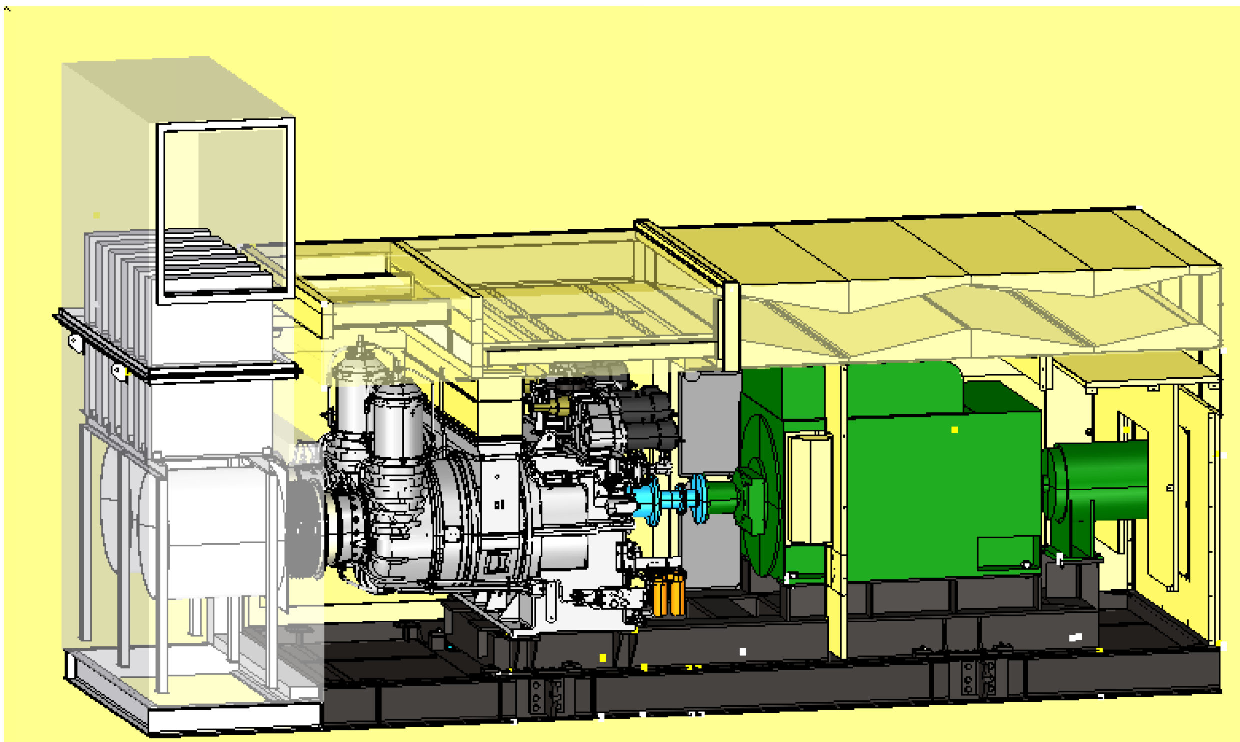
Initial Type Test Result of Class 1E Gas Turbine Generator System



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Revision History

Revision	Page	Description
0	All	Original issued
1	6-2	Added unit of parameters of Tables 6.2-1 and 6.2-2
	6-3	Added unit of parameters of Table 6.2-3.
	6-4	Added unit of parameters of Tables 6.3-1 and 6.3-2.
	7-1	Added title of Section 7.1 Added Section 7.2.
	7-2	Added Section 7.3.
	Appendix E-1 – E-8	Added Appendix E (Sections E.1.0 – E.3.0)
	Appendix F-1 – F-6	Added Appendix F (Sections F.1.0 – F.4.0)

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Abstract

This technical report describes the summary of result of initial type test of Class 1E Gas Turbine Generator (GTG) unit of US-APWR.
MHI have performed initial type test required in IEEE 387-1995 as part of Class 1E qualification program of Class 1E GTG units of US-APWR.
This report notices that GTG passed the initial type test required and verified the availability to apply for Class 1E emergency power units.

This technical report describes the followings

Scope of qualification
Specification of components tested
Procedures, acceptance criteria and test conditions of tests
Summary of result
Consideration

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List of Acronyms

ac	Alternate Current
dc	Direct Current
CDP	Compressor Discharge Pressure
CPS	Control Protection and Surveillance systems
CPU	Central Processing Unit
CT	Current Transformer
DG	Diesel Generator
ECCS	Emergency Core Cooling System
EGT	Exhaust Gas Temperature
ESI	Engine System Inc.
ESFAS	Engineered Safety Features Actuation System
FMEA	Failure Modes and Effects Analysis
FOA	Fuel, Oil and Air
GTG	Gas Turbine Generator
I&C	Instrumentation and Control
I/O	Input/Output
IV&V	Independent Verification and Validation
KHI	Kawasaki Heavy Industries
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
MCR	Main Control Room
MHI	Mitsubishi Heavy Industries
MTBF	Mean Time Between Failure
QA	Quality Assurance
RTD	Resistance Temperature Detector
SLS	Safety Logic System
UV	Under Voltage
VDU	Visual Display System
VT	Voltage Transformer

1.0 INTRODUCTION/OVERVIEW

The US-APWR applies Gas Turbine Generators (GTG), as Emergency Power Supply in lieu of the most commonly used Diesel Generators (DGs).

Since GTG has not been applied for Class 1E Emergency Power Sources (EPSs) of nuclear power plants in US, there is no regulatory requirement for Class 1E GTG. MHI decided to perform the Class 1E qualification in accordance with R.G 1.9/IEEE 387. MHI performed Initial Type Test of US-APWR’s GTG system required in IEEE 387. NRC has issued Interim Staff Guidance ISG-21 which is requirement about design and qualification of Class 1E GTG. ISG-21 seems to be regulatory guideline in future. MHI also reflects the requirement of ISG GTG in qualification. This report describes and concludes the result of initial type test of GTG. MHI will submit the whole qualification detail report including seismic qualification in March of 2011.

Initial type test consists of three kinds of test, “Load capability test”, “Start and load acceptance test” and “margin test”. MHI performed all the three tests and this report summarizes those test results. It should be noted that part of the voltage and frequency data specified in this report is draft data. The final data will be replaced according to the report from the qualification company in the above mentioned detailed report that will be released in March.

2.0 LIST OF STANDARDS AND REGULATIONS

The requirements of various standards and regulations presently used for DGs that are pertinent to a GTG will be implemented in US-APWR design.

2.1 NRC Documents

(1) Regulatory Guide 1.6 Rev 0. Independence Between Redundant Standby (Onsite) Power Sources and Between Their Distribution Systems (Safety Guide 6)
(2) Regulatory Guide 1.9 Rev. 4 Application and Testing of Safety-Related Diesel Generators in Nuclear Power Plants
(3) Regulatory Guide 1.28 Rev. 3 Quality Assurance Program Requirements
(4) Regulatory Guide 1.32 Rev. 3. Criteria for Power Systems for Nuclear Power Plants
(5) Regulatory Guide 1.38 Rev. 2 Quality Assurance Requirements for Packaging, Shipping, Receiving, Storage, and Handling of Items for Water-Cooled Nuclear Power Plants (Rev. 2)
(6) Regulatory Guide 1.75 Rev. 3. Physical Independence of Electric Systems
(7) Regulatory Guide 1.93 Rev. 0. Availability of Electric Power Sources
(8) Regulatory Guide 1.118 Rev. 3. Periodic Testing of Electric Power and Protection Systems
(9) Regulatory Guide 1.137 Rev. 1. Fuel-Oil Systems for Standby Diesel Generators
(10) NUREG/CR-6928, Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power plant, February 2007
(11) NRC Information Notice 2006-22 New Ultra-low-sulfur Diesel Fuel Oil Could Adversely Impact Diesel Engine Performance
(12) 40CFR 50 NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS
(13) 40CFR 52 APPROVAL AND PROMULGATION OF IMPLEMENTATION PLANS
(14) 40CFR 60 STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES
(15) 40CFR 61 NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS
(16) 40CFR 63 NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS FOR SOURCE CATEGORIES
(17) 40CFR 68 CHEMICAL ACCIDENT PREVENTION PROVISIONS
(18) 40CFR 70 STAGE OPERATING PERMIT PROGRAMS
(19) 40CFR 71 FEDERAL OPERATING PERMIT PRGRAMS
(20) 40CFR 81 DESIGNATION OF AREAS FOR AIR QUALITY PLANING PURPOSES
(21) DC/COL-ISG-021, Interim Staff Guidance on the Review of Nuclear Power Plant Designs using a Gas Turbine Driven Standby Emergency Alternating Current Power System

2.2 Industry Standards – IEEE

(1) IEEE 1-2000, Recommended Practice - General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation
(2) IEEE 43-2000, Recommended Practice for Testing Insulation Resistance of Rotating Machinery
(3) IEEE Std 96-1969, General Principles for Rating Electric Apparatus for Short-Time, Intermittent, or Varying Duty
(4) IEEE Std 115-1995, Test Procedures for Synchronous Machines
(5) IEEE 142-2007, Recommended Practice for Grounding of Industrial and Commercial Power Systems

(6) IEEE 275-1992, Recommended Practice for Thermal Evaluation of Insulation Systems for Alternating-Current Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900 V and Below
(7) IEEE Std 308-2001 - IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations
(8) IEEE Std 323-2003 - IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations
(9) IEEE 336-2005 IEEE Guide for Installation, Inspection, and Testing for Class 1E Power, Instrumentation, and Control Equipment at Nuclear Facilities
(10) IEEE 338-2006 – IEEE Standard Criteria for the Periodic Surveillance Testing of Nuclear Power Generating Station Safety Systems
(11) IEEE-344-2004 IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations
(12) IEEE-379-2000 IEEE Standard Application of the Single Failure Criterion to Nuclear Power Generating Stations Safety Systems
(13) IEEE Std 384-2008 IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits
(14) IEEE Std 387-1995 - IEEE Standard Criteria for Diesel Generator Units Applied as Standby Power Supply for Nuclear Power Generating Stations.
(15) IEEE-415-1986 IEEE Guide for Planning of Preoperational Testing Programs for Class 1E Power Systems for Nuclear Power Generating Stations.
(16) IEEE-421.3-1997 IEEE Standard for High Potential Test Requirements for Excitation Systems for Synchronous Machines
(17) IEEE-421.4-2004 IEEE Guide for the Preparation of Excitation System Specifications
(18) IEEE 429-1994, Recommended Practice for Thermal Evaluation of Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900 V and Below
(19) IEEE-493-2007, Recommended Practice for the Design of Reliable Industrial and Commercial Power System
(20) IEEE Std 500-1984 IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear-Power Generating Stations
(21) IEEE-603-1998, IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations
(22) IEEE-627-1980, IEEE Standard Criteria for Design Qualification of Safety Equipment Used in Nuclear Power Generating Stations

2.3 Other Industry Standards

(1) NEMA FU-1-2002 Low Voltage Cartridge Fuses
(2) NEMA MG-1-2006 Motors and Generators
(3) ANSI/ASME NQA-1-2008 Quality Assurance Requirements for Nuclear Facility Applicants
(4) ANSI B31.1-2007 Power Piping
(5) ANSI B37.20 Switchgear Assemblies including Metal Enclosed Bus
(6) ANSI C37-90.1-2002 IEEE Standard for Surge Withstand Capabilities (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus
(7) ANSI C37-101-2006 IEEE Guide for Generator Ground Protection
(8) ANSI C37.102-2006 IEEE Guide for AC Generator Protection
(9) ANSI C50.13-2005 IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above

(10) ANSI C50.14-1977 American National Standard Requirements for Combustion Gas Turbine Driven Cylindrical Rotor Synchronous Generators
(11) ANSI C57.13-1993 IEEE Standard Requirements for Instrument Transformers (if needed)
(12) ANSI C62.92.2-1989 IEEE Guide for the Application Guide for Neutral Grounding in Electrical Utility Systems, Pt II - Grounding of Synchronous Generator Systems.
(13) ANSI/ASME B16.11-2009, Forged Fittings, Socket Welding and Threaded.
(14) ANSI/ASME B16.25-2007, Buttwelding Ends.
(15) ANSI/ANS-59.51-1997, Fuel Oil Systems for Standby Diesel Generators
(16) ASTM D975-1981, Standard Specification for Diesel Fuel Oils
(17) ANSI/NFPA 37-2006, Combustion Engines and Gas Turbines, Stationary
(18) ASME Boiler and Pressure Vessel Code
(19) Standard Practices for Low and Medium Seed Stationary Diesel and Gas Engines, 6th Edition, p. 94, Diesel Engine Manufacturers Association (DEMA), 1972
(20) TEMA Standards of the Tubular Exchanger Manufacturers Association, 9th Edition
(21) ICEA S-19-81 (NEMA WC3) Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
(22) ICEA S-66-524 Cross-linked Thermosetting Polyethylene Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
(23) ICEA S-68-516 (NEMA WCB) Ethylene-Propylene-Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.
(24) NFPA Vol. 1 Flammable Liquids - Tank Storage
(25) NFPA No. 30 Flammable and Combustible Liquids Code
(26) NFPA No. 37 Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines
(29) Boiler and Pressure Vessel Code. Section iii, Division 1, Nuclear Power Plant Components, ASME, 2001 Edition including Addenda through 2003.

3.0 DEFINITIONS

3.1 Acceptable:

Demonstrated to be adequate by the safety analysis of the plant.

3.2 Continuous Rating (of Unit):

The electric power output capability that the GTG unit can maintain in the service environment for 1,000 hrs of operation between overhauls only scheduled outages for maintenance.

3.3 Design Basis Events:

Postulated events used in the design to establish the performance requirements of the structures and systems.

3.4 Design Load:

That combination of electric loads (kW and kVAR), having the most severe power demand characteristic, which is provided with electric energy from a GTG unit for the operation of engineered safety features and other systems required during and following shutdown of the reactor.

3.5 Gas Turbine Generator Unit:

An independent source of standby electrical power that consists of a diesel-fueled internal combustion engine (or engines) coupled to an electrical generator (or generators) through a reducing gearbox; the associated mechanical and electrical auxiliary systems; and the control, protection, and surveillance systems.

3.6 Engine Equilibrium Temperature:

The conditions at which the lube oil temperatures are both within ± 5.5°C (10°F) of their normal operating temperatures established by the engine manufacturer.

3.7 Load Profile:

The magnitude and duration of loads (kW and kVAR) applied in a prescribed time sequence, including the transient and steady-state characteristics of the individual loads.

3.8 Qualified Gas Turbine Generator Unit:

A GTG unit that meets the qualification requirements of the applicable standards and regulations.

3.9 Redundant Equipment or System:

An equipment or system that duplicates the essential function of another equipment or system to the extent that either may perform the required function regardless of the state of operation or failure of the other.

3.10 Service Environment:

The aggregate of conditions surrounding the GTG unit in its enclosure, while serving the design load during normal, accident, and post-accident operation.

3.11 Short-Time Rating (of Gas Turbine Generator Unit):

The electric power output capability that the GTG unit can maintain in the service environment for 300 hrs , without exceeding the manufacturer's design limits and without reducing the maintenance interval established for the continuous rating.

3.12 Slave Equipment:

Equipment not permanently installed, used for testing only.

3.13 Standby Power Supply:

The power supply that is selected to furnish electric energy when the preferred power supply is not available.

3.14 Start Signal:

That input signal to the GTG unit start logic that initiates a GTG unit start and run sequence.

3.15 Surveillance:

The determination of the state or condition of a system or subsystem.

4.0 SCOPE

4.1 General

When in service, the GTG unit has the capability of performing as a redundant unit of a standby power supply, in accordance with the requirements stated in IEEE Std 308.

EEE 387 defines the boundaries of systems and equipment included its scope. Although there is no regulatory requirement for Class 1E GTG system, MHI decided the scope of systems and equipment to be tested in Class 1E GTG qualification same with IEEE 387 shown in Figure-4.1. MHI manufactured prototype system based on Figure-4.1 and tested.

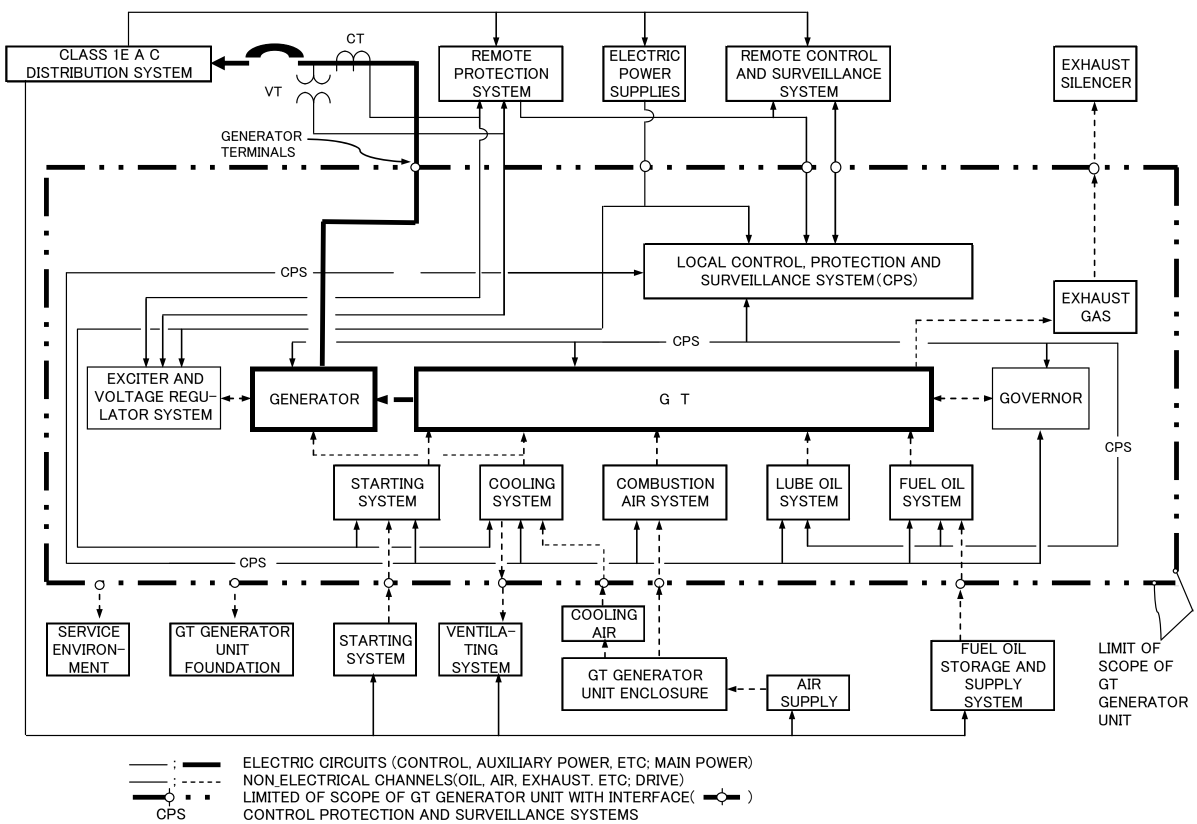


Figure 4.0-1 Scope Diagram

4.2 PROTOTYPE SYSTEM TESTED

Table-4.1 shows the list of systems, components and equipment of prototype system to be performed initial type test.

Systems or components of prototype GTG system inside the broken line in the previous figure were designed and manufactured in the same design conditions as actual plant system. The other systems or components outside the line are temporary and commercial and only supplied for these tests.

Table 4.0-1 Design Condition of Prototype GTG System

Component	Condition
Gas Turbine Engine With gearbox	Same with actual plant design
Generator	Same with actual plant design
Enclosure	Same with actual plant design
Skid	Same with actual plant design
Fuel day tank	Same with actual plant design
Starting air receiver	Same with actual plant design
Air start valve unit	Same with actual plant design
Air intake/ exhaust air duct	Temporary equipment for test
Local control cabinet	Same with actual plant design
Plant control cabinet	Temporary equipment for test
Power supply	Temporary equipment for test
Fuel storage and transfer system	Temporary equipment for test
Starting air compressor	Temporary equipment for test

5.0 PROTOTYPE SYSTEM

5.1 General

When in service, the GTG unit has the capability of performing as a redundant unit of a standby power supply, in accordance with the requirements stated in IEEE Std 308. Also GTG system should be designed in accordance with IEEE Std 387.

5.2 System specification

5.2.1 Starting Time

(1) Starting time of GTG is required within 100 seconds by safety design and analysis of US-APWR. GTG to be reached set voltage and frequency, and GTG breaker should be closed within 100 seconds after starting signal is initiated.
(2) US-APWR GTG is reached set voltage and frequency within 40 seconds as its standard specification.

5.2.2 Rating

The US–APWR GTG is rated as follows:
- ✓ 4500 kW Continuous @ 1,000 hrs Engine Overhaul Interval, 115°F Air Intake Temperature
- ✓ 4950 kW Short Time @ 300 hrs Engine Overhaul Interval, 115°F Air Intake Temperature

5.2.3 Fuel Oil System

(1) Engine fuel will be commercial grade No. 2 fuel oil with limits as stated in ASTM Specification D-396.
(2) A direct engine/gearbox driven pump that pumps fuel oil from the day tank to the fuel control valve is provided.
(3) The welded steel day tank, to hold a total quantity of fuel required for 1.5 hours operation at the continuous rating (2000 gallon rated) is provided. Tank is constructed in accordance with ASME Section Ⅲ, Class 3.

The system configuration is shown in Figure B.1.0-8.

5.2.4 Lubrication Oil System

(1) A complete lube oil system is furnished to supply oil under pressure to the engine bearings and reducing gear bearings.
(2) A lube oil cooler is supplied to remove heat from the engine and speed reducer oil during operation. The cooler shall be of the air to oil type and shall be driven by an electric motor driven fan, mounted close to the radiator core.

The system configuration is shown in Figure B.1.0-7.

5.2.5 Starting Air System

The engine shall be capable of being started by compressed air within 100 seconds after signal for start.

There are two air receivers in prototype system tested. In the actual plant design, four receivers capacity is designed that there is sufficient air at required pressure for three starts. The receivers are to be constructed in accordance with ASME Section Ⅲ, Class 3.

The starting manifold assembly consists of reduction valves, pipes, gauges, Y-strainer, and control valves. This unit reduces air pressure at the inlet of this unit to the specified pressure (the secondary air pressure). The secondary air pressure depends on air starter's maximum limit pressure at inlet.

The air compressor and compressor motor are designed as non safety related components.

The system configuration of starting air system is shown in Figure B.1.0-9.

5.2.6 Intake/Exhaust Air System

Air intake and exhaust systems consist of duct, silencer and ventilation fans. Drawing of tested system is shown in Figure B.1.0-10. Those will be designed in accordance with the site specific condition at actual plant project stage.

5.2.7 Enclosure/Skid

The skid type base plate is provided of rolled steel sections welded together to form a rigid base for mounting the engine and generator systems above and suitable for bolting to a reinforced concrete foundation.

5.2.8 Control system

One free standing local control panel having following function is furnished.
・ Manual GTG start/stop operation for maintenance
・ Individual start/stop operation of related GTG components for maintenance
・ Monitoring of GTG and related component parameters for maintenance

The local control cabinet is actuated by sent signal from safety logic system of GTG which is digital control cabinet and not within the qualification scope.

5.2.7 Load Profiles

The load profiles of US-APWR used as test condition are shown in Appendix A.

5.3 Component specification

5.3.1 Gas Turbine Engine & Gearbox

Specification of gas turbine engine & gearbox is shown in Table 5.3-1.

Table 5.3-1 Specification Of GT

Item		Specification
Gas Turbine Engine	Product	Kawasaki M1T-33 (twin engines with on gearbox) ✓ Two-stage Centrifugal Compressor ✓ Single Can Type Combustor ✓ Three-stage Axial Turbine
	Type	Simple & Open Cycle Single-shaft type
	Rotation Speed	17,944 min^{-1}
	Dimension Size (L, W, H)	3,398 mm, 2,679 mm, 2,403 mm (with Gearbox)
	Weight	14,000 kg (with Gearbox)
Gearbox	Type	Epicyclic Gear + Parallel Gear,
	Rotation Speed	1800 min^{-1}
Drawing		Figure B.1.0-1 to -3

5.3.2 Generator

Specification of generator is shown in Table 5.3-2.

Table 5.3-2 Specification Of Generator

Item	Specification
Rating	5625 kVA
Power Factor	0.8 Rated
Rated Voltage	6900 V
Phase	3
Connection	Wye
Wire	6
Frequency	60 Hz
Insulation	Class F
Enclosure	Drip proof
Drawing	Figure B.1.0-11

5.3.3 Enclosure

Drawings of enclosure are shown in Figure B.1.0-6.

5.3.4 Skid

Drawings of skid are shown in Figure B.1.0-6.

5.3.5 Fuel Day Tank

Table 5.3-3 Specification Of Fuel Day Tank

Item	Specification
Quantity	1
Capacity	2000 gallon (7.57 cubic meter)
Drawings	Figure B.1.0-4

5.3.6 Air Receiver

Table 5.3-4 Specification Of Air Receiver

Item	Specification
Quantity	1
Capacity	1250 gallon
Drawings	Figure B.1.0-5

6.0 INITIAL TYPE TEST

6.1 General

The testing was in accordance with the initial type test portion of IEEEStd-387-1995 (section 6.2) and ISG-021 for application to gas turbine generator sets.

6.2 Load Capability Test

6.2.1 Outline

These tests demonstrate the capability of the GTG unit to carry the following rated loads at rated power factor for the period of time indicated, and to successfully reject load. One successful completion of the test sequence shall satisfy this particular requirement.

6.2.2 Procedure, Test Condition

a) Load equal to the continuous rating shall be applied for the time required to reach engine temperature equilibrium.
b) Immediately following step a), the short-time rated load shall be applied for a period of 2 h and the continuous rated load shall be applied of 22 h. The short-time rating load rejection test shall be performed.
c) Light-load or no-load capability as described shall be demonstrated by test. Light –load or no-load operation shall be followed by a load application ≧50% of the continuous kilowatt rating for a minimum of 0.5 h.

The detail test procedure is shown in Appendix D.

6.2.3 Acceptance Criteria

1）Maintain for duration while maintain normal temperature limits.
2) The load rejection test will be acceptable if the increase in speed of the engine does not exceed 75% if the difference between nominal speed and the overspeed trip set point, or 15% above nominal, whichever is lower.

6.2.3 Result

Parameters measured during the test are shown in Tables 6.2-1 to 6.2-3. The GTG was operated in the stable condition with no troubles, failures or abnormal conditions. All the parameters remained almost constant.
Also at the rejection of 110 % load, the engine did not stall. And the frequency did not exceed 63 Hz as shown in Figure C.1.0-1 which satisfies the acceptance criteria.
It is concluded that these test results are successful.

Table 6.2-1 Engine Lubricant Oil Parameter

		Engine #1			Engine #2		
		Oil Pressure [PSIG]	Oil Temp Engine In [℃]	Oil Temp Bug Drain [℃]	Oil Pressure [PSIG]	Oil Temp Engine In [℃]	Oil Temp Bug Drain [℃]
Average during 100% 1 hour operation		46	150	157	46	155	142
Average during 110% operation		45	154	160	46	154	148
Average during 100% 22 hour operation	Minimum	44	150	144	46	150	135
	Average	46	151	155	48	151	141
	Maximum	47	155	162	50	156	145

Table 6.2-2 Engine Temperature Parameter

		Ambient Temp [°F]	Engine #1			Engine #2		
			Exhaust Temp [°F]	Air Inlet Restriction [°F]	Compressor Discharge Pressure [PSIG]	Exhaust Temp [°F]	Air Inlet Restriction [°F]	Compressor Discharge Pressure [PSIG]
Average during 100% 1 hour operation		81	388.8	6.5	126	385.4	6.1	128
Average during 110% operation		78	496.1	6.4	135	512.7	6.1	140
Average during 100% 22 hour operation	Minimum	56	441.0	6.5	135	438.0	6.1	140
	Average	65	453.5	6.5	141	449.4	6.4	143
	Maximum	73	468.0	6.5	150	463.0	6.5	150

Table 6.2-3 Generator Parameter

		AC Volts [VAC]	AC Amps [A]	Exciter Field DC Amps [A]	Exciter Field DC Volts [VDC]
Average during 100% 1 hour operation		6.94	292.6	1.85	40.75
Average during 110% operation		6.96	537.4	2.8	64.75
Average during 100% 22 hour operation	Minimum	6.90	452.3	2.6	56
	Average	6.91	469.3	2.6	57.5
	Maximum	6.92	477.60	2.6	58

6.3 Start and Load Acceptance Tests

6.3.1 Outline

A series of tests shall be conducted to establish the capability of the GTG unit to start and accept load within the period of time necessary to satisfy the plant design requirement. Total 150 starts were performed.

6.3.2 Procedure, Test Condition

a) Engine cranking shall begin upon receipt of the start-diesel signal, and the diesel-generator unit shall accelerate to specified frequency and voltage within the required time interval.
b) Immediately following step a), the diesel-generator unit shall accept a single-step load ≧50% of the continuous kilowatt rating. Load may be totally resistive or a combination of resistive and inductive loads.
c) 20 starts were performed under the cold condition, and 130 starts were performed under the hot condition.

The detail test procedure is shown in Appendix D.

Note) GT manufacture defines the cold condition of GT that the condition 10 hours turning performed after GT stopped run.

6.3.3 Acceptance Criteria

All starts should be achieved within 100 seconds. 150 starts should be performed with no failures.

6.3.4 Result

A part of the charts of 151 starts (Starts No.77 to No.81) are shown in Figures C.1.0-2 to C.1.0-6. Starting time is shown in Table 6.3-1. And the parameters measured during the test are shown in Table 6.3-2.
MHI has performed total 151 starts, and all the starts were conducted successfully without failures or abnormal conditions. Also all the starts achieved the “ready to load condition” within 30 seconds.
It is concluded that these test results are successful.

Table 6.3-1 Starting Time

	Minimum[Sec]	Average[Sec]	Maximum[Sec]
Cold (20 times)	26.0	26.6	27.5
Hot （131 times）	26.0	28.0	29.0

Table 6.3-2 Engine Parameter

		Cold	Hot
Intake Air [°F]		59.4	64.6
Engine #1	EGT[°F]	323.3	357.3
	Lube Oil temperature[°F]	33.2	67.0
	Lube Oil Pressure[PSIG]	56.5	46.4
Engine #2	EGT[°F]	323.4	357.6
	Lube Oil temperature[°F]	33.1	66.7
	Lube Oil Pressure[PSIG]	57.4	46.5

6.4 Margin tests

6.4.1 Outline

Tests shall be conducted to demonstrate the GTG unit capability to start and carry loads that are greater than the magnitude of the most severe step load within the plant design load profile, including step changes above base load.

6.4.2 Procedure, Test Condition

At least two margin tests shall be performed using either the same or different load arrangement. A margin test load at least 10% greater than the magnitude of the most severe single-step load within the load profile is considered sufficient for the margin test. The frequency and voltage excursions recorded may exceed those values specified for the plant design load.
The detail test procedure is shown in Appendix D.

6.4.3 Acceptance Criteria

a) Demonstrate the ability of the generator and excitation system to accept the margin test load (usually the low power factor, high inrush, and high starting current of a pump motor) without experiencing instability resulting in generator voltage collapse, or significant evidence of the inability of the voltage to recover.
b) Demonstrate that there is sufficient engine torque available to prevent engine stall, and to permit the engine speed to recover, when experiencing the margin test load.

6.4.4 Result

Charts of two margin tests are shown in Figures C.1.0-7 to C.1.0-8.
The GTG did not stall in the two tests. Although the voltage and frequency dropped just after loaded, they recovered within 2 seconds as shown in Figures C.1.0-7 and Figure C.1.0-8.
It is concluded that these test results are successful.

6.5 Load Transient Tests

6.5.1 Outline

This test is not required in R.G 1.9/IEEE Std 387. MHI performed this test as internal test in accordance with recommendation of manufacture. This test confirms capability for load transient and rejection.

6.5.2 Procedure, Test Condition

Three load transient tests were performed using condition with 25% to 100 % load.
The detail test procedure is shown in Appendix D.

6.5.3 Acceptance Criteria

Demonstrate that there is sufficient engine torque available to prevent engine stall, and to permit the engine speed to recover.

6.5.4 Result

Charts of the tests are shown in Figures C.1.0-9 to C.1.0-12. And the variation of voltage and frequency is shown in Table 6.5-1.
The GTG did not stall at all the transients and rejections. Although the voltage and frequency were fluctuated at load transient and rejection, the frequency recovered within 4 seconds.
It is concluded that these test results are successful.

Table 6.5-1 Voltage and Frequency Variation

	Parameters	Rejection		Transient	
		Variation %	Recovery Time Sec	Variation %	Recovery Time Sec
25%	Voltage	3.5	0.7	-4.4	0.8
	Frequency	0.3	2.5	-0.3	2.6
50%	Voltage	7.5	0.7	-8.6	1.1
	Frequency	0.6	3.0	-0.6	3.2
75%	Voltage	12.1	0.7	-12.5	2.2
	Frequency	0.9	3.9	-0.9	2.9
100%	Voltage	16.9	0.7	-16.6	2.4
	Frequency	1.4	3.4	-1.4	2.4

7.0 CONSIDERATION

7.1 Test Result Consideration

Based on the test results provided in this Technical Report it is concluded that the GTG unit provided by KHI and Class 1E qualified by Engine System Inc. (ESI) was successful in the initial type test.

(1) US-APWR GTG system was successful in all three initial type tests, “Load Capability Test”, “Start and Load Acceptance Test” and “Margin Test”.
(2) During “Load Capability Test”, GTG was operated without failures or troubles. Each parameter such as engine lubricant oil temperature, engine compressor pressure, exhaust gas temperature (EGT) and others was almost constant during 100% operation. During 110% operation EGT remained stable although it was higher than 100% operation.
(3) The 150 starts test was carried out with no failures or troubles. “Ready to Load” time of all starts was less than 30 seconds. The rotation speed increased at almost the same rate between all the tests conducted. When comparing the starting time between cold and hot conditions, the average starting time was shorter at the cold condition. This is because the governor is controlled by EGT to supply more fuel in the cold condition and start the GTG faster. Such design properties were confirmed during this test.
(4) GTGs rotate at $18000 min^{-1}$ and GD^2 is large. Therefore, transient load changes do not have much impact on rotation speed and also recovering from the rotation speed variation is quick because the governor is controlled by rotation speed and EGT. At 100% load transient/rejection, the frequency variation was -1.4 %/ 1.4 % respectively, which is very small and the recovery to the rated frequency was 2.4 seconds/ 3.5 seconds. Results were achieved which would not have happened in DG tests. This GTG’s frequency stabilizing capability is one of the advantages for GTG and well known in the specification of GTGs. It can be said that GTG is well qualified for nuclear power plant Class 1E emergency power sources which assume loading of large loads in sequence. It can be concluded that the Class 1E test proves this GTG’s capability and was meaningful.

7.2 Hot/Cold Starting Discussion

Based on the manufacture’s experiences and technical knowledge, the reliability and/or loading capability of the MHI’s GTG are not significantly affected by either ambient temperature or the temperature of the GTG components.

(1) Evaluating from the GTG’s structure, design, operational principle, there are no significant differences between hot and cold conditions in GTG due to ambient or component temperature at the time of starting. For details, please see Attachment E.
(2) Therefore, there is no requirement to conduct a minimum number of starts at prescribed conditions. Performing the start & load acceptance tests at conditions close to the normal operation conditions is sufficient to prove the starting reliability.
(3) As recommended by the Manufacture starting should not be attempted when lube Oil is greater then 70°C. Although this condition does not impact starting reliability; it does impact life and places undue stress on the unit.
Although there is no difference between the hot/cold conditions in GTG, there are definitions for hot/cold conditions given by the Manufacture. In this document, the cold condition refers to the condition in which 10 hours have passed and the temperature of the GTG structure has dropped as low as the ambient temperature since the engine stopped and turning

began. The hot condition refers to the condition which is not a cold condition defined as above, such as just after the engine has stopped.

(4) The test results show there is no difference between the hot/cold conditions. Moreover, the required starting time of 100 seconds was met with a wide margin for all the 150 starts in both hot/cold conditions, although the average starting time for hot condition was a little longer than the cold condition as shown in Table 6.3-1. It can be concluded that the starting reliability of GTG is independent of temperature from the test.

7.3 Reliability Discussion

The summary of the reliability discussion of the GTG are as follows. For details, please see Attachment F:

(1) According to a domestic GTG's field data, the GTG failure rate is statistically evaluated as 3.5×10^{-4}/demand, which proves high reliability of the GTG.
(2) However, the PRA analysis of US-APWR uses 4.53×10^{-3}/demand for GTG failure rate which is the same value as US Class 1E EDG reliability data to be more conservative.
(3) In addition, to satisfy the starting reliability of 0.975 with 95% confidence as required by the R.G1.155, 150 times of start tests shall be performed with no failure.
(4) The test result of the start & load acceptance tests shows 0 failure and has proved that the GTG satisfies the reliability requirement of 0.975 with 95% confidence.

8.0 CONCLUSIONS

Based on the results provided in this Technical Report, it is concluded that the US-APWR GTG unit is successful in the initial type test and meets the requirements for Class 1E emergency power sources described in R.G 1.9 and IEEE Std-38.

9.0 REFERENCES

In this section, references in this technical report except for applicable codes, standards and regulatory guidance in section 2 are listed.

1. ASME Section Ⅲ, Class 3
2. The requirements of MNES, Quality Assurance Administrative and System Requirements (Nuclear)
3. The requirements of MNES, Quality Assurance Administrative and System Requirements for Safety Related Electrical Equipment
4. MUAP-07024, Qualification and Test Plan of Class 1E Gas Turbine Generator System

Appendix A US-APWR Typical Load Profiles

Typical load profiles of Loss of Coolant Accident (LOCA) and LOOP are shown in Table A.1.0-1 to A.1.0-10 and Fig. A.1.0-1 to A.1.0-8

Table A.1.0-1 Class 1E GTG - LOCA Load List

Load Group	Load Name	Rated Output (kW)	Load Factor (%)	Efficiency (%)	Power Factor (%)	Ratio of Starting Current to Normal Current (%)	Power Factor at Starting (%)	Load Starting Capacity (kW)	Load Necessary Input (kW)
1	Moter Control Center	861.0	----	----	----	----	30.0	258.3	77.0
		371.0	----	----	----	----	----	----	371.0
2	MOV Operated by SI Signal MOV Operated by SP Signal	109.1	----	90.0	85.0	6.5	30.0	278.1	----
3	Safety Injection Pump	900.0	95.0	90.0	85.0	6.5	25.0	1911.8	950.0
4	Componet Cooling Water Pump	610.0	95.0	90.0	85.0	6.5	25.0	1295.8	643.9
5	Service Water Pump	720.0	95.0	90.0	85.0	6.5	25.0	1529.4	760.0
6	Containment Spray/Residual Heat Removal Pump	400.0	95.0	90.0	85.0	6.5	25.0	849.7	422.2
7	Emergency Feed Water Pump	590.0	72.5	90.0	85.0	6.5	25.0	1253.3	475.0
8	Class 1E Electrical Room Air Handling Supply Fan	80.0	95.0	85.0	80.0	6.5	25.0	191.2	89.4
9	Safety Chiller Unit	290.0	95.0	85.0	80.0	6.5	25.0	693.0	324.1
10	Safety Chilled Water Pump	53.0	95.0	94.0	91.0	6.5	25.0	100.7	53.6

Table A.1.0-2 Class 1E GTG -LOOP Load List

Load Group	Load Name	Rated Output (kW)	Load Factor (%)	Efficiency (%)	Power Factor (%)	Ratio of Starting Current to Normal Current (%)	Power Factor at Starting (%)	Load Starting Capacity (kW)	Load Necessary Input (kW)
1	Moter Control Center	687.0	----	----	----	----	30.0	206.1	55.0
		326.0	----	----	----	----	----	----	326.0
2	Componet Cooling Water Pump	610.0	95.0	90.0	85.0	6.5	25.0	1295.8	643.9
3	Service Water Pump	720.0	95.0	90.0	85.0	6.5	25.0	1529.4	760.0
4	Containment Spray/Residual Heat Removal Pump	400.0	95.0	90.0	85.0	6.5	25.0	849.7	422.2
5	Charging Pump	820.0	95.0	90.0	85.0	6.5	25.0	1741.8	865.6
6	Emergency Feed Water Pump	450.0	95.0	90.0	85.0	6.5	25.0	955.9	475.0
7	Class 1E Electrical Room Air Handling Supply Fan	80.0	95.0	85.0	80.0	6.5	25.0	191.2	89.4
8	Safety Chiller Unit	290.0	95.0	85.0	80.0	6.5	25.0	693.0	324.1
9	Plessurizer Heater	562.0	100.0	100.0	100.0	-----	-----	562.0	562.0
10	Safety Chilled Water Pump	53.0	95.0	94.0	91.0	6.5	25.0	100.7	53.6

Table A.1.0-3 Class 1E GTG Starting Sequence Train A - LOCA

LOCA Signal Initiated Time [Sec]	LOCA Sequence Time [Sec]	Invest Load	Refer Load Group	Base Load1 [KW]	Start Load [KW]	Max Load [KW]	Base Load2 [KW]
100	0	MOV Operated by SI Signal MOV Operated by SP Signal	2	0	907	907	448
		Moter Control Center	1				
105	5	A Safety Injection Pump	3	448	1912	2360	1398
110	10	A Component Cooling Water Pump	4	1398	1296	2694	2042
		A Safety Chilled Water Pump	10				
115	15	A Service Water Pump	5	2042	1529	3571	2802
130	30	A Containment Spray/Residual Heat Removal Pump	6	2802	850	3652	3224
140	40	A Class 1E Electrical Room Supply Air Handling Unit	8	3224	191	3415	3313
150	50	A Safety Chiller Unit	9	3313	693	4006	3637
	Manual Start	Moter Control Center		3637	102	3739	3739

Table A.1.0-4 Class 1E GTG Starting Sequence Train A - LOOP

LOOP Signal Initiated Time [Sec]	LOOP Sequence Time [Sec]	Invest Load	Refer Load Group	Base Load1 [KW]	Start Load [KW]	Max Load [KW]	Base Load2 [KW]
100	0	Moter Control Center	1	0	532	532	381
105	5	A Charging Pump	5	381	1742	2123	1247
110	10	A Component Cooling Water Pump	2	1247	1296	2543	1891
115	15	A Service Water Pump	3	1891	1630	3521	2705
		A Safety Chilled Water Pump	10				
130	30	A Class 1E Electrical Room Supply Air Handling Unit	7	2705	191	2896	2794
140	40	A Safety Chiller Unit	8	2794	693	3487	3118
	Manual Start	Moter Control Center	1	3118	627	3745	3745
		A Plessurizer Heater	9				

Table A.1.0-5 Class 1E GTG Starting Sequence Train B - LOCA

LOCA Signal Initiated Time [Sec]	LOCA Sequence Time [Sec]	Invest Load	Refer Load Group	Base Load1 [KW]	Start Load [KW]	Max Load [KW]	Base Load2 [KW]
100	0	MOV Operated by SI Signal MOV Operated by SP Signal	2	0	907	907	448
		Moter Control Center	1				
105	5	B Safety Injection Pump	3	448	1912	2360	1398
110	10	B Component Cooling Water Pump	4	1398	1296	2694	2042
		B Safety Chilled Water Pump	10				
115	15	B Service Water Pump	5	2042	1529	3571	2802
120	20	B Emergency Feed Water Pump	7	2802	1253	4055	3277
130	30	B Containment Spray/Residual Heat Removal Pump	6	3277	850	4127	3699
140	40	B Class 1E Electrical Room Supply Air Handling Unit	8	3699	191	3890	3788
150	50	B Safety Chiller Unit	9	3788	693	4481	4112
	Manual Start	Moter Control Center		4112	102	4214	4214

Table A.1.0-6 Class 1E GTG Starting Sequence Train B - LOOP

LOOP Signal Initiated Time [Sec]	LOOP Sequence Time [Sec]	Invest Load	Refer Load Group	Base Load1 [KW]	Start Load [KW]	Max Load [KW]	Base Load2 [KW]
100	0	Moter Control Center	1	0	532	532	381
110	10	B Component Cooling Water Pump	2	381	1296	1677	1025
115	15	B Service Water Pump	3	1025	1630	2655	1839
		B Safety Chilled Water Pump	10				
120	20	B Emergency Feed Water Pump	6	1839	956	2795	2314
130	30	B Class 1E Electrical Room Supply Air Handling Unit	7	2314	191	2505	2403
140	40	B Safety Chiller Unit	8	2403	693	3096	2727
	Manual Start	Moter Control Center	1	2727	627	3354	3354
		B Plessurizer Heater	9				

Table A.1.0-7 Class 1E GTG Starting Sequence Train C - LOCA

LOCA Signal Initiated Time [Sec]	LOCA Sequence Time [Sec]	Invest Load	Refer Load Group	Base Load1 [KW]	Start Load [KW]	Max Load [KW]	Base Load2 [KW]
100	0	MOV Operated by SI Signal	2	0	907	907	448
		MOV Operated by SP Signal					
		Moter Control Center	1				
105	5	C Safety Injection Pump	3	448	1912	2360	1398
110	10	C Component Cooling Water Pump	4	1398	1296	2694	2042
		C Safety Chilled Water Pump	10				
115	15	C Service Water Pump	5	2042	1529	3571	2802
120	20	C Emergency Feed Water Pump	7	2802	1253	4055	3277
130	30	C Containment Spray/Residual Heat Removal Pump	6	3277	850	4127	3699
140	40	C Class 1E Electrical Room Supply Air Handling Unit	8	3699	191	3890	3788
150	50	C Safety Chiller Unit	9	3788	693	4481	4112
	Manual Start	Moter Control Center		4112	102	4214	4214

Table A.1.0-8 Class 1E GTG Starting Sequence Train C - LOOP

LOOP Signal Initiated Time [Sec]	LOOP Sequence Time [Sec]	Invest Load	Refer Load Group	Base Load1 [KW]	Start Load [KW]	Max Load [KW]	Base Load2 [KW]
100	0	Moter Control Center	1	0	532	532	381
110	10	C Component Cooling Water Pump	2	381	1296	1677	1025
115	15	C Service Water Pump	3	1025	1630	2655	1839
		C Safety Chilled Water Pump	10				
120	20	C Emergency Feed Water Pump	6	1839	956	2795	2314
130	30	C Class 1E Electrical Room Supply Air Handling Unit	7	2314	191	2505	2403
140	40	C Safety Chiller Unit	8	2403	693	3096	2727
	Manual Start	Moter Control Center	1	2727	627	3354	3354
		C Plessurizer Heater	9				

Table A.1.0-9 Class 1E GTG Starting Sequence Train D - LOCA

LOCA Signal Initiated Time [Sec]	LOCA Sequence Time [Sec]	Invest Load	Refer Load Group	Base Load1 [KW]	Start Load [KW]	Max Load [KW]	Base Load2 [KW]
100	0	MOV Operated by SI Signal MOV Operated by SP Signal	2	0	907	907	448
		Moter Control Center	1				
105	5	D Safety Injection Pump	3	448	1912	2360	1398
110	10	D Component Cooling Water Pump	4	1398	1296	2694	2042
		D Safety Chilled Water Pump	10				
115	15	D Service Water Pump	5	2042	1529	3571	2802
130	30	D Containment Spray/Residual Heat Removal Pump	6	2802	850	3652	3224
140	40	D Class 1E Electrical Room Supply Air Handling Unit	8	3224	191	3415	3313
150	50	D Safety Chiller Unit	9	3313	693	4006	3637
	Manual Start	Moter Control Center		3637	102	3739	3739

Table A.1.0-10 Class 1E GTG Starting Sequence Train D - LOOP

LOOP Signal Initiated Time [Sec]	LOOP Sequence Time [Sec]	Invest Load	Refer Load Group	Base Load1 [KW]	Start Load [KW]	Max Load [KW]	Base Load2 [KW]
100	0	Moter Control Center	1	0	532	532	381
105	5	D Charging Pump	5	381	1742	2123	1247
110	10	D Component Cooling Water Pump	2	1247	1296	2543	1891
115	15	D Service Water Pump	3	1891	1630	3521	2705
		D Safety Chilled Water Pump	10				
130	30	D Class 1E Electrical Room Supply Air Handling Unit	7	2705	191	2896	2794
140	40	D Safety Chiller Unit	8	2794	693	3487	3118
	Manual Start	Moter Control Center	1	3118	627	3745	3745
		D Plessurizer Heater	9				

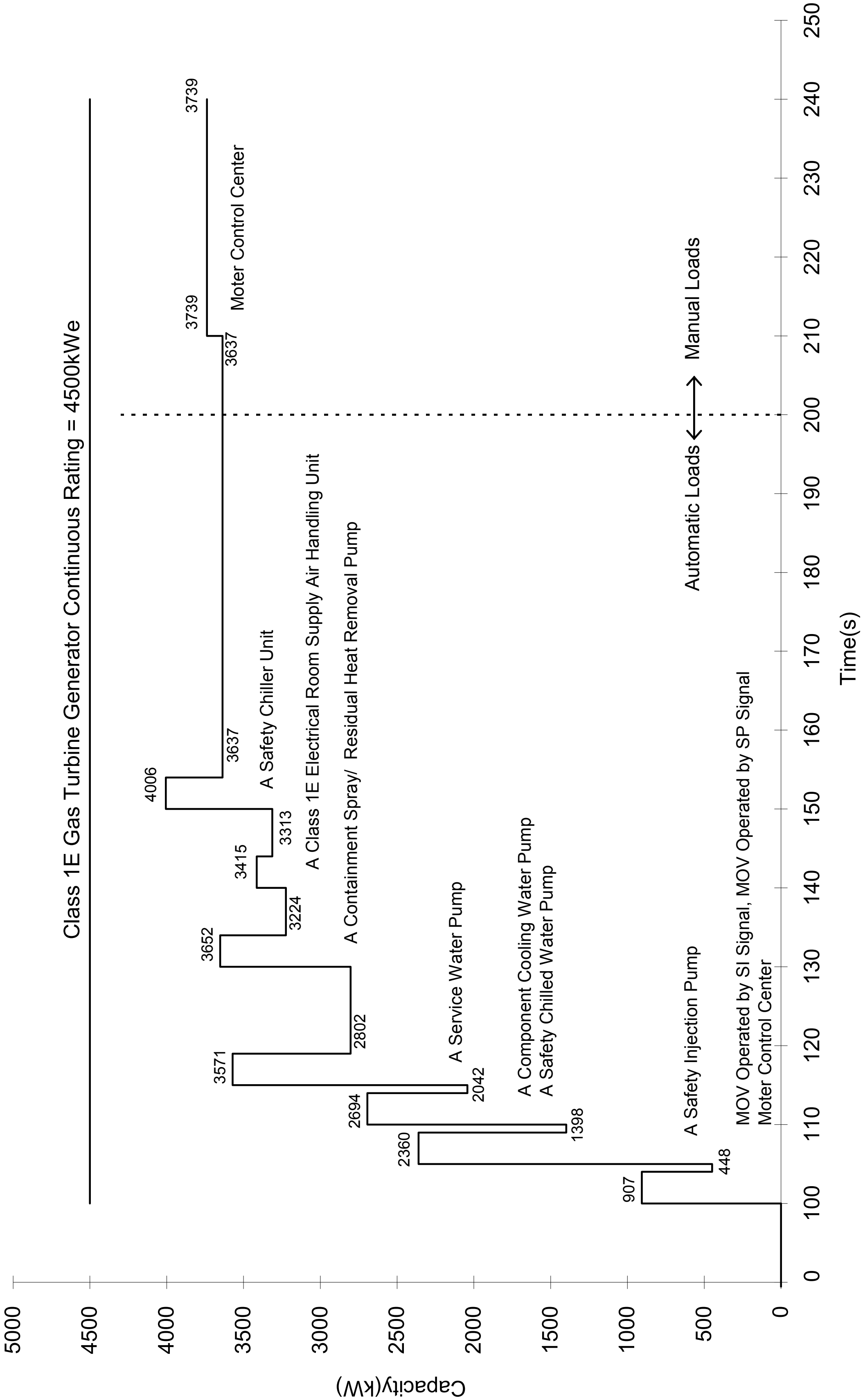


Figure A.1.0-1 LOCA Condition Class 1E GTG Load Profile (Train A)

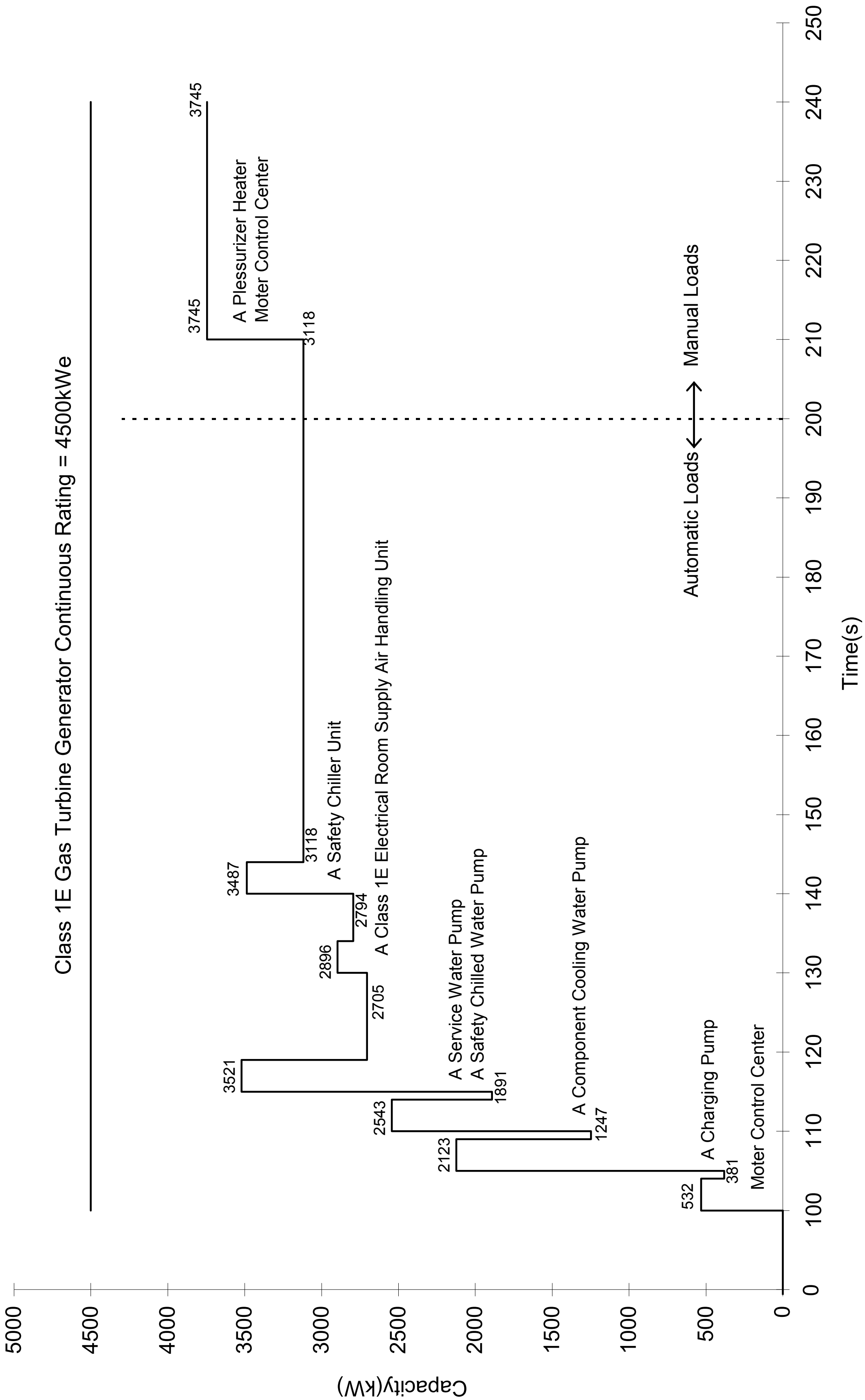


Figure A.1.0-2 LOOP Condition Class 1E GTG Load Profile (Train A)

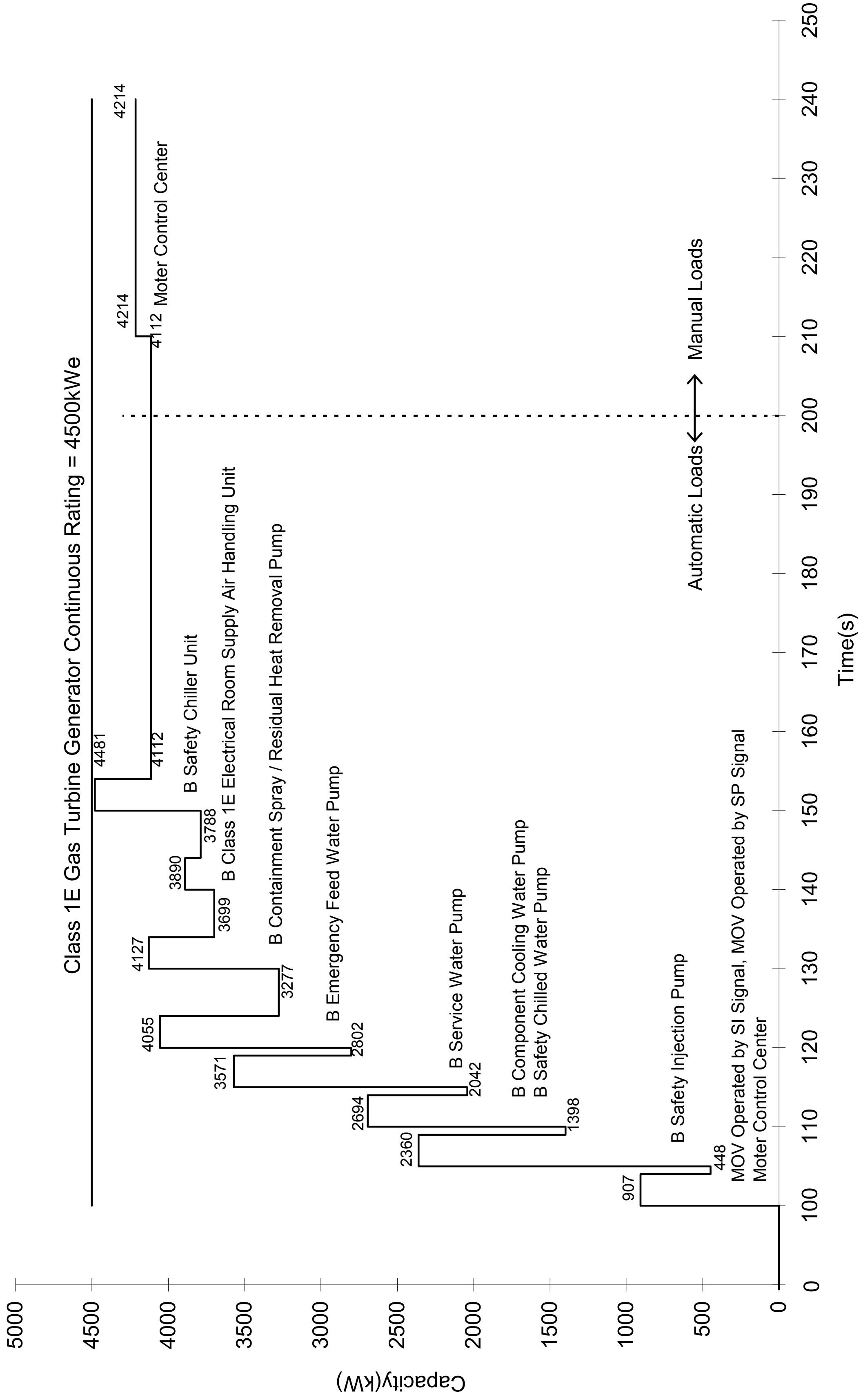


Figure A.1.0-3 LOCA Condition Class 1E GTG Load Profile (Train B)

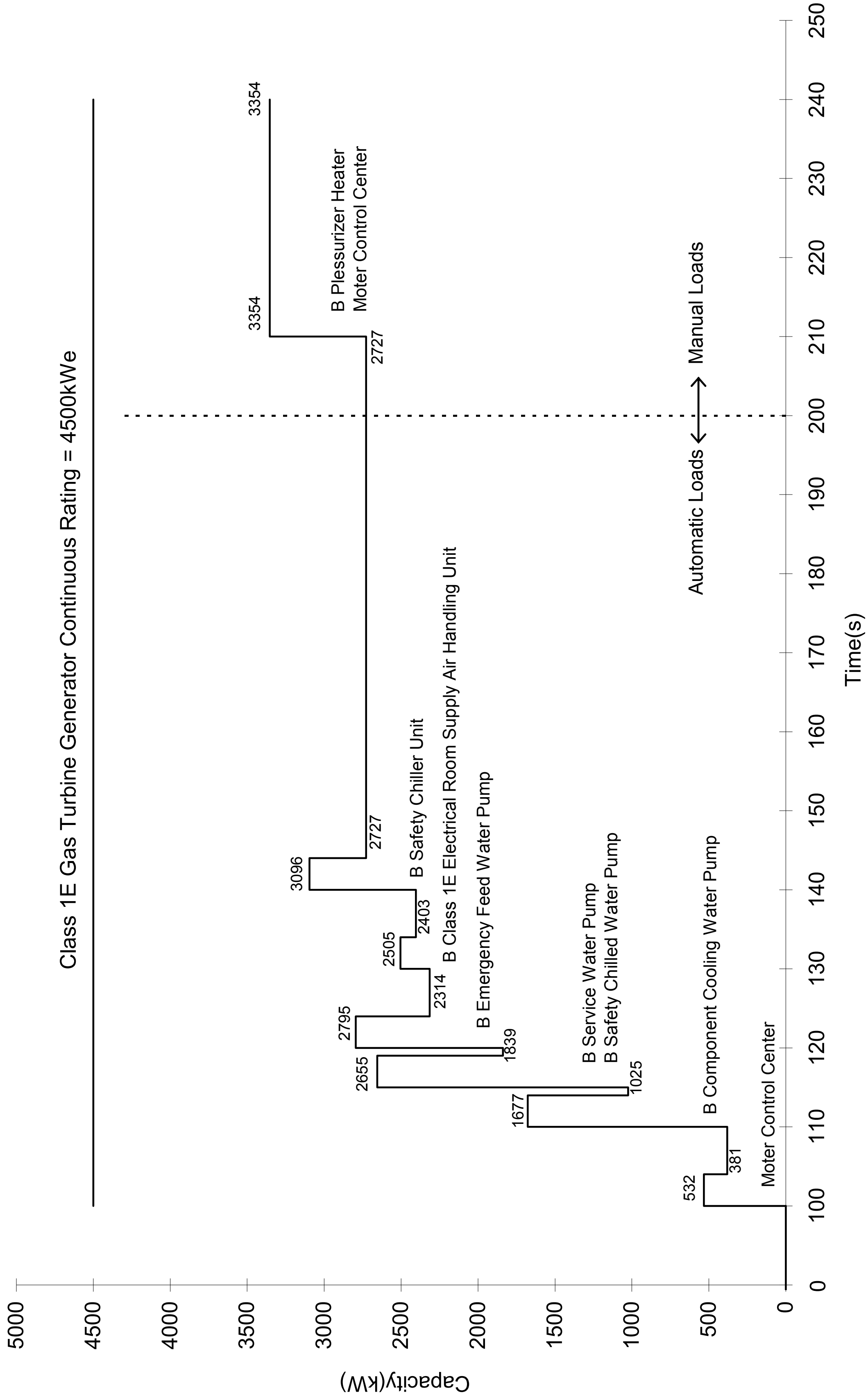


Figure A.1.0-4 LOOP Condition Class 1E GTG Load Profile (Train B)

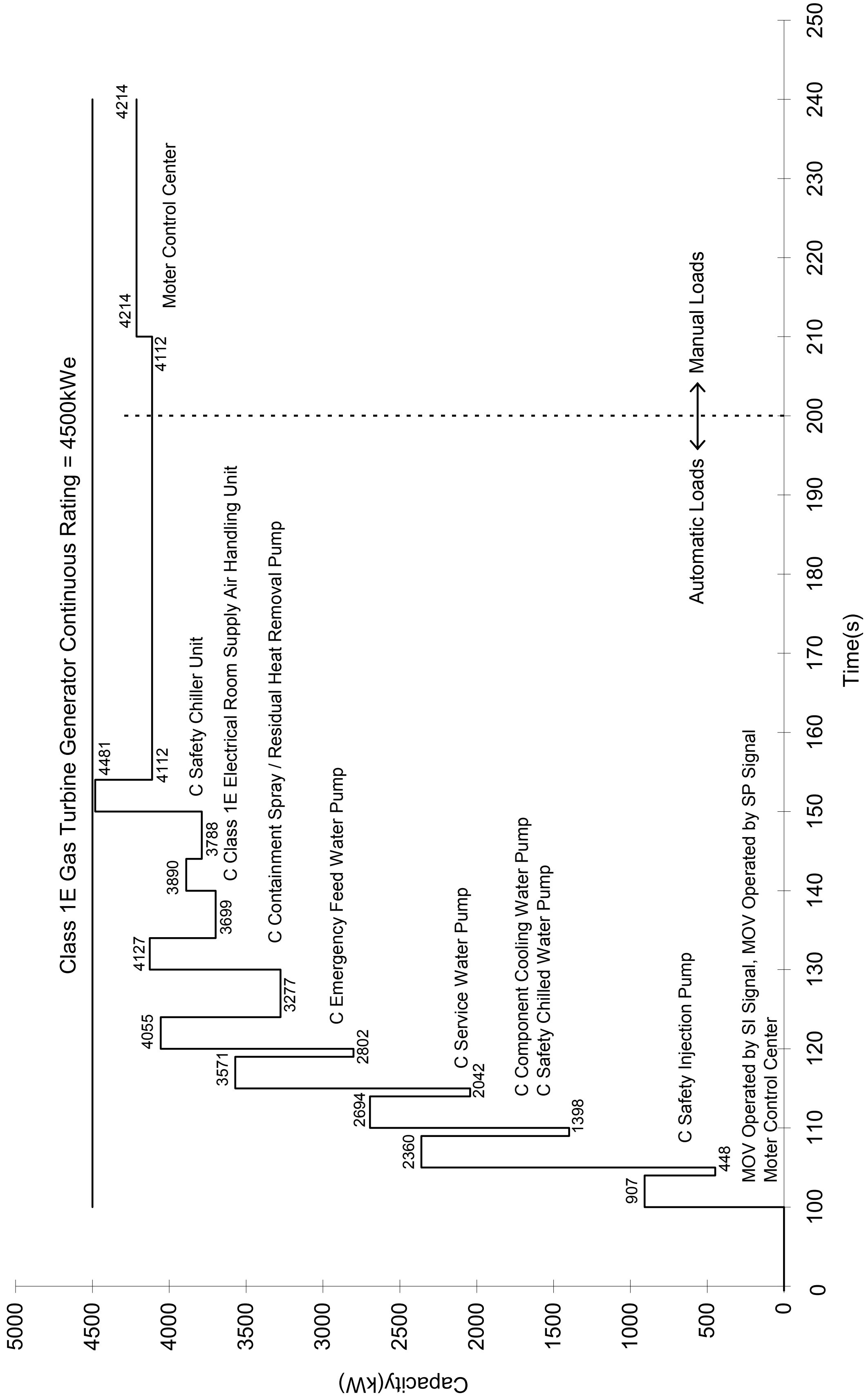


Figure A.1.0-5 LOCA Condition Class 1E GTG Load Profile (Train C)

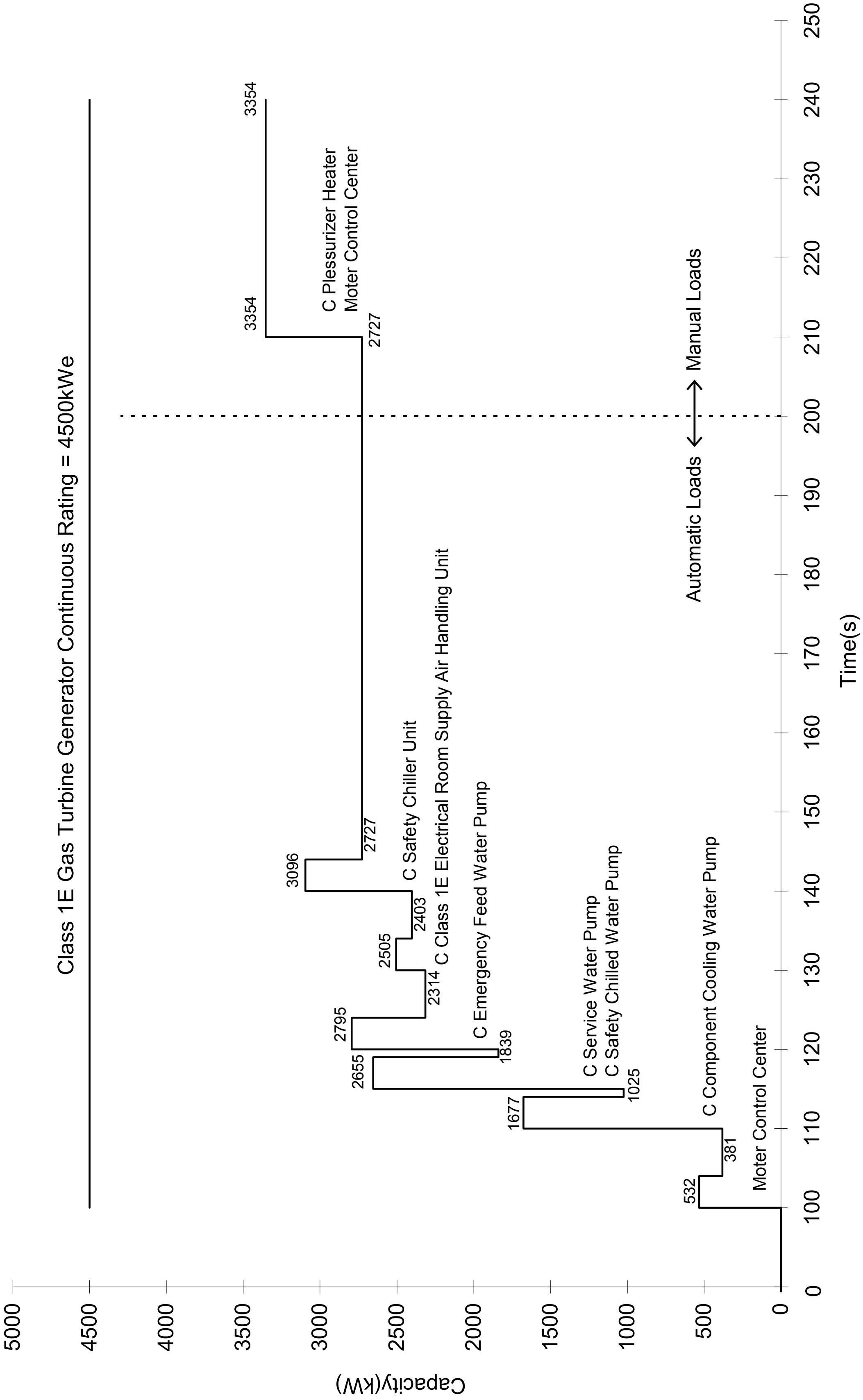


Figure A.1.0-6 LOOP Condition Class 1E GTG Load Profile (Train C)

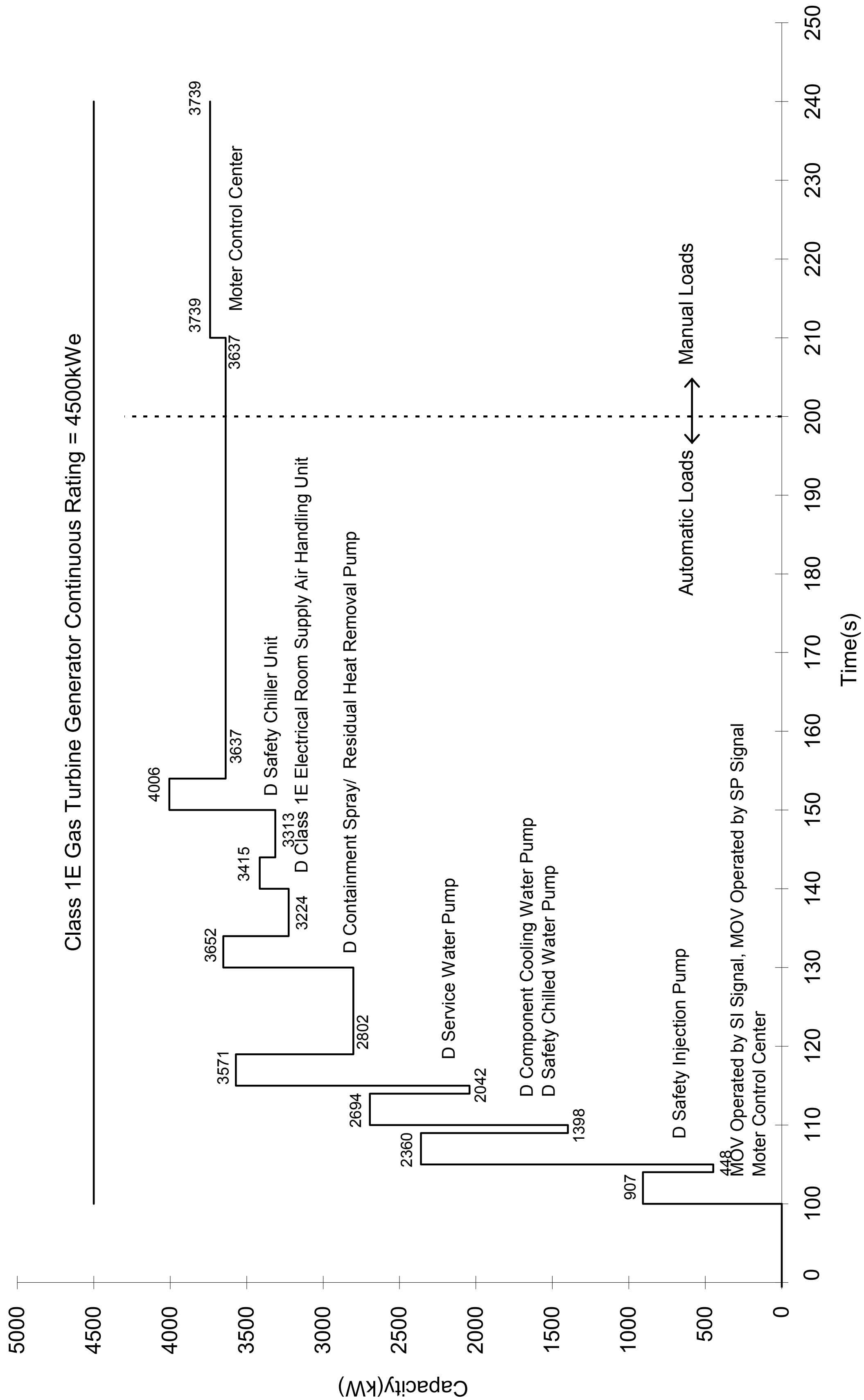


Figure A.1.0-7 LOCA Condition Class 1E GTG Load Profile (Train D)

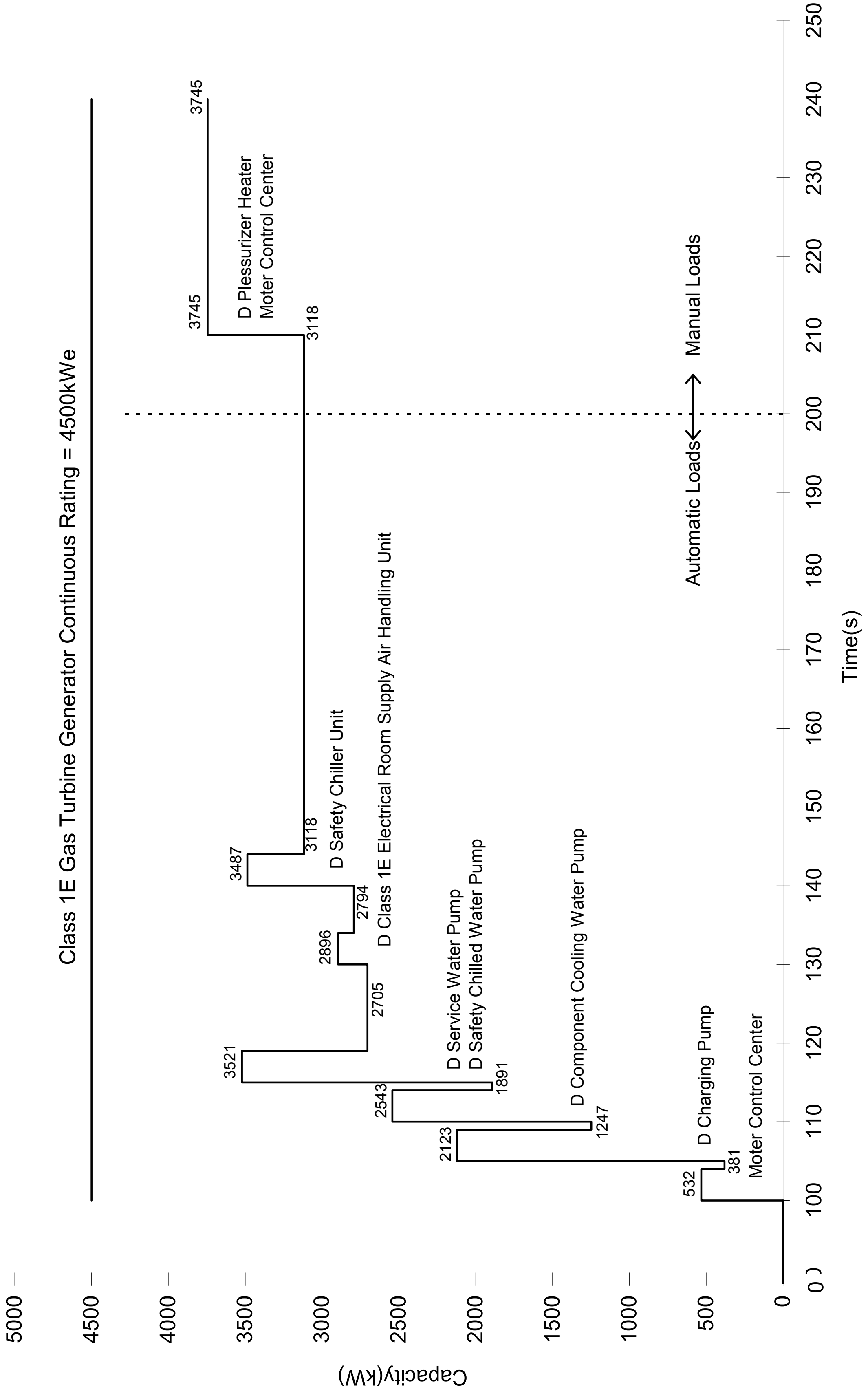


Figure A.1.0-8 LOOP Condition Class 1E GTG Load Profile (Train D)

Appendix B GTG Technical specification

Table B.1.0-1 Main Parts of Fuel, Oil, and Air System

Table B.1.0-2 Main Parts of Electric System

Table B.1.0-3 Engine Operation Limit and Protective Device Set Value

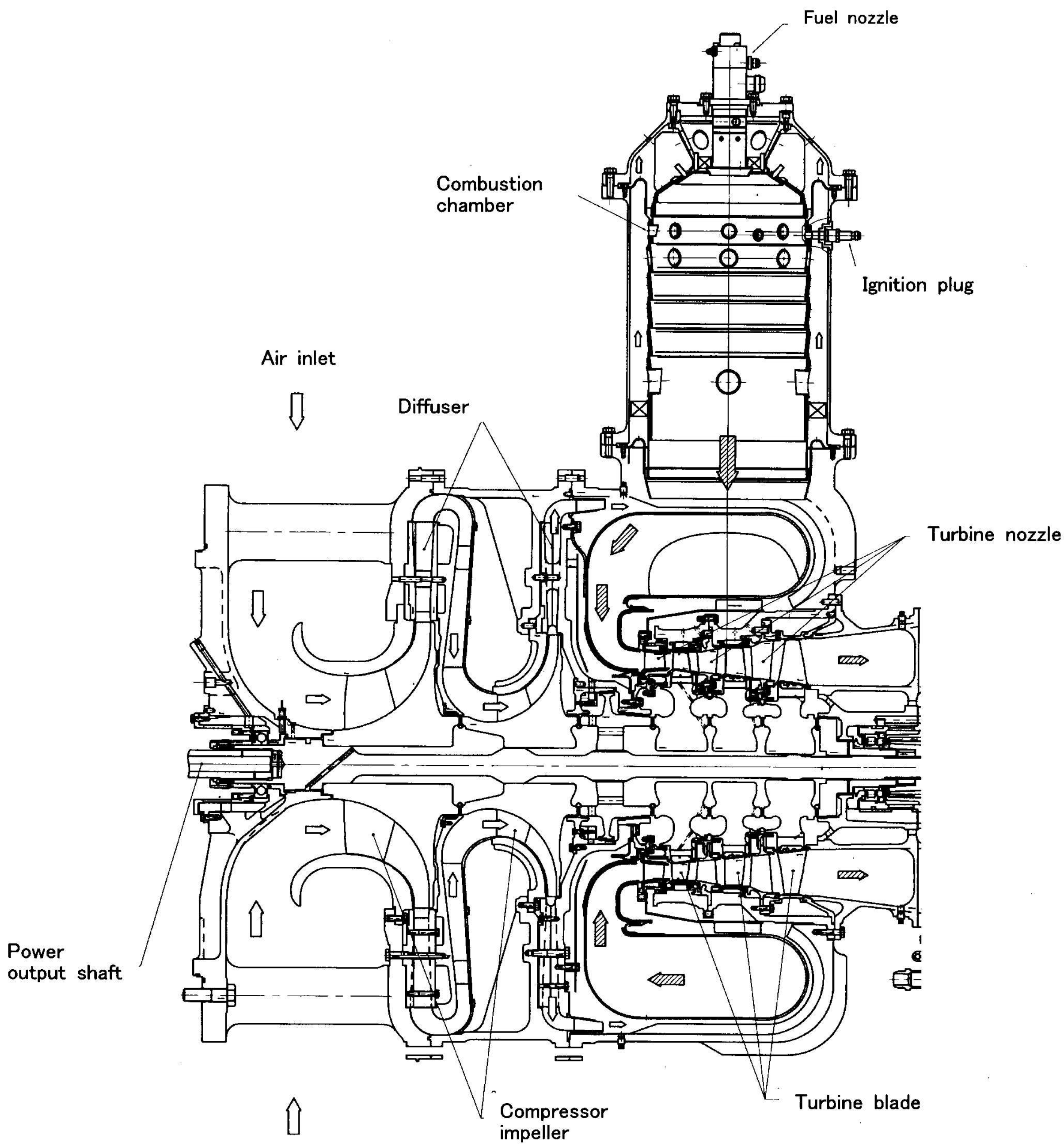
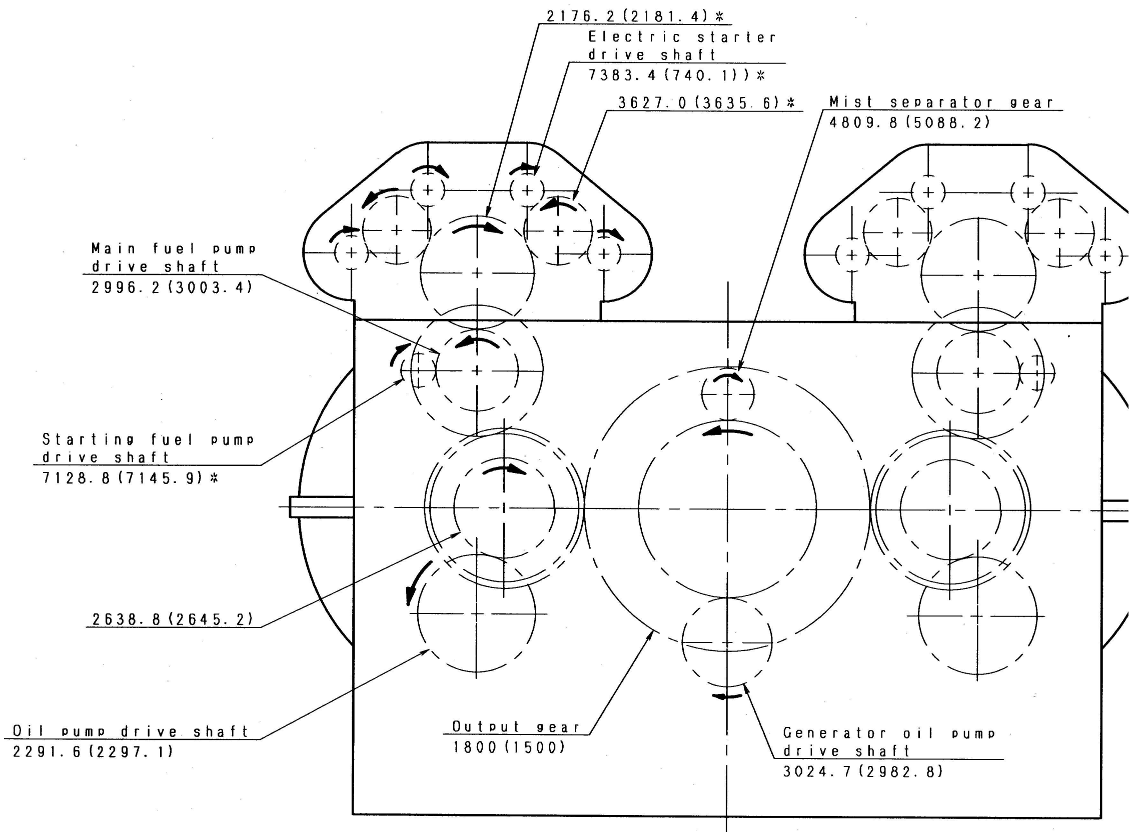


Figure B.1.0-1 Cross Sectional View of Power Section



Note : 1 Figures show the revolution speed (rpm).
The values are for 60Hz version machine and the values shown in parentheses are for 50Hz version machine.
: 2 The parts shown in asterisk * are intercepted by 55% revolution in case of electric starting system and by 50% revolution in case of pneumatic starting system.
That is, revolution speed at starter cut-off is 0.55 times of the above-mentioned value in case of electric starting system and 0.50 times of the above-mentioned value in case of pneumatic starting system.
: 3 The rotating direction is specified when it was viewed from the output shaft side.

Figure B.1.0-2 Gear Train of Reduction Gear Box

Figure B.1.0-3 Installation Drawing of Gas Turbine Assembly (Sheet 1 of 6)

Figure B.1.0-3 Installation Drawing of Gas Turbine Assembly (Sheet 2 of 6)

Figure B.1.0-3 Installation Drawing of Gas Turbine Assembly (Sheet 3 of 6)

Figure B.1.0-3 Installation Drawing of Gas Turbine Assembly (Sheet 4 of 6)

Figure B.1.0-3 Installation Drawing of Gas Turbine Assembly (Sheet 5 of 6)

Figure B.1.0-3 Installation Drawing of Gas Turbine Assembly (Sheet 6 of 6)

Figure B.1.0-4 Drawing of Fuel Day Tank (Sheet 1 of 2)

Figure B.1.0-4 Drawing of Fuel Day Tank (Sheet 2 of 2)

Figure B.1.0-5 Drawing of Air Receiver (Sheet 1 of 3)

Figure B.1.0-5 Drawing of Air Receiver (Sheet 2 of 3)

Figure B.1.0-5 Drawing of Air Receiver (Sheet 3 of 3)

Figure B.1.0-6 Drawing of Enclosure and Skid (Sheet 1 of 3)

Figure B.1.0-6 Drawing of Enclosure and Skid (Sheet 2 of 3)

Figure B.1.0-6 Drawing of Enclosure and Skid (Sheet 3 of 3)

Figure B.1.0-7 Configuration of Lubricant Oil System (Sheet 1 of 2)

Figure B.1.0-7 Configuration of Lubricant Oil System (Sheet 2 of 2)

Figure B.1.0-8 Configuration of Fuel Oil System

Figure B.1.0-9 Configuration of Starting Air System (Sheet 1 of 2)

Figure B.1.0-9 Configuration of Starting Air System (Sheet 2 of 2)

Figure B.1.0-10 Drawing of Inlet Air / Exhaust System

Figure B.1.0-11 Drawing of Generator Circuit

Figure B.1.0-12 Drawing of Alarm Panel

Appendix C Parameter Chart

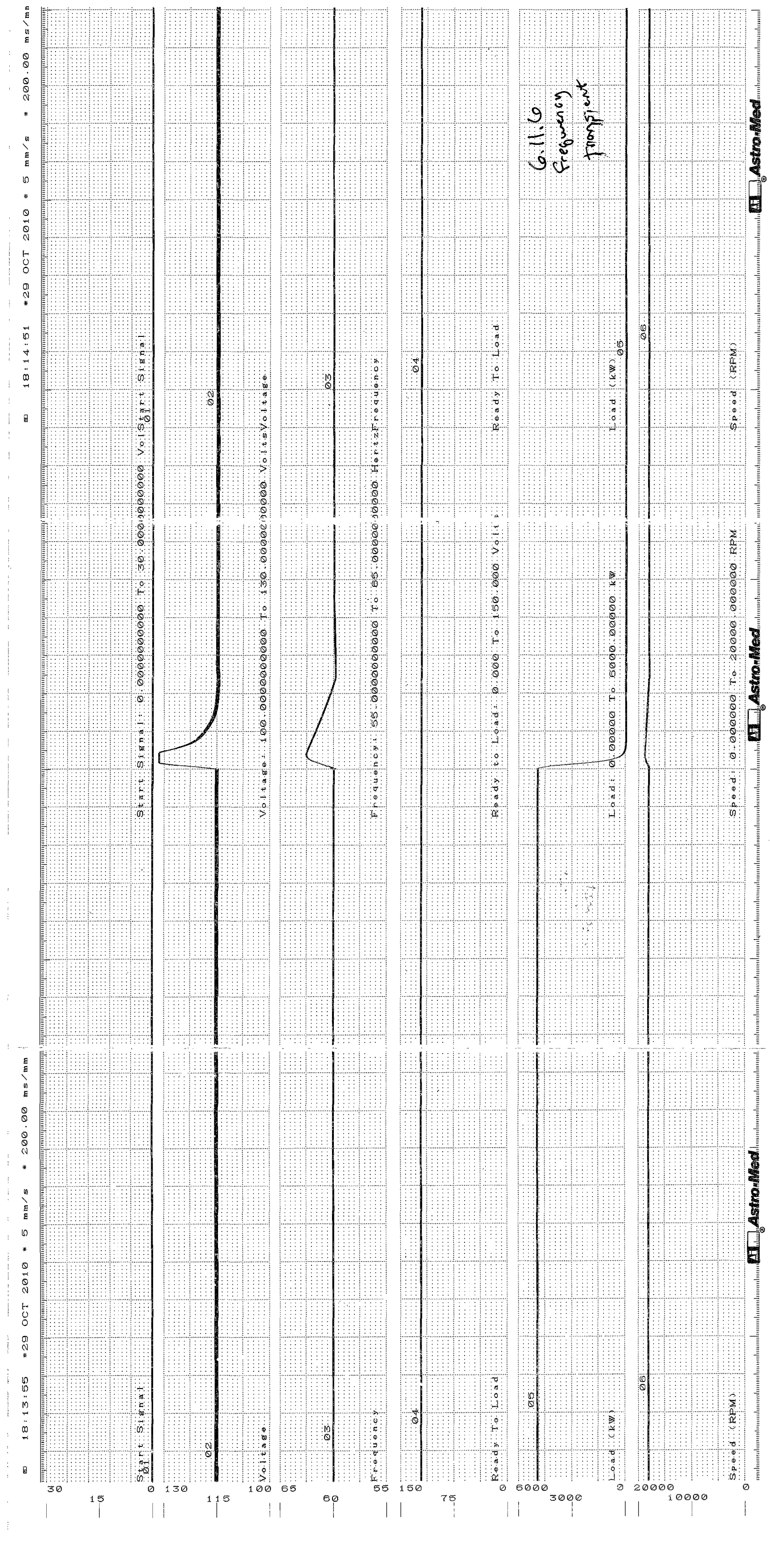


Figure C.1.0-1 Parameter Chart of Load Capability Test

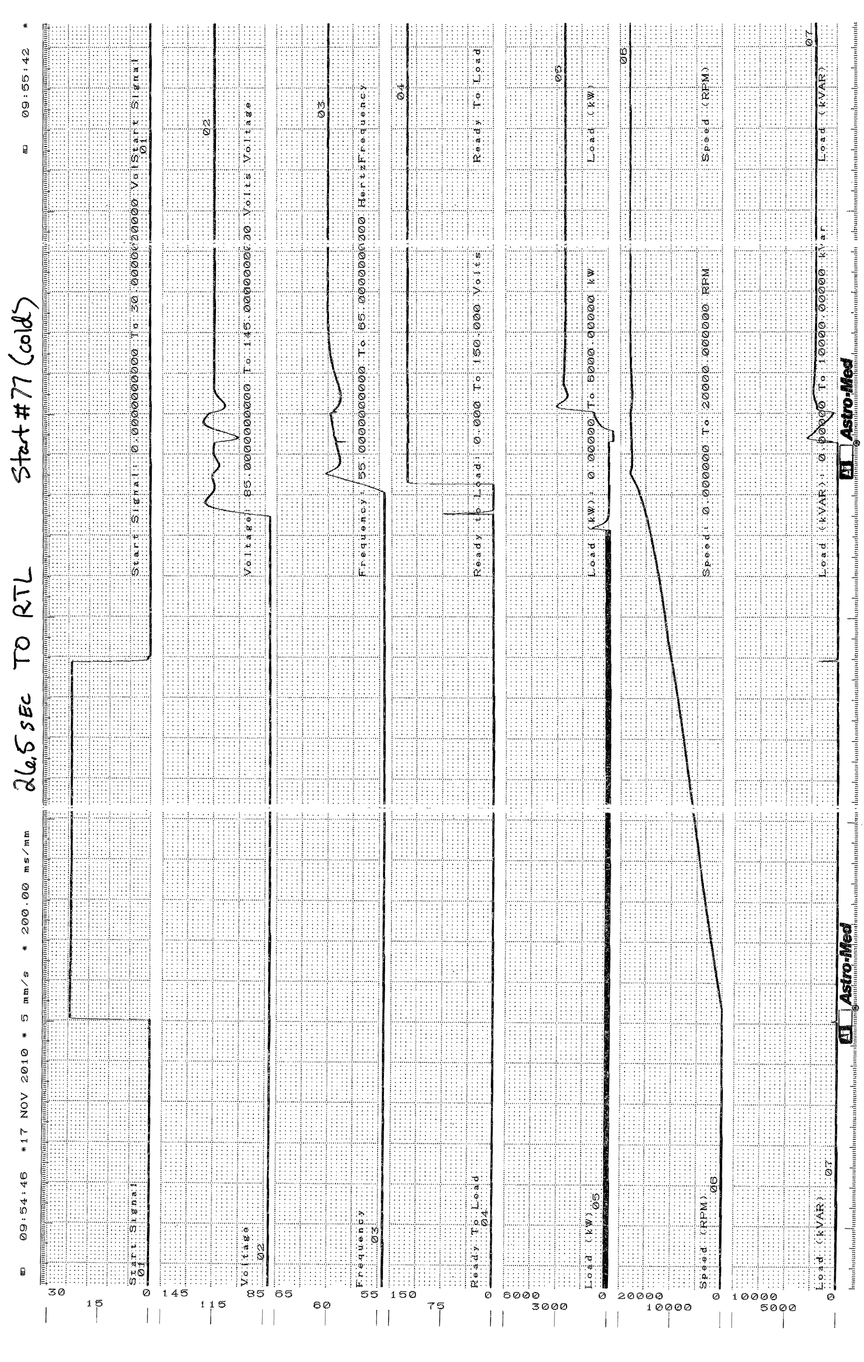


Figure C.1.0-2 Parameter Chart of Start and Load Acceptance Test, No.77, Cold

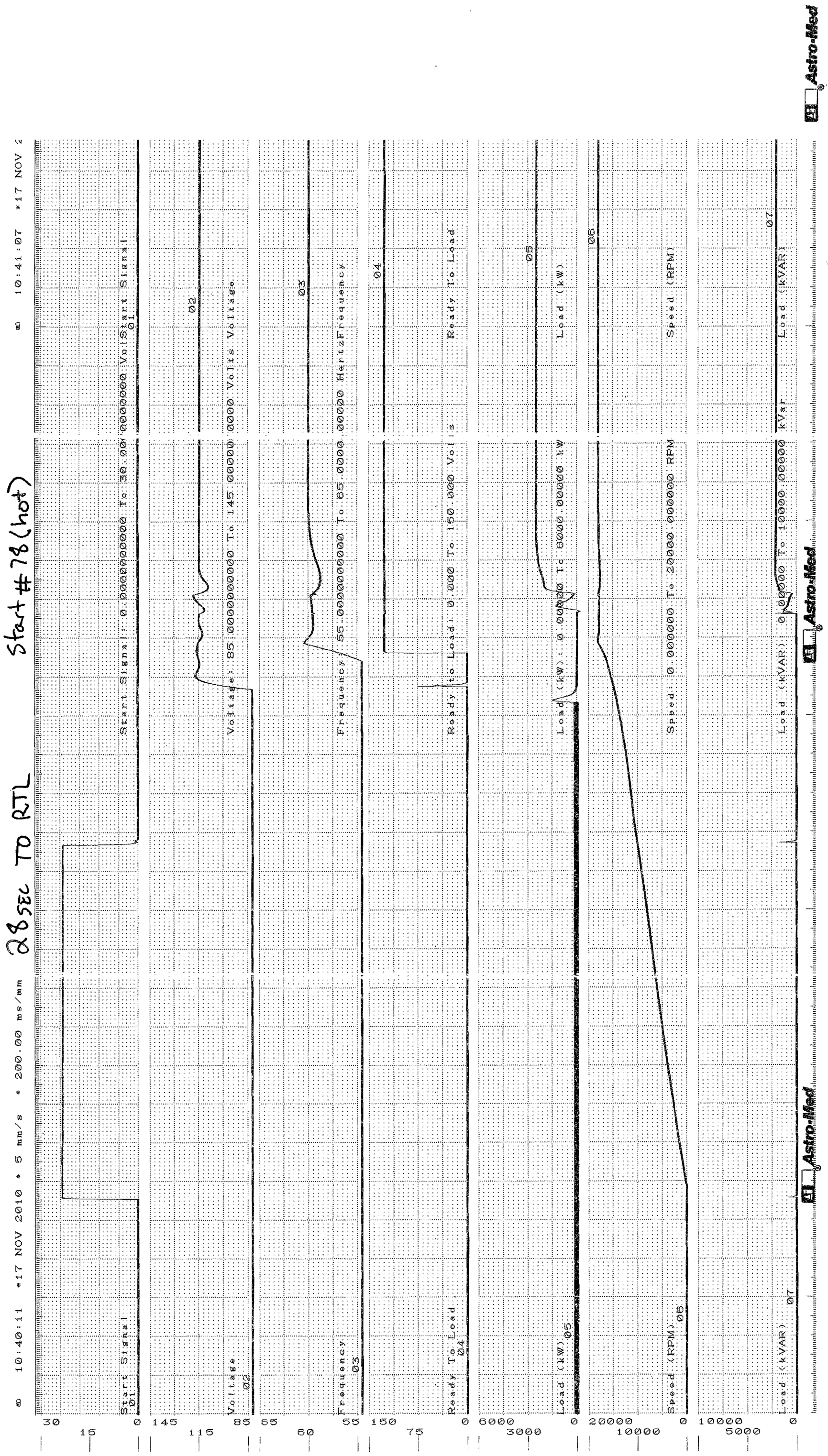


Figure C.1.0-3 Parameter Chart of Start and Load Acceptance Test, No.78, Hot

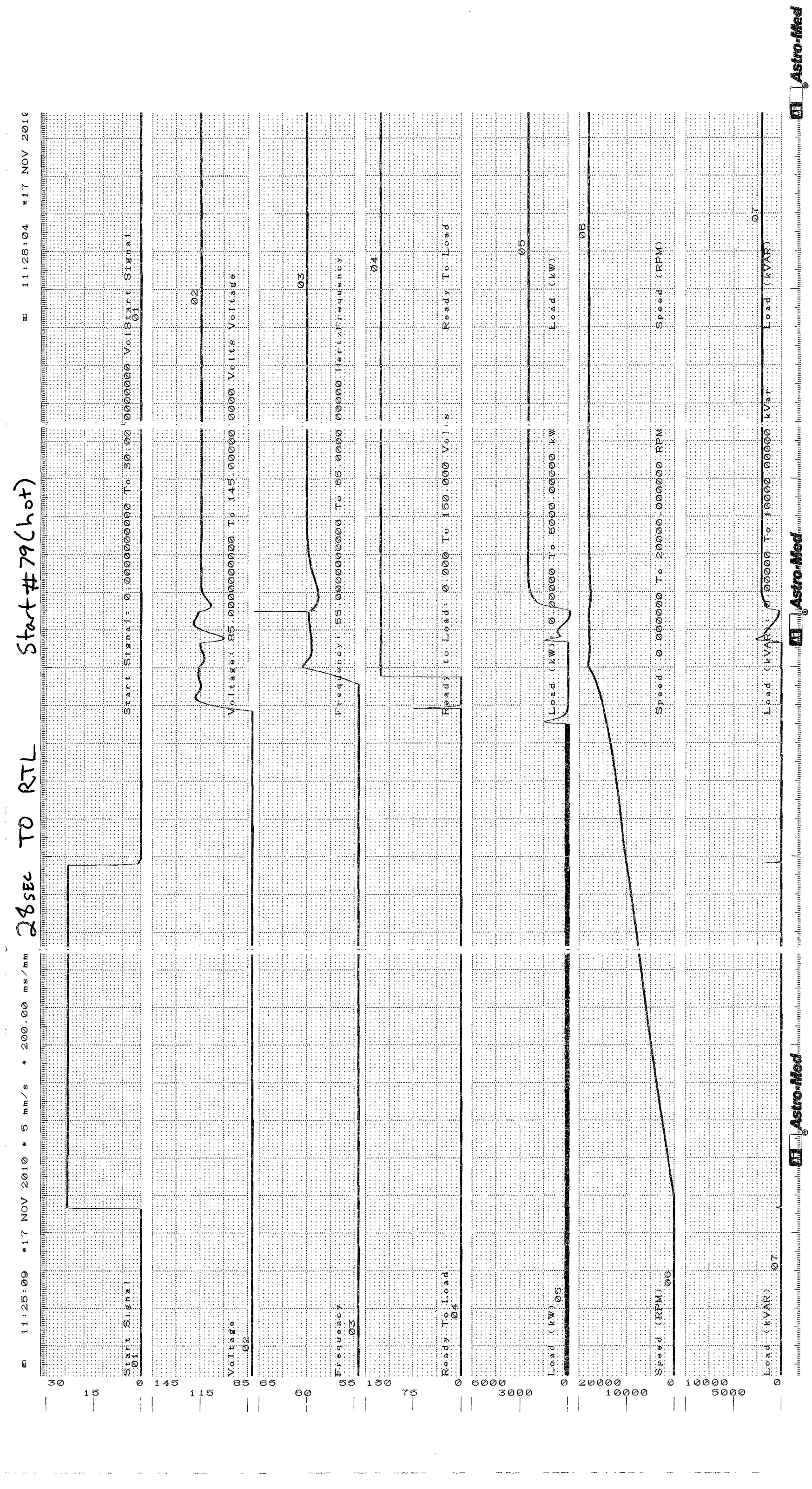


Figure C.1.0-4 Parameter Chart of Start and Load Acceptance Test, No.79, Hot

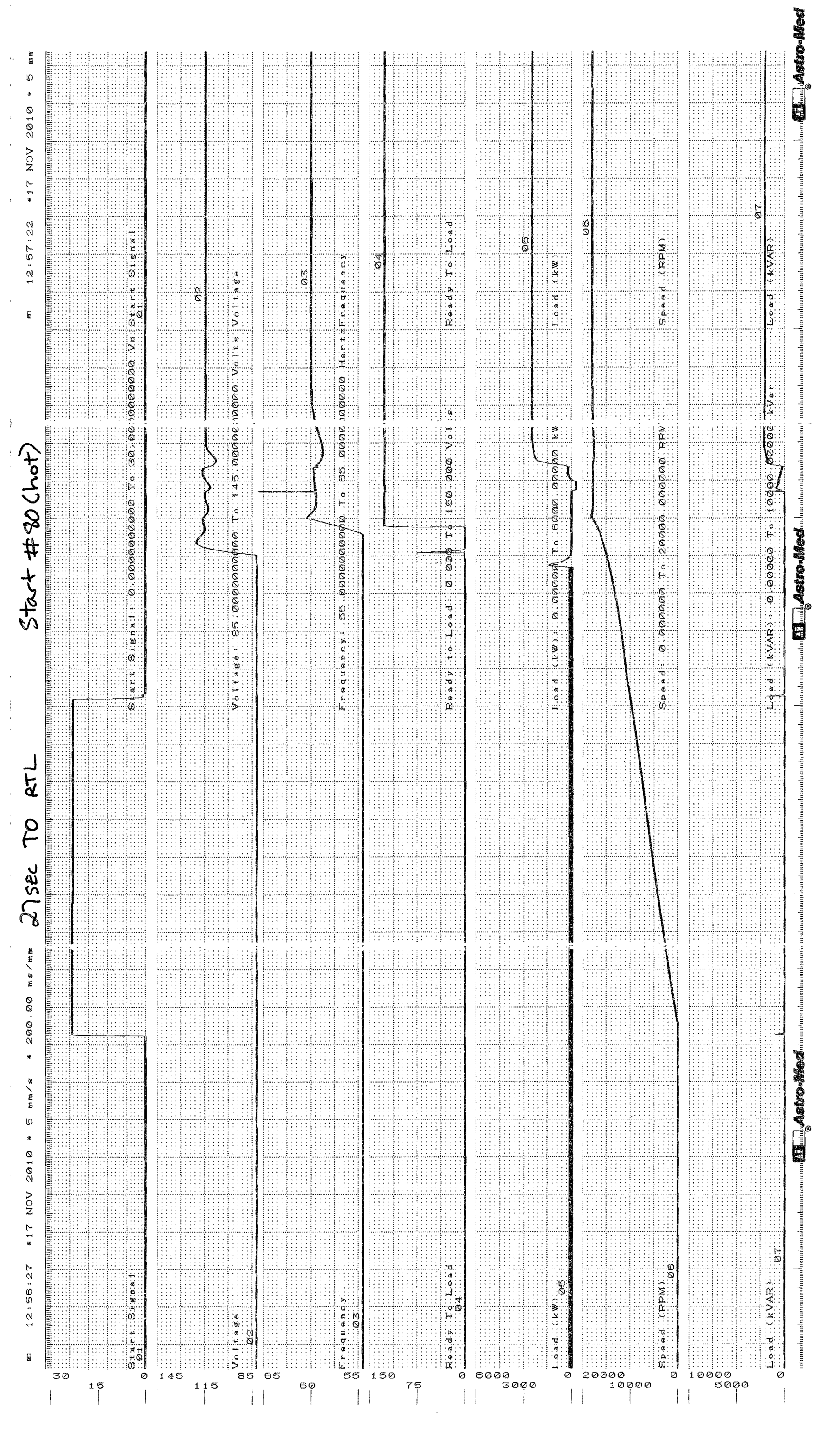


Figure C.1.0-5 Parameter Chart of Start and Load Acceptance Test, No.80, Hot

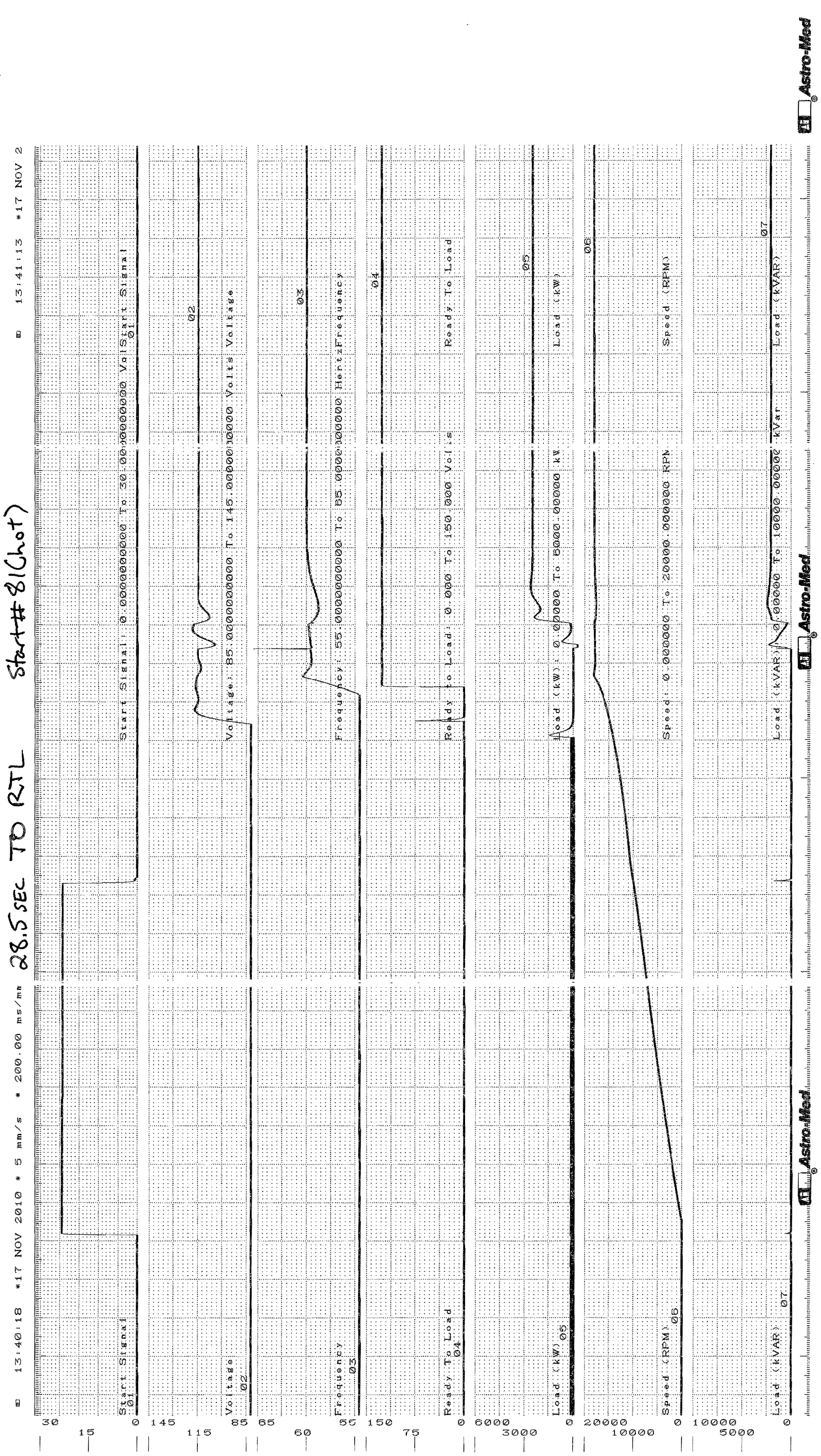


Figure C.1.0-6 Parameter Chart of Start and Load Acceptance Test, No.81, Hot

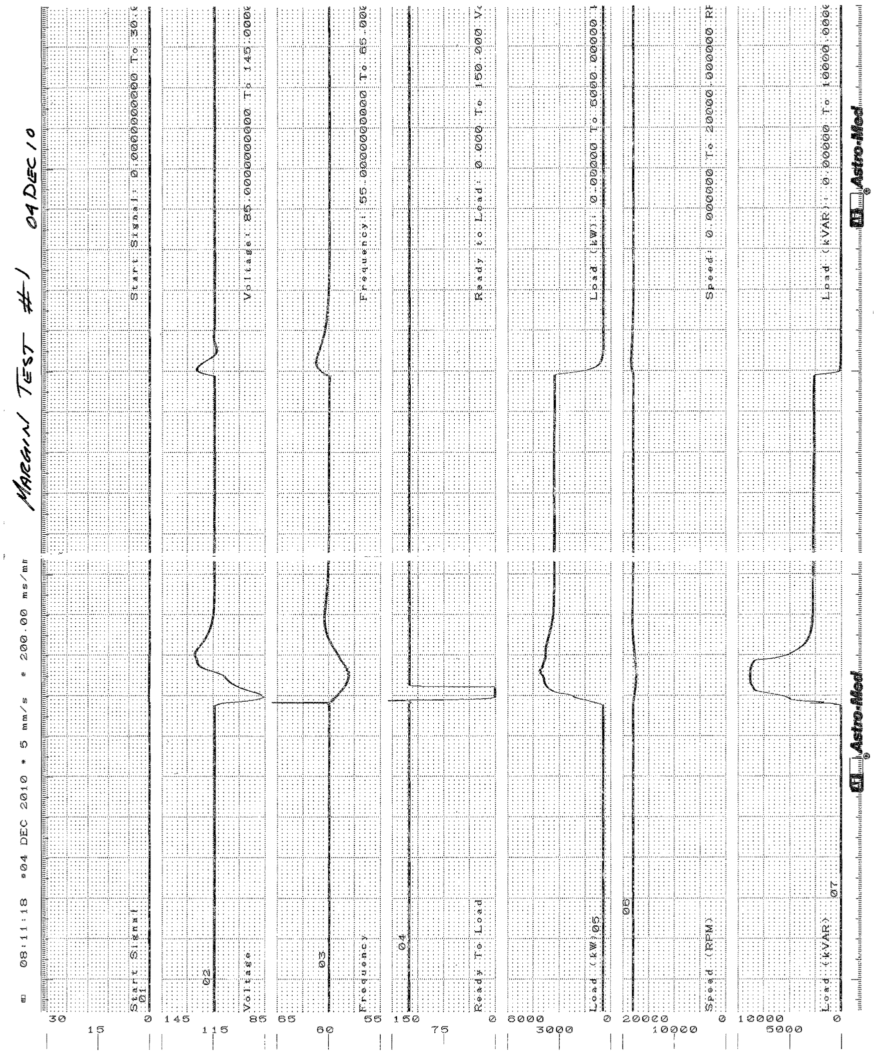


Figure C.1.0-7 Parameter Chart of No.1 Margin Test

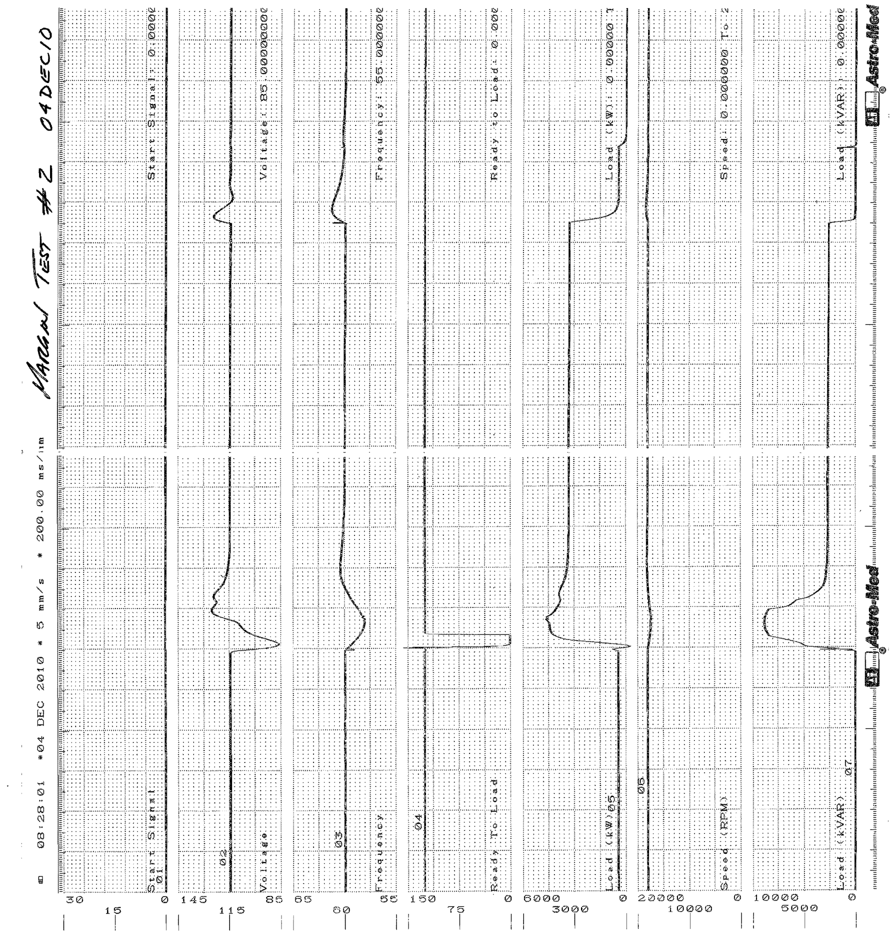


Figure C.1.0-8 Parameter Chart of No.2 Margin Test

Sheet 1

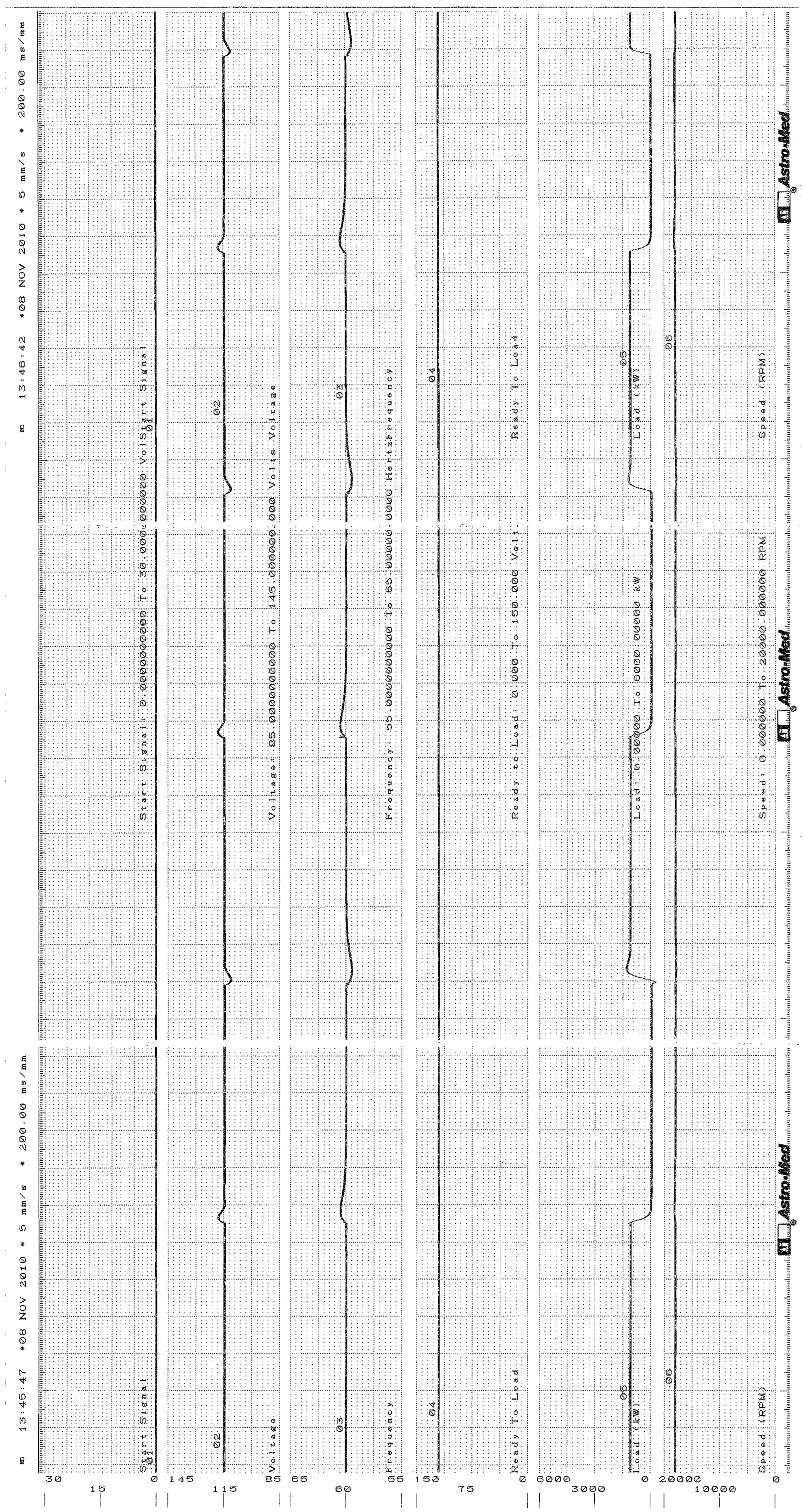


Figure C.1.0-9 Parameter Chart of Load Transient Test , 25%

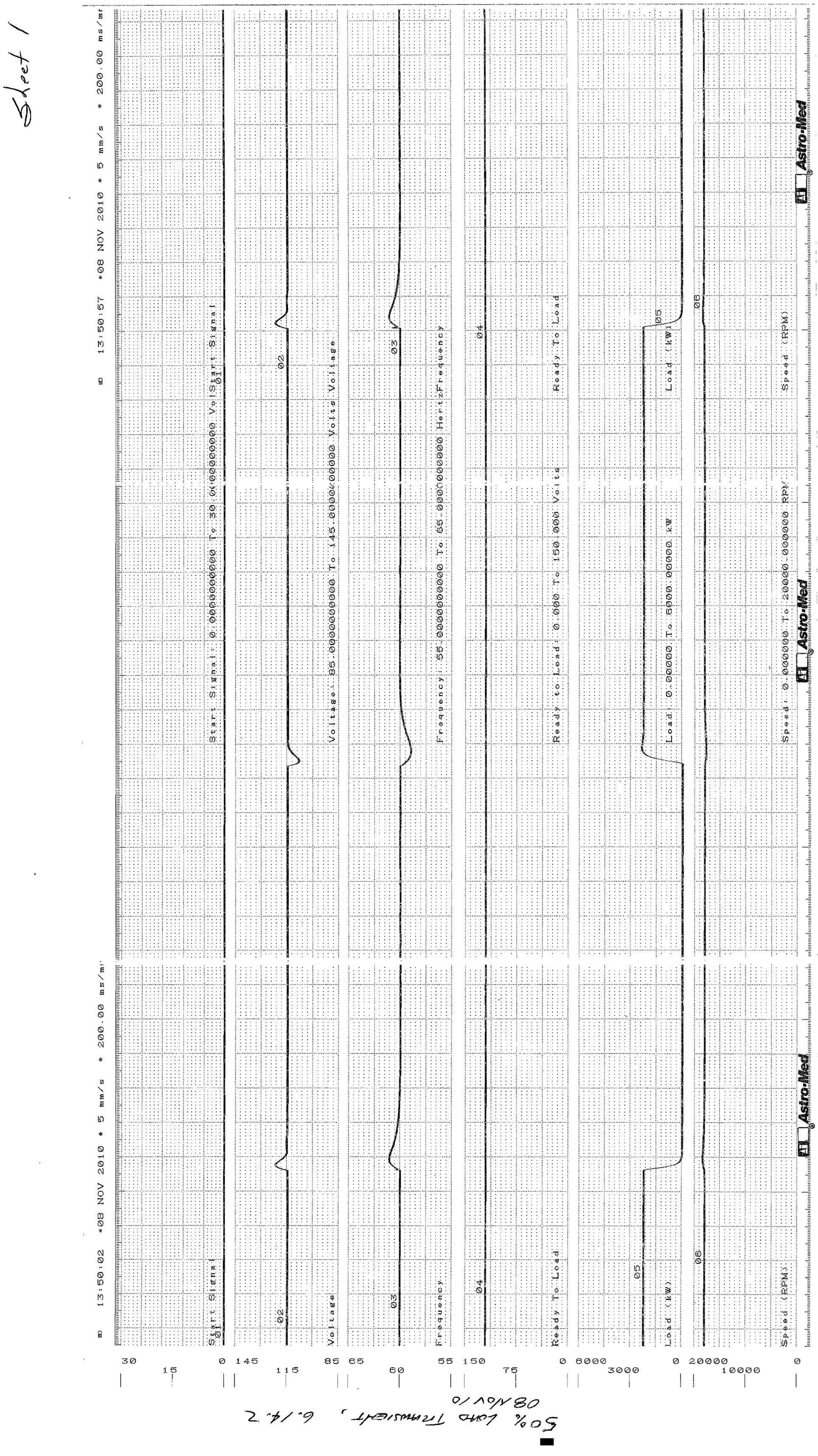


Figure C.1.0-10 Parameter Chart of Load Transient Test , 50% (Sheet 1 of 2)

Sheet 2

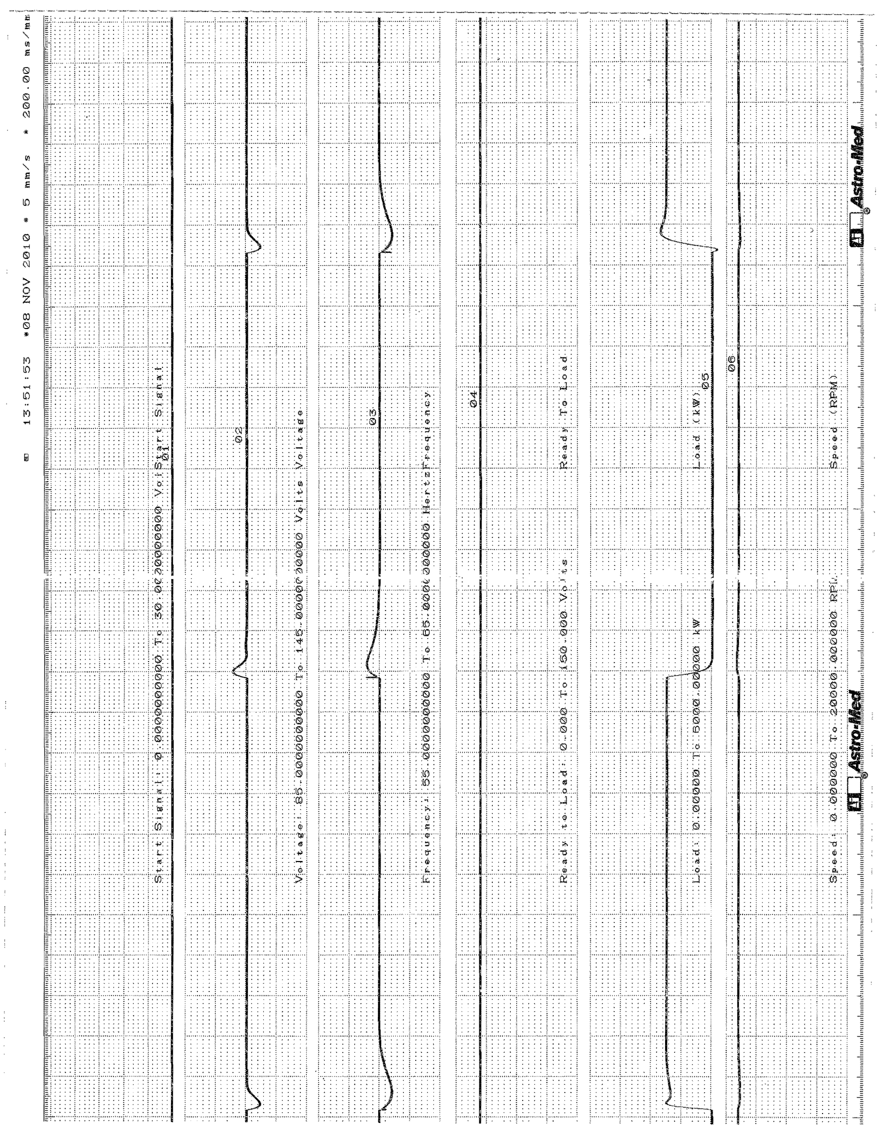


Figure C.1.0-10 Parameter Chart of Load Transient Test , 50% (Sheet 2 of 2)

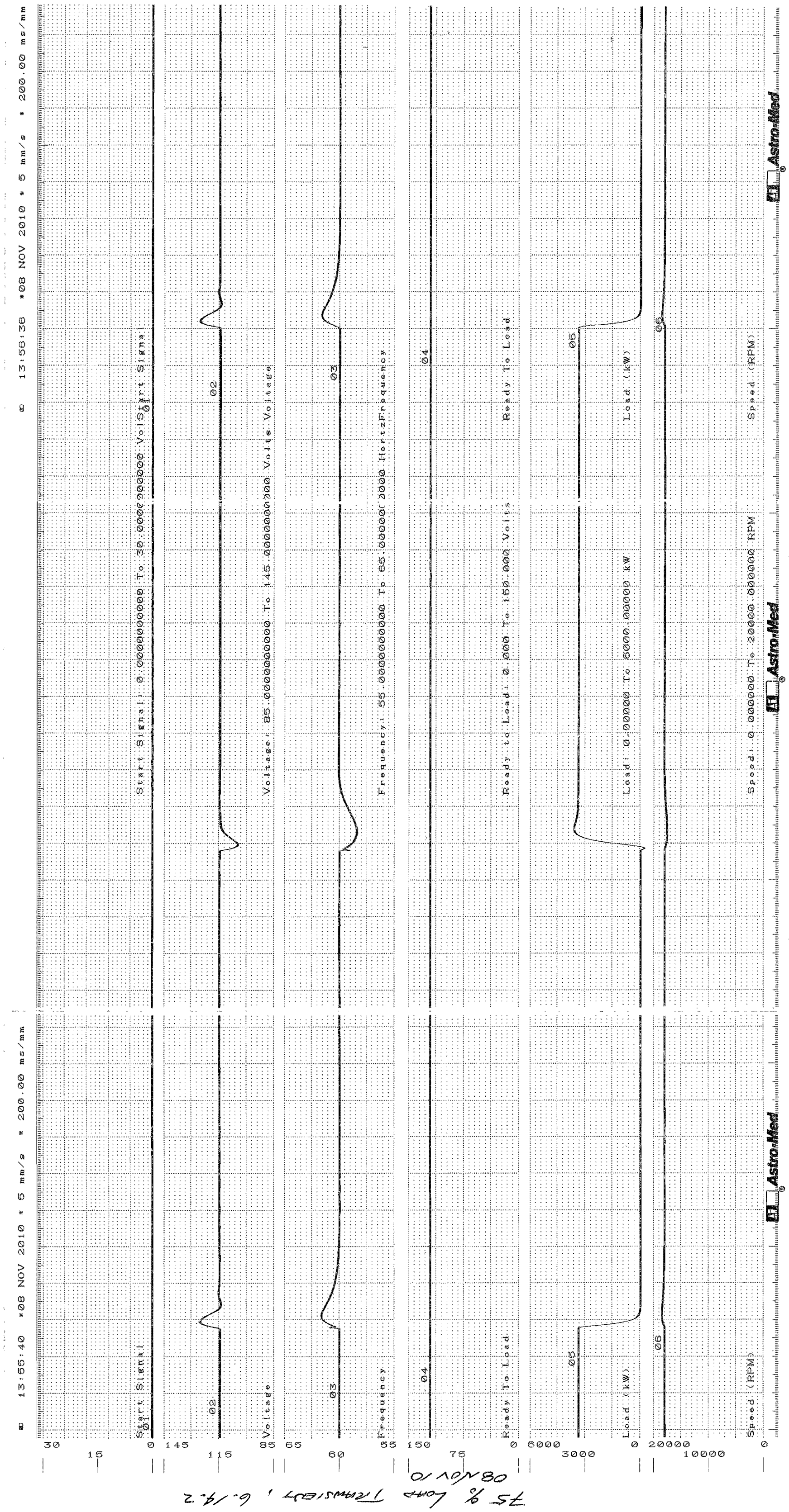


Figure C.1.0-11 Parameter Chart of Load Transient Test , 75% (Sheet 1 of 2)

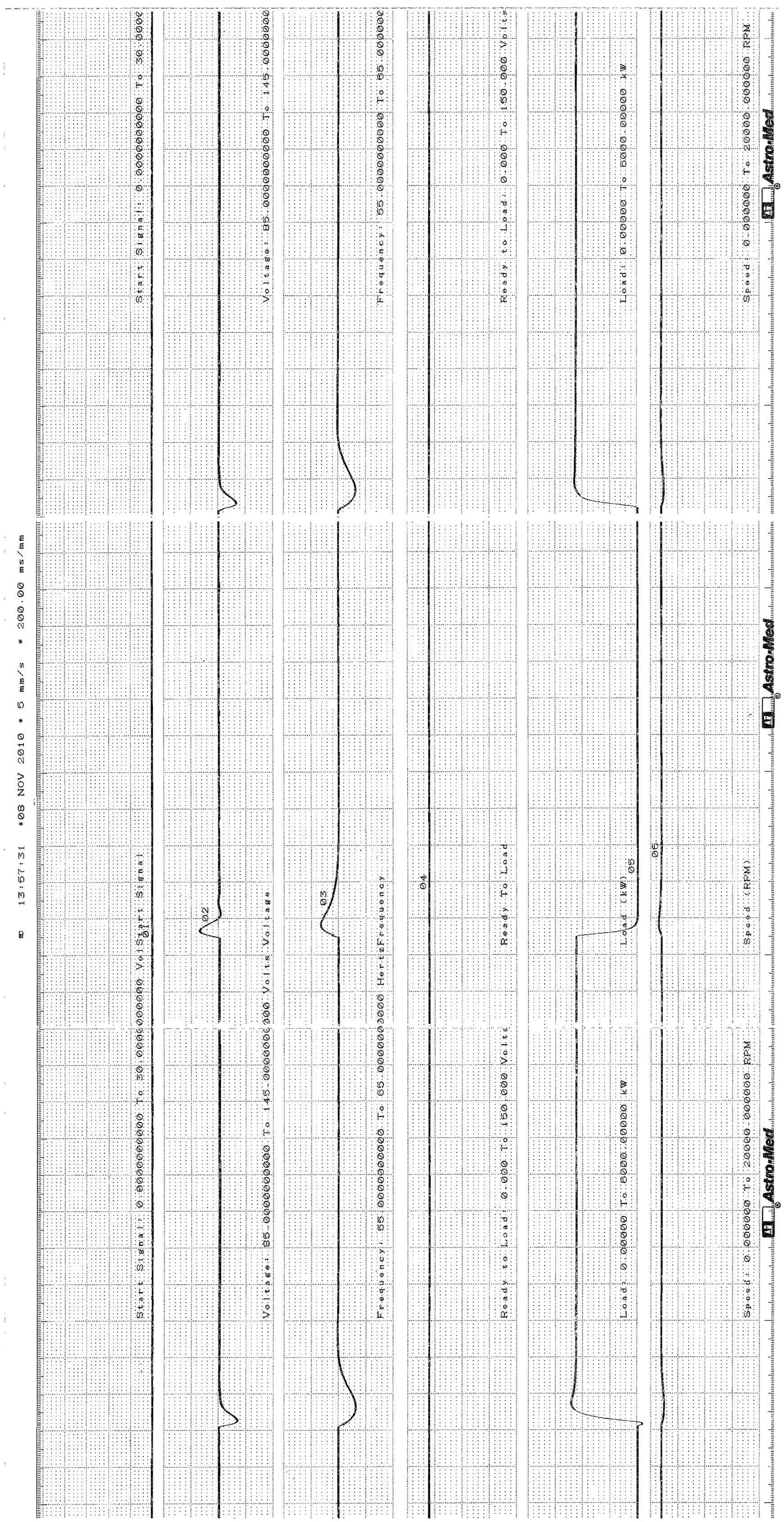


Figure C.1.0-11 Parameter Chart of Load Transient Test , 75% (Sheet 2 of 2)

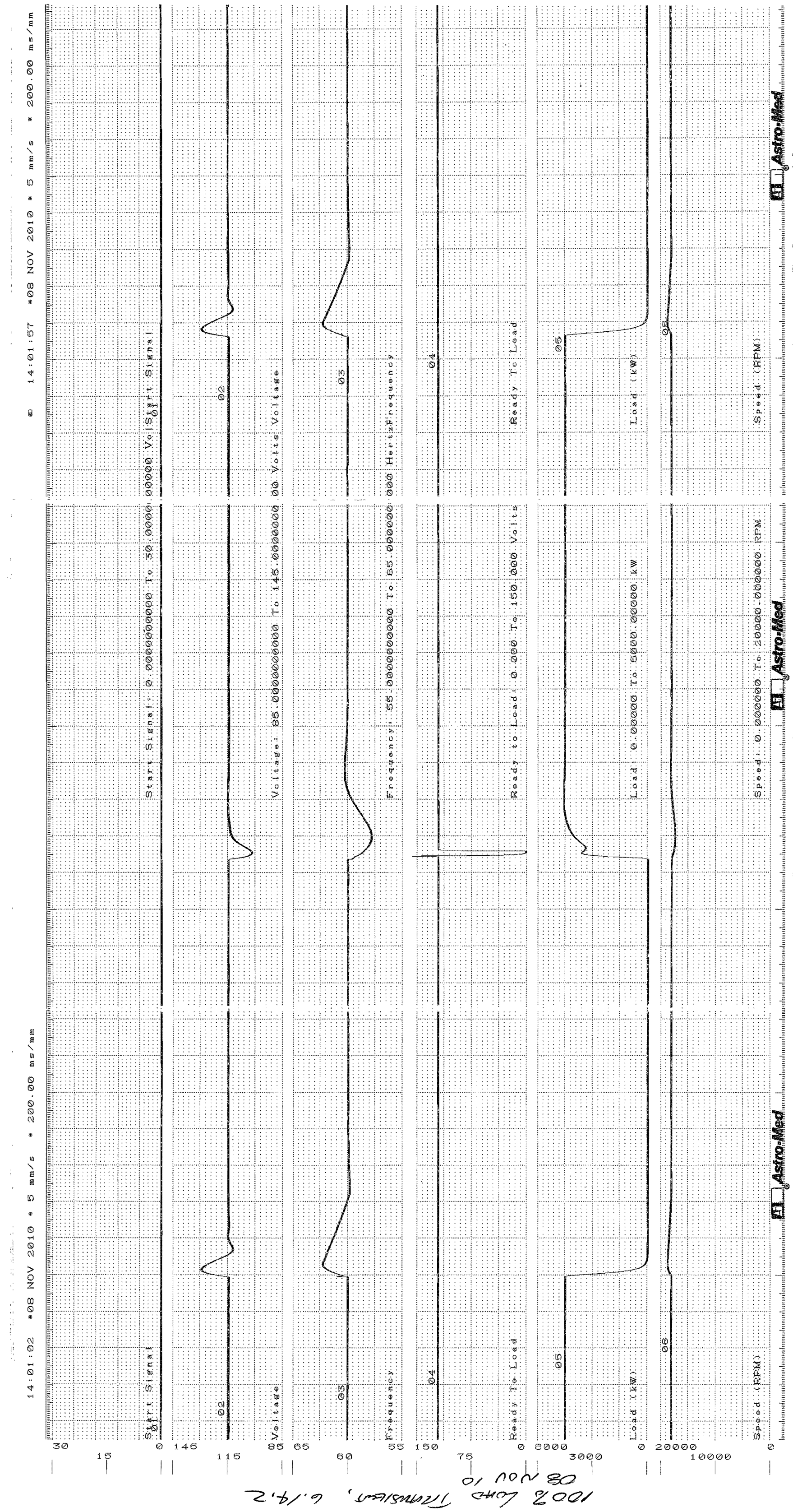


Figure C.1.0-12 Parameter Chart of Load Transient Test , 100% (Sheet 1 of 2)

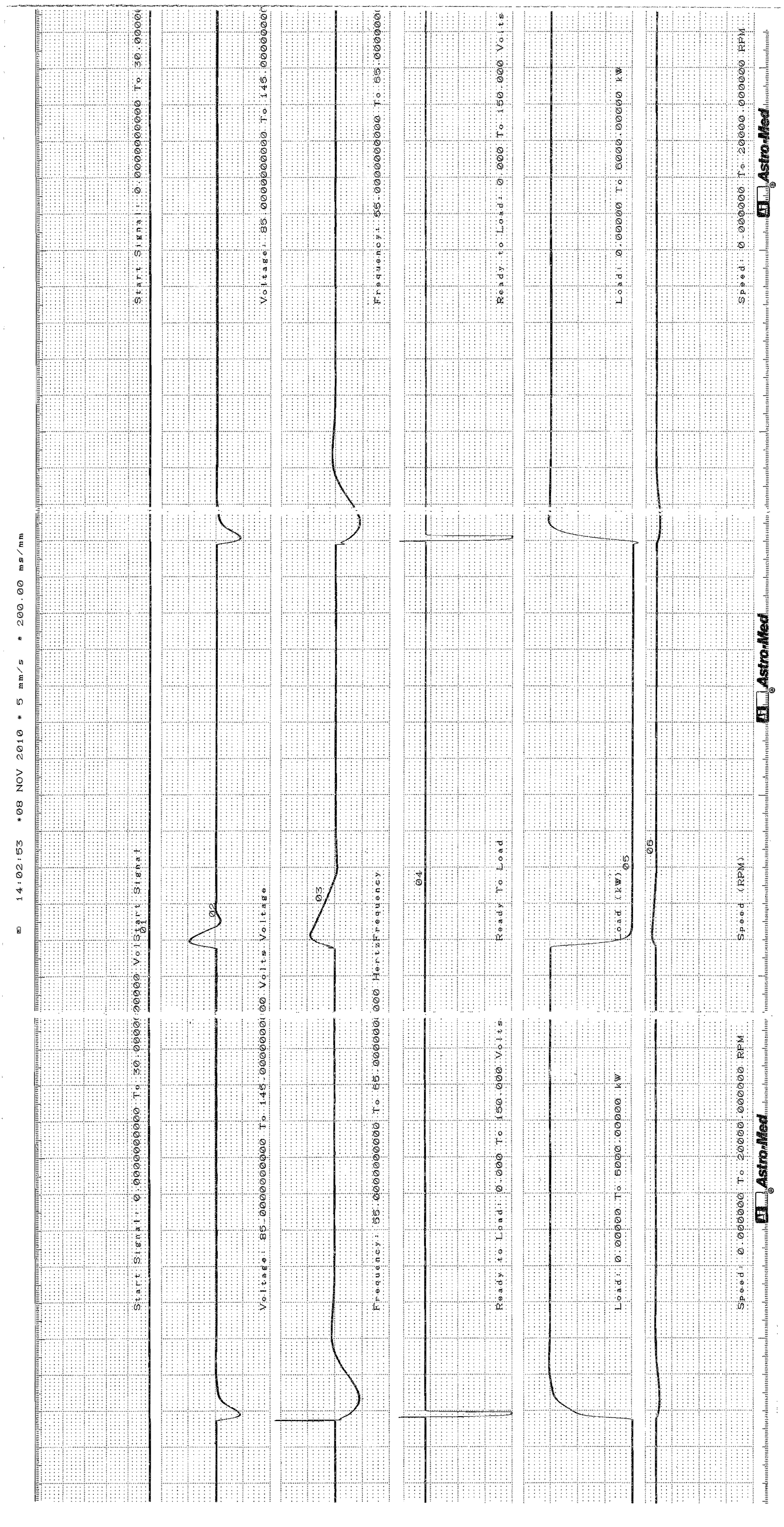


Figure C.1.0-12 Parameter Chart of Load Transient Test , 100% (Sheet 2 of 2)

Appendix D Initial Type Test Procedure

Appendix E Hot/Cold Starting Comparison

E.1.0 Prime Mover Comparison

E.1.1 Diesel Generator (DG)

As shown in Figure E.1.1-1, DGs consist of a shaft producing a rotary motion and a piston producing an up-and-down movement and are complex in structure. Therefore, the direction and amount of thermal expansion and contraction vary from element to element and that makes it difficult to include each thermal behavior of the components in the design. DGs used in standby power application, including Nuclear power plants need to start and assume loads in a short time. The interaction and combined effects of these components negatively impact the ability of the engine to start. In order to meet the start and load time requirements a DG must be kept warm, typically 35°C. It is important that DGs maintain the engine coolant and lube-oil at adequate temperature by keep warm systems. This is to optimize conditions in terms of starting reliability and reduce stress on the mechanical portion of the engine during emergency starts. Additionally, keep warm systems prevent damage and improper operation of components caused by friction due to the rapid thermal expansion and contraction which occur at startup. Each manufacturer has their own recommended temperature for warm standby conditions that are based on the dynamic characteristics, starting characteristics, and ignition characteristics of DGs.

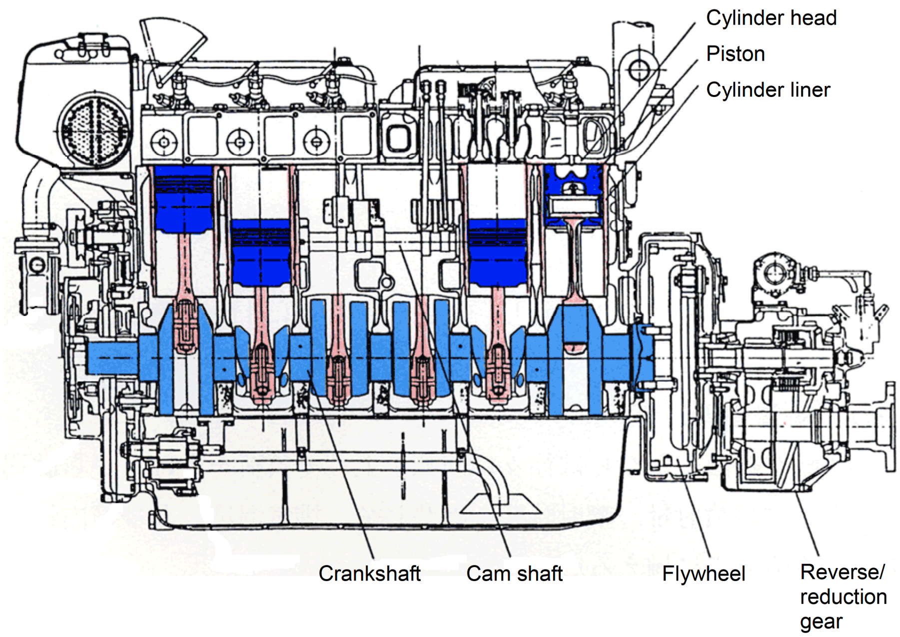


Figure E.1.1-1 Diesel Engine Structure

E.1.2 GAS TURBINE GENERATOR (GTG)

GTGs are different from DGs in structure, characteristics/starting characteristic, and ignition characteristics. As indicated by Figure E.1.2-1, unlike DGs, GTGs produce a rotary motion directly, not a reciprocating motion that is converted to a rotary motion. GTGs start by rotating a rotor/blade disks mechanically with a power outside and igniting fuel when they reach a specified speed that is typically around 20% of the operating speed. The number of critical components necessary to establish combustion is dramatically reduced.
Additionally, since the thermal expansion and contraction is only toward the circumferential and axial direction and the components are few, it is easy to include the thermal behavior of the critical components in the design. The negative effects of thermal expansion and the interaction of the critical components and material are well known and have been eliminated or significantly reduced in the design. This significantly reduces the effect of starting temperature conditions that impact starting the unit. Therefore, the start reliability is significantly higher across a broader range of starting conditions.

In conclusion, unlike DGs, whose starting characteristics are affected by heat expansion and contraction of components, it is not necessary for ground-based GTGs to be kept warm and many GTGs are not designed to need to be kept in a warm condition. This enables the GTG to consistently start under a broad range of ambient and component temperatures. None of the inherent operating principles are not significantly affected by ambient or component temperatures at the time of starting.

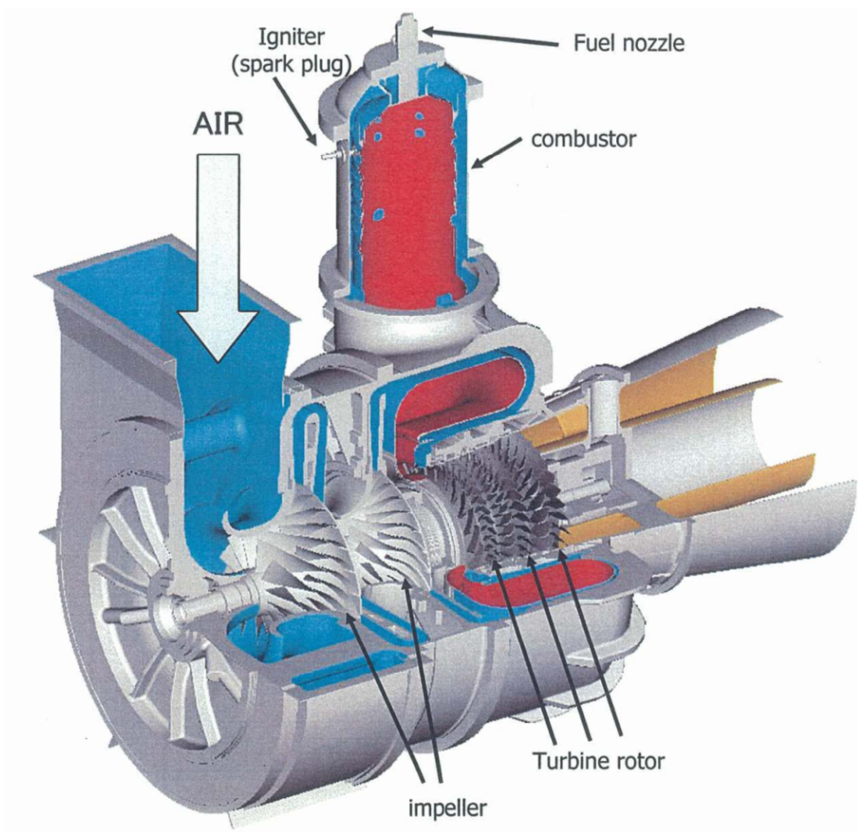


Figure E.1.2-1 Gas Turbine Engine Structure

E.2.0 Starting Functional Comparison

Impact evaluation of cold/hot start (starting reliability) is shown in Table E.2.0-1.

Table E.2.0-1 Impact Evaluation of Cold/Hot Start (Starting Reliability)

Starting Basic Function	Major Component or subsystem	Function	Temperature effects		Diesel Engine Differences
			Hot Start (Normal Operating)	Cold Start (Warm Standby)	
Ignition	Combustion Chamber	To contain the combustion and convert the energy released to mechanical energy; rotational torque and velocity. The combustion chamber is also where the air and fuel are mixed and combust to produce energy.	**Negligible;** At normal operating temperature the air entering the combustion chamber is slightly warmer; therefore fuel/air mixture is easier to ignite and ignition performance is better.	**Negligible;** At warm Standby conditions the air entering the combustion chamber is slightly cooler; therefore fuel/air mixture is slightly harder to ignite and ignition performance is reduced.	Diesel engines are significantly more sensitive to low ambient conditions. A diesel engine relies upon the heat of compression to initiate combustion. The flow of air into the cylinders is directly related to the movement of the pistons during starting.
			<u>Basis Discussion:</u> At ignition there is little difference in the fuel/air mixture temperature within the combustion chamber during starting. But also, any air remaining in the combustion chamber from the previous operating cycle is effectively purged during the starting sequence as the rotation of the main shaft accelerated.		
	Igniter	The function of the igniter is to initiate combustion of the fuel during starting. An igniter is similar to a spark plug in an internal combustion engine utilizing rapid burning fuels such as gasoline.	**Independent of temperature.** The spark produced contains sufficient energy to initiate combustion of the fuel independent of the temperature of the fuel air mixture.	**-Independent of Temperature**	Typical Diesel engines do not contain igniters or spark plugs within the cylinders. They rely only upon the heat of compression to ignite the fuel air mixture. Consequently are susceptible cold temperatures.
			<u>Basis Discussion:</u> The presence of an igniter in the combustion chamber is to initiate the combustion of the fuel. The operation of an igniter produces a highly localized area of very high temperature that will initiate combustion independent of temperature.		
	Fuel properties	Variations of Fuel temperature affect the energy content or the amount of fuel delivered to the combustion chamber (s).	**Negligible;** Fuel density is less at higher temperatures.	**Negligible;** Fuel viscosity and density is greater.	
			<u>Basis Discussion:</u> Neither condition significantly affects the ability to start and assume load. The turbine is designed to use standard fuels the effects will be insignificant provided that the fuel is within specified properties set by the manufacture.		

Starting Basic Function	Major Component or subsystem	Function	Temperature effects		Diesel Engine Differences
			Hot Start (Normal Operating)	Cold Start (Warm Standby)	
	Rotation	The function of the starter motors is to bring the turbine to its starting rotational speed, typically approximately 20% of Rated.	**Negligible**; under high ambient or operating temperatures friction is less due to oil viscosity, the turbine may reach starting speed slightly quicker.	**Negligible;** under warm standby temperatures or low ambient temperatures friction is greater due to oil viscosity; the turbine may take slightly longer to reach starting speed.	Temperatures less the 50°C significantly reduces the start reliability of Diesel engines. As a compensatory action "keep warm systems," are generally required for Diesel engines utilized in standby power applications.
			Basis Discussion: Combustion chamber compression is established by the rotation of the main shaft; it does not depend upon seals or piston rings as in an engine driven generator. Because it does not rely upon components that are sensitive to tolerances which are impacted by temperature performance is not impacted.		
Fuel control	Fuel pump	The function of the fuel pump is to deliver fuel at the correct pressure and rate to the combustion chamber through a set of control and stop valves.	**Independent of temperature.**	**Independent of temperature.**	With a diesel engine the amount of fuel injected into the cylinders is controlled by the engine governor in conjunction with the fuel injectors.
			Basis Discussion: A separate DC motor driven starting fuel pump is provided to supply fuel during starting. The flow rate required during starting is less than 25% of rated load. The fuel oil pump is insulated from the high temperature turbine components; therefore independent of turbine temperature. The engine mounted fuel pump is designed to deliver the required flow rate for rated load conditions plus margin during normal operations.		
	Fuel stop valve /Fuel control valve	The function of the fuel control valves and piping are to control the amount of fuel delivered to the combustion chamber and is proportional to the load.	**- Independent of temperature**	**- Independent of temperature**	Diesel engines do not have fuel control valves, the amount of fuel injected into the cylinder is controlled by the fuel injectors and engine governor.
			Basis Discussion: The fuel control valves and piping are designed to deliver the required flow rate for rated load conditions plus margin. The flow rate required during starting is less than 25% of rated load. The flow rate is controlled by the engine governor and flow control valves. These valves are insulated from the high temperature turbine components; therefore independent of turbine temperature.		

E.3.0 Manufacture's Analysis

Manufacture's analysis is shown in Table F.3.0-1.

Table E.3.0-1 Manufacture's Analysis of Starting Reliability

		Difference in performance between cold/hot starts	Is it cold or hot start that affects performance negatively	Influence on starting reliability
Ignition performance	Fuel nozzle	**Independent of Temperature**	-	**Independent of Temperature**
	Combustor	**Negligible** (Any remaining air is purged.)	-	**Independent of Temperature** (Since large volumes of air are drawn into the combustor at startup, at the time of ignition the ambient temperature is about the same between cold and hot start conditions. In addition, none of our record shows a failure of start caused by the ambient temperature of combustors.)
	Exciter/ ignitor	**Independent of Temperature**	-	**Independent of Temperature**
	Fuel property	**Independent of Temperature**	-	**Independent of Temperature**
Rotational resistance characteristics	Lube oil viscosity of GT bearing	**Negligible** (In a cold condition lube oil viscosity is higher and rotational resistance increases.)	Cold	**Independent of Temperature** (It takes longer (about 1 second) to start in a cold starting condition because rotational resistance increases due to an increase in the lube oil viscosity. However, lube oil viscosity has no influence on starting reliability.)
	Labyrinth seal clearance/ blade tip clearance	**Negligible** (The clearance decreases at a high temperature.)	Hot	**Independent of Temperature** (The clearance is designed assuming an increase during operation. The temperature is higher and the labyrinth seal clearance/ blade tip clearance are smaller during operation than startup. Therefore, the starting reliability is not affected by the temperature at startup and none of our record shows a failure of start caused by rubbing due to a higher temperature.)
Starting torque characteristics	Starter	**Independent of Temperature**	-	**Independent of Temperature**

		Difference in performance between cold/hot starts	Is it cold or hot start that affects performance negatively	Influence on starting reliability
Fuel control performance	Fuel pump	**Independent of Temperature**	-	**Independent of Temperature**
	Fuel stop valve	**Independent of Temperature**	-	**Independent of Temperature**
	Fuel control valve	**Independent of Temperature**	-	**Independent of Temperature** (The fuel amount is automatically controlled depending on the exhaust gas temperature of startup. When the temperature of the engine is either high or low, the fuel amount is suitably controlled and there is no influence on the starting reliability including starting time.)

Appendix F Reliability

F.1.0 US EDG Reliability Data

(1) NUREG/CR-6928 reports the reliability of nuclear EDG. This data is based on EPIX database which collects and evaluates operational experiences of nuclear EDG units applied to US NPPs. In addition, NRC had issued the report in 2007 about reliability of EDG based on EPIX database. (Note 1)
Both NUREG/CR-6928 and NRC's 2007 report are based on EPIX database. However, NRC's 2007 report had considered longer period of operation experiences than period evaluated in NUREG/CR-6928.
(Note 1) "Enhanced Component Performance Study Emergency Diesel Generators 1998-2007"

(2) NRC's 2007 report shows that 223 units consist of a large variety of products of engine. The report provides the breakdown of 223 units shown in Table F.1.1-1 and Table F.1.1-2. This shows that design of EDG (manufacture, type, output, number of cylinders) has large varieties.

Table F.1.1-1 US EDG Data(1/2)

Output	Number of Units
50 to 249 kW	2
1000 to 4999 kW	169
Over 5000 kW	52

Table F.1.1-2 US EDG Data(2/2)

Manufacture	Number of Units
A	4
B	3
C	8
D	20
E	24
F	65
G	31
H	68

(3) Even if it is assumed that one manufacture supplies only one type EDG, number of identical EDGs is estimated only 68 units as maximum. If one manufacture had supplied 2 or more same type of engines, it is supposed the largest identical engine group does not consist of over 30 units. Also this data is classified from only difference of engine type. If the differences of support system components (cooling system components, starting system components, lubricant system components etc.) are considered, completely identical GTG sets are less.

(4) US reliability data is evaluated by operational experiences of those various products, in NUREG/CR-6928. And “Failure to Start (FTS)” is calculated as following.

- mean: 4.53×10^{-3} / demand
- 95%: 1.32×10^{-2} / demand

F.2.0 MHI GTG Reliability Data

(1) MHI has shown NRC the operational experiences of commercial GTGs in MHI RAI responses No.5 issued on June 6 in 2008 shown in Table F.2.0-1.

Table F.2.0-1 MHI GTG Data

Data GroupNo.	Number of GTG Sets	Number of Failures/ Number of Starts	Type			
			Output (kVA)	Single engine or Twin engine	Fuel Type	Starting system
1	70	2/4891	150 to 300	Single	Diesel Oil	DC motor
2	19	0/2503	1000 to 1750	Single	Kerosene	DC motor
3	9		1000 to 1750	Single	Diesel Oil	DC motor
4	157		1000 to 1750	Single	Heavy Oil	DC motor
5	1		1000 to 1750	Single	Kerosene	Air
6	9		1000 to 1750	Single	Heavy Oil	Air
7	10		2000 to 4500	Twin	Kerosene	DC motor
8	5		2000 to 4500	Twin	Diesel Oil	DC motor
9	90		2000 to 4500	Twin	Heavy Oil	DC motor
10	5		2000 to 4500	Twin	Heavy Oil	Air

(2) The GPS series is designed based on same design concept and manufacturing control. MHI thinks the data of GPS series is applicable to evaluate the EPS's reliability using the same approach as NUREG's.

(note)
MHI shows the classical estimation as follows;

- mean: 2.7×10^{-4} / demand (2/7394)
- S (standard deviation): 1.91×10^{-4} / demand
  S = {p(1-p)/n}1/2
- maximum (95% distribution):
  mean + 2S = 6.52×10^{-4} / demand

Mean and 95% maximum are low than US nuclear EDGs'.

(3) MHI understands there are differences between GTG's data, which is based on commercial products, and EDG's data, which is based on nuclear EDGs qualified as safety-related. It is proper to consider that product qualified as nuclear safety-related would have higher reliability than commercial product. However, MHI has never used Kawasaki engines for nuclear safety-related application. MHI performs detailed analysis of the data of commercial products to be able to evaluate reliability precisely.

F.3.0 MHI's Reliability Verification

(1) As explained before by MHI, the reliability target of US-APWR Class 1E GTG is as shown below. It is based on US EDG's data of NUREG-CR/6928. And this value is used to perform PRA analysis.

Fail to Start
- Mean : 5.0×10^{-3} / demand
- 95% maximum : 1.5×10^{-2} / demand

Fail to Run
- Mean : 8.0×10^{-4} / hr
- 95% maximum : 2.0×10^{-3} / hr

(2) MHI shows GTS6000 satisfies with reliability target of US-APWR using Bayesian approach.
(note)
Bayesian approach is one of general method of statistics, and is widely used to evaluate component reliability.
NUREG-CR/6928 also uses this approach.

(3) In order to estimate GTS6000's reliability accurately, collection of data based on appropriate categorization is necessary. MHI has analyzed the GPS's operational data. Operational data has been collected from manufacture's records as shown in Table F.3.0-1.

Table F.3.0-1 GPS's Operational Data (1/2)

Product	Output(kVA)	Single engine or Twin engine	Fuel Type	Starting system	Failure/Number of starts	Failure/Operation hours
1	2000	Twin	Heavy Oil	Air	0 /251 d	0 /98 hr
2	2000	Twin	Heavy Oil	DC	0 /265 d	0 /75.4 hr
3	2000	Twin	Diesel Oil	DC	0 /100 d	0 /71.3 hr
4	2000	Twin	Kerosene	DC	0 /1053 d	0 /205 hr
5	2500	Twin	Heavy Oil	Air	0 /383 d	0 /1129.8 hr
6	2500	Twin	Heavy Oil	DC	0 /95 d	0 /16.4 hr
7	4000	Twin	Heavy Oil	Air	0 /540 d	0 /982 hr
8	4000	Twin	Heavy Oil	DC	0 /149 d	0 /96.8 hr
9	4000	Twin	Diesel Oil	Air	0 /225 d	0 /156.4 hr
10	4000	Twin	Diesel Oil	DC	0 /105 d	0 /50.8 hr
11	4000	Twin	Kerosene	DC	0 /263 d	0 /109.6 hr

Table F.3.0-2 GPS's Operational Data (2/2)

Product	Output(kVA)	Single engine or Twin engine	Fuel Type	Starting system	Failure/Number of starts	Failure/Operation hours
12	4500	Twin	Heavy Oil	Air	0 /327 d	0 /125.1 hr
13	4500	Twin	Heavy Oil	DC	0 /130 d	0 /63.2 hr
14	4500	Twin	Diesel Oil	DC	0 /69 d	0 /80.3 hr
15	4500	Twin	Diesel Oil	DC	0 /147 d	0 /32.1 hr
16	4500	Twin	Kerosene	Air	0 /341 d	0 /455.1 hr
17	4500	Twin	Kerosene	DC	0 /251 d	0 /68.0 hr
18	5000	Twin	Unidentified	DC	0 /48 d	Operation period of those products are short. These are not used for evaluation as conservative.
19	5000	Twin	Unidentified	DC	0 /48 d	
20	6000	Twin	Unidentified	DC	0 /24 d	
21	6000	Twin	Unidentified	DC	0 /24 d	
22	6000	Twin	Unidentified	DC	0 /13 d	
23	6000	Twin	Unidentified	DC	0 /13 d	
24	6000	Twin	Unidentified	DC	0 /12 d	
25	6000	Twin	Unidentified	DC	0 /12 d	
26	6000	Twin	Unidentified	DC	0 /6 d	
27	6000	Twin	Unidentified	DC	0 /1 d	

(4) Data collection of GTG fail to start

- GPS series have been produced with common design concept such as structure, dynamic characteristics and materials. Increase of output is achieved by sizing up the design of small output product analogously. The smaller the difference of output is, the more similar design the products have. MHI applies GPS6000 as EPS. GPS5000 is similar design as GPS6000. Also, GPS4000/4500 are nearly the same design as GPS6000, and there are no significant difference of starting capability based on operation experiences. Another mean of increasing of output is using two engines with one generator. Over GPS 2000 products are all twin type.

- Starting type is also considered whether air or DC motor.

- MHI has selected the data of Table F.3.0-3 as follows;
  - Data of GPS4000 to 6000 with air starting type

    ⇒ 1433 demands with 0 failure

  This data is used to perform Bayesian approach of GTG reliability.

(5) Data collection of GTG fail to run

From view point of running reliability, type of starting system is not needed to consider. Also, there are no significant differences from operation experiences of large output twin engine products of over GPS2000. MHI has classified the data of running time into over GPS2000 and over GPS4000.

1) Data of over GPS2000 ⇒ 3820 hours with 0 failure
2) Data of over GPS4000 ⇒ 2224 hours with 0 failure

Although MHI evaluates it is appropriate to use both 1) and 2) above to perform Bayesian approach, MHI performs evaluation using only data of 2) conservatively.

(6) Reliability estimation of GTGs based on industry operational experience

- Applicable data
  - 1433 demands with 0 failure
  - 2224 run hours with 0 failure

- Uncertainty of failure rate/probability
  - Estimated applying simplified constrained non-informative distribution

Table F.3.0-3 Reliability Estimation of GTGs Based on Industry Operational Experience

	5%	Mean	95%	Distribution		
				Type	a	b
Fail to start	1.4E-6	3.5E-4	1.3E-3	Beta	0.5	1433
Fail to run	8.9E-7	2.2E-4	8.3E-4	Gamma	0.5	2224

F.4.0 Requirement for Initial Type Test

(1) According to a domestic GTG's field data, the GTG failure rate is statistically evaluated as 3.5×10^{-4}/demand, which proves high reliability of the GTG.

(2) R.G.1.155 describes the requirement for reliability of Class 1E EDG: 0.975 with 95% confidence or 0.95 with 95% confidence. MHI has chosen 0.975 with 95% confidence as a reliability target.

(3) The initial type test condition to achieve reliability 0.975 with 95% confidence is statistically evaluated with the following math formula:
Reference; Probability Concepts in Engineering Planning and Design
Alfredo H-S. Ang Wilson H.Tang

$$\sum_{i=0}^{r} \frac{n!}{(n-i)!\,i!}(1-R)^i \cdot R^{(n-i)} = 1 - C$$

n: number of trials
c: confidence
R: reliability
r: number of failure

(4) If the number of failure (r) is 0, the above formula is rearranged as follows:

$R^n = 1\text{-}C$

If the number of trials 150 is assigned to the above, 97.75% of confidence is obtained as follows:

$0.975^n = 1\text{-}C$
$C = 1\text{-}(0.975^{150})$
$=97.75\%$

As a conclusion, if the GTG startup test results in 150 trials with zero failures, that means the reliability of GTGs is higher than 0.975 with approximately 98% confidence.
In this way, the initial type test condition to achieve the required reliability has been determined to be 150 times with no failure.