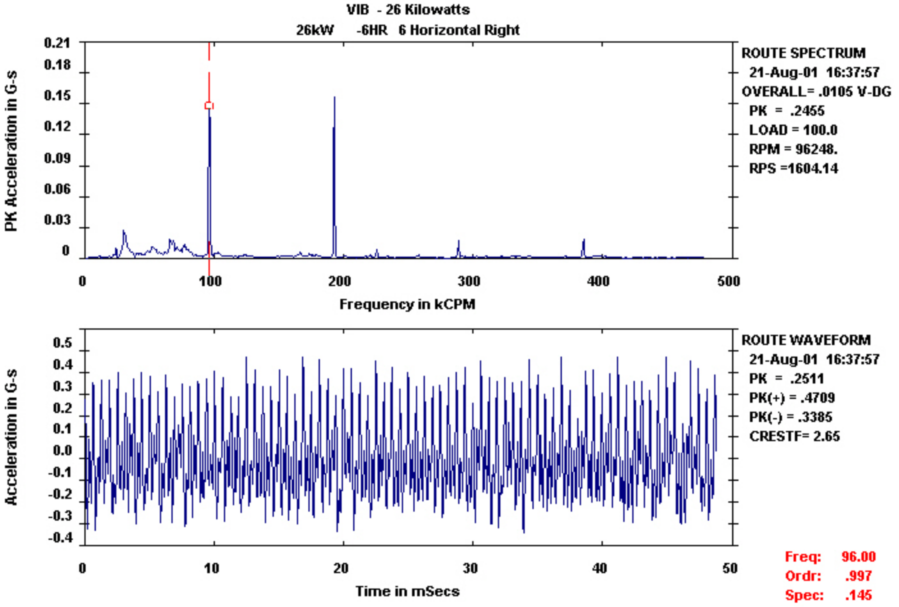
5HR


VIB - 26 Kilowatts
26kW -5HR 5 Horizontal Right
PK Acceleration in G-s
0.12
0.09
0.06
0.03
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:37:52
OVERALL= .0109 V-DG
PK = .1640
LOAD = 100.0
RPM = 96243.
RPS =1604.05
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:37:52
PK = .1769
PK(+) = .3205
PK(-) = .3221
CRESTF= 2.57
Freq: 96.00
Ordr: .997
Spec: .07250

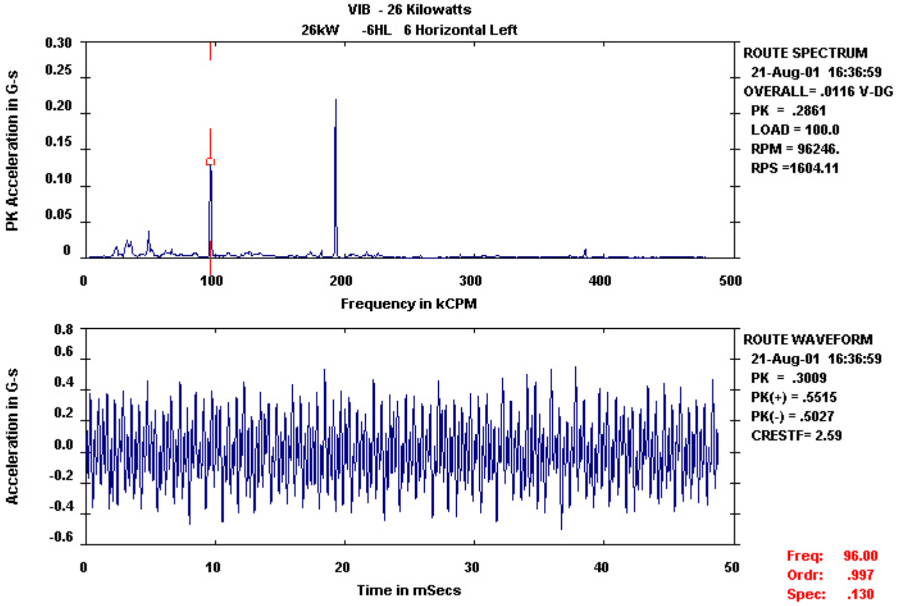
5HL


VIB - 26 Kilowatts
26kW -5HL 5 Horizontal Left
PK Acceleration in G-s
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:36:53
OVERALL= .0112 V-DG
PK = .1799
LOAD = 100.0
RPM = 96252.
RPS =1604.19
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:36:53
PK = .1829
PK(+) = .3276
PK(-) = .3570
CRESTF= 2.76
Freq: 96.00
Ordr: .997
Spec: .09942

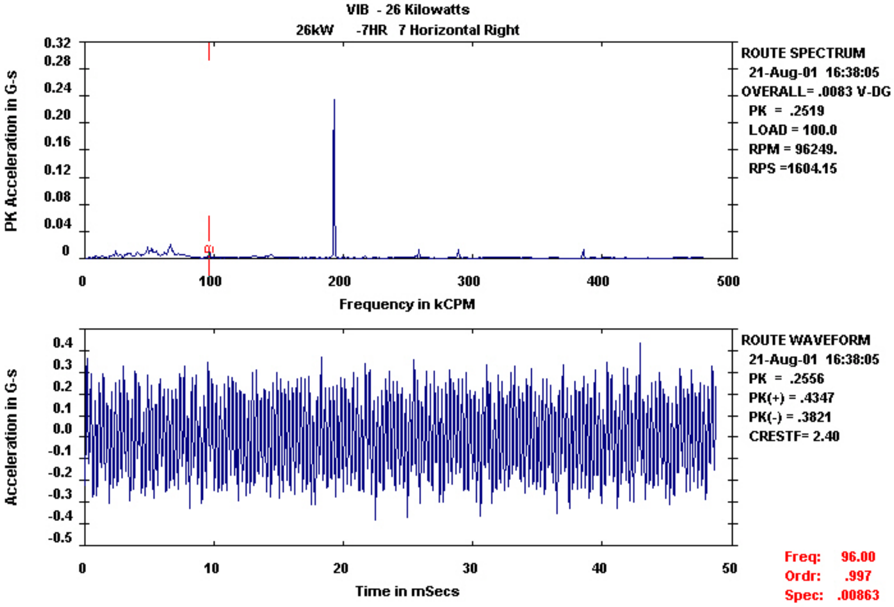
6HR


VIB - 26 Kilowatts
26kW -6HR 6 Horizontal Right
PK Acceleration in G-s
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:37:57
OVERALL= .0105 V-DG
PK = .2455
LOAD = 100.0
RPM = 96248.
RPS =1604.14
Acceleration in G-s
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:37:57
PK = .2511
PK(+) = .4709
PK(-) = .3385
CRESTF= 2.65
Freq: 96.00
Ordr: .997
Spec: .145

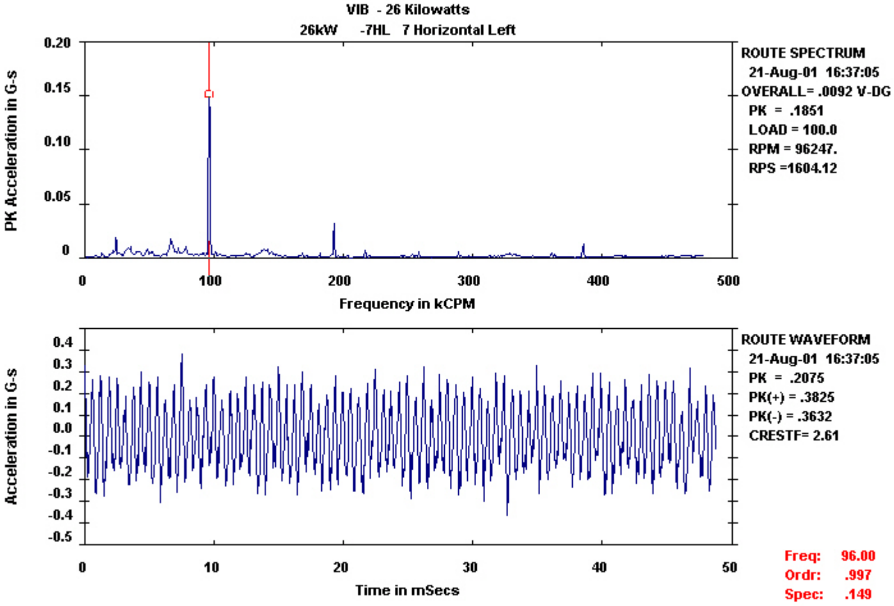
6HL


VIB - 26 Kilowatts
26kW -6HL 6 Horizontal Left
PK Acceleration in G-s
0.30
0.25
0.20
0.15
0.10
0.05
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:36:59
OVERALL= .0116 V-DG
PK = .2861
LOAD = 100.0
RPM = 96246.
RPS =1604.11
Acceleration in G-s
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:36:59
PK = .3009
PK(+) = .5515
PK(-) = .5027
CRESTF= 2.59
Freq: 96.00
Ordr: .997
Spec: .130

7HR


VIB - 26 Kilowatts
26kW -7HR 7 Horizontal Right
PK Acceleration in G-s
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:38:05
OVERALL= .0083 V-DG
PK = .2519
LOAD = 100.0
RPM = 96249.
RPS =1604.15
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:38:05
PK = .2556
PK(+) = .4347
PK(-) = .3821
CRESTF= 2.40
Freq: 96.00
Ordr: .997
Spec: .00863

7HL


VIB - 26 Kilowatts
26kW -7HL 7 Horizontal Left
PK Acceleration in G-s
0.20
0.15
0.10
0.05
0
0
100
200
300
400
500
Frequency in kCPM
ROUTE SPECTRUM
21-Aug-01 16:37:05
OVERALL= .0092 V-DG
PK = .1851
LOAD = 100.0
RPM = 96247.
RPS =1604.12
Acceleration in G-s
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
10
20
30
40
50
Time in mSecs
ROUTE WAVEFORM
21-Aug-01 16:37:05
PK = .2075
PK(+) = .3825
PK(-) = .3632
CRESTF= 2.61
Freq: 96.00
Ordr: .997
Spec: .149

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13. ABSTRACT *(Maximum 200 words)*

This report describes NiSource Energy Technologies Inc.'s base year of a planned 3-year effort to advance distributed power development, deployment, and integration. Its long-term goal is to design ways to extend distributed generation into the physical design and controls of buildings. NET worked to meet this goal through advances in the implementation and control of CHP systems in end-user environments and a further understanding of electric interconnection and siting issues.

Important results from the first year were a survey of the state of the art of interconnection issues associated with distributed generation, a survey of the local zoning requirements for the NiSource service territory, and the acquisition of data about the operation, reliability, interconnection, and performance of CHP systems and components of two test sites.

14. SUBJECT TERMS
NiSource, combined heat and power; chp; microturbines; codes; zoning; interconnection; distributed power; distributed generation; DP; DG; Distribution and Interconnection R&D; National Renewable Energy Laboratory; NREL

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