US-APWR

GAS TURBINE GENERATOR

used as Emergency Power Supply

April 13, 2009

Mitsubishi Heavy Industries, Ltd.

Contents

1. Reliability

US-APWR

1.1 US EDG 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"

1. Reliability

US-APWR

1.1 US EDG data(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-1 and Table-2.

This shows that design of EDG (manufacture, type, output, number of cylinders) has large varieties.

1. Reliability

1.1 US EDG data(3)

Table-1

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

Table-2

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

1. Reliability

1.1 US EDG data(4)

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.

1. Reliability

1.1 US EDG data(5)

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

1. Reliability

1.2 MHI GTG data(1)

MHI has shown to NRC the operational experiences of commercial GTGs in MHI RAI responses No.5 issued on June 6 in 2008 shown in Table-3.

1. Reliability

1.2 MHI GTG data(2)

Table-3

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

1. Reliability

1.2 MHI GTG data(3)

The GTS series is designed based on same design concept and manufacturing control.

MHI thinks the data of GTS 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'.

1. Reliability

1.2 MHI GTG data(4)

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 considered proper that product qualified as nuclear safety-related would have high reliability than commercial product.

MHI will perform Class 1E qualification and initial tests of GTG, and the result of this GTG test is expected to be high reliability.

1. Reliability

1.3 MHI's Reliability Verification Plan(1)

MHI has already explained that reliability target of US-APWR Class 1E GTG is shown below. It is based on US EDG' s data of NUREG-CR/6928. And this value is used to 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

1. Reliability

1.3 MHI's Reliability Verification Plan(2)

From this slide, 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.

1. Reliability

1.3 MHI's Reliability Verification Plan(3)

In order to estimate GTS6000's reliability accurately, collection of data based on appropriate categorization is necessary.

MHI has analyzed the GTS's operational data.

Operational data has been collected from manufacture' s records as shown in Table-4.

1. Reliability

1.3 MHI's Reliability Verification Plan(4)

Table-4(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

1. Reliability

1.3 MHI's Reliability Verification Plan(5)

Table-4(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	

1. Reliability

1.3 MHI's Reliability Verification Plan(6)

➢ **Data collection of GTG fail to start**

1. GPS series have been produced with common design concept such as structure, dynamic characteristics and materials. Increasing of output is achieved to size up the design of small product analogously. Near output products have more similar design. MHI apply GPS6000 as EPS. GPS5000 is similar design as GPS6000. Also, GPS4000/4500 are almost similar design as GPS6000, and these 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 twin type all.

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

1. Reliability

1.3 MHI's Reliability Verification Plan(7)

➢ **Data collection of GTG fail to start (continued)**

3. MHI has selected the data of Table-4 as follow;
   - Data of GPS4000 to 6000 with air starting type

     ⇒ 1433 demands with 0 failure

This data is used to Bayesian approach of GTG reliabilty.

1. Reliability

1.3 MHI's Reliability Verification Plan(8)

➢ **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 difference from operation experiences of large output twin engine products of over GPS2000. MHI has classified data into running time of over GPS2000 and running time over GPS4000.

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

Result of this, MHI evaluates both above 1) and 2) are considered proper to use to Bayesian approach. However, MHI evaluates using only data of 2) conservatively.

1. Reliability

1.3 MHI's Reliability Verification Plan(9)

➢ **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-5

	5%	Mean	95%	Distribution		
				Type	α	β
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

1. Reliability

1.3 MHI's Reliability Verification Plan(10)

➢ US-APWR GTG test plan

✓ **Start test**

- Operational experience show that failure rate is lower than the mean failure rate of DGs (5.0E-3 /d), with 95% confidence.
- Start tests will be performed as a typical "qualification starting test". Total starting times is 100.
- Reliability will be updated by the starting test and surveillance test results obtained during plant operation

✓ **Run test**

- Operational experience show that failure rate is lower than the mean failure rate of DGs (8.0E-4 /hr), with approximately 95% confidence.
- Run test is not needed.
- Reliability will be confirmed and updated by surveillance test results obtained during plant operation

Table-6 GTG unreliability given start test results

Start Test results		Estimated US-APWR GTG reliability		
Trials	failures	5%	Mean	95%
100	0	1.3E-6	3.3E-4	1.3E-3

1. Reliability

1.3 MHI's Reliability Verification Plan(11)

➢ MHI verified the GTG reliability is sufficiently high, based on appropriate estimation with selected data

➢ MHI will perform total 100 start test as "Qualification test"

➢ MHI will update the GTG reliability during operation through surveillance test

2. Diversity

Detail of diversity between EPS and AAC(1)

- US-APWR applies GPS6000 as EPS, GPS5000 as AAC. Design and specification of these engine portion are almost similar. Table-4 shows detail differences between whole GTG system component and design between both systems.
- Each item of engine portion of both are almost similar. However, difference of output means difference of combustion rate, also dynamic characteristics of both are different. This deference effects to decrease the CCF potential.
- Also, there are many differences of spec., design and manufacture for supporting system component.

2. Diversity

Detail of diversity between EPS and AAC(2)

- As explained, design and specification of both engine portions are almost similar. However, NRC's report (discussed on "Reliability"), evaluates the cause and portion of failures.
- According to NRC report, cause and portion of failures of FY1998 to FY2007 has been researched as Table-8.

Table-8

Fail to start Total:116 failures		Fail to Run Total:65 failures	
Lank	Portion	Lank	Portion
1	I&C : 34 failures	1	Cooling : 15 failures
2	Generator : 23 failures	2	Engine : 12 failures
3	Starting air : 13 failures	3	Fuel oil : 11 failures
4	Governor: 12 failures	4	I&C : 9 failures
5	Fuel oil: 10 failures	5	Lube oil : 8 failures
6	cooling: 10 failures	6	Generator : 6 failures
8	Engine: 4 failures		

2. Diversity

Detail of diversity between EPS and AAC(3)

- According to Table-8, failure caused by engine are considered low probability. GPS6000 and GPS5000 planed to US-APWR are designed different supporting system including starting system.

  Based on this fact, Fail to Start caused by engine are considered low probability.

- In addition, GPS6000 and GPS5000 are designed different output, combustion rate.

  This different is expected to prevent the Fail to Run.

- MHI considers although GPS6000 and GPS5000 are similar engine design, it is expected to minimize the CCF potential view point both of start and run availability.

2. Diversity

Detail of diversity between EPS and AAC(4)

Table-7(1/3)

Group	No	Item	EPS	AAC
Engine	1	Type	M1T-33	M1T-33A
	2	Rated output (engine edge)	5200kW	4362kW
	3	Combustor spec/material/size	Single CAN Type/heat-resistant alloy	Same as follows
	4	Number of turbine blades /rows	1st row = 44 2nd row = 40 3rd row = 36	Same as follows
	5	Turbine engine spec/material/size	3-Stage Axial / nickel-based heat-resisting alloys	Same as follows
	6	Compressor spec/material/size	2-Stage Centrifugal / titanium alloy	Same as follows
	7	Number of compressor blade rows	Total 54	Same as follows
	8	Compressor compression ratio	10.23	10.08
	9	Exhaust gas temperature	595 degree C	540 degree C
	10	Exhaust gas flow	3830 m^3/min	3650 m^3/min
	11	Gear spec/material/size	Planetary + Parallel	Same as follows
	12	Change gear ratio	10:1	Same as follows

2. Diversity

Detail of diversity between EPS and AAC(5)

Table-7(2/3)

Group	No	Item	EPS	AAC
Supporting system Equipment installed on Engine	13	Starting Motor type	Air	DC motor
	14	Starting Motor quantity	4	8
	15	Starting Motor spec	Air Turbines x 4	40kW DC60V Motors x 8
	16	Main fuel pump (shaft driven) spec/quantity	screw type 23L/min @3.3MPa x 2	Potentially change manufacture
	17	Starting fuel pump (shaft driven) spec/quantity	Gear type x 2	Potentially change manufacture
	18	Starting fuel pump (DC motor driven)	DC24V gear type x 2	Potentially change manufacture
	19	Fuel control valve spec/quantity	Electric type x 2	Potentially change manufacture
	20	Main lube oil pump spec/quantity	Gear type x 2	Potentially change manufacture
	21	Pressure control valve spec/quantity	Plunger type x 2	Potentially change manufacture
	22	Ignition plug spec/quantity	surface gap type x 4	Potentially change manufacture
	23	Governor spec/quantity	Electric type x 2	Potentially change manufacture
Design control, Engineering, manufacturing	24	Designing/ manufacturing manual	Base with ESI	Base (without ESI)
	25	Manufacturing department	Base with ESI	Base (without ESI)
	26	Designing department	Base with ESI	Base (without ESI)
	27	Quality control department	Base with ESI	Base (without ESI)
	28	Manufacturing line	Base with ESI	Base (without ESI)

2. Diversity

Detail of diversity between EPS and AAC(6)

Table-7(3/3)

Group	No	Item	EPS	AAC
GTG system supporting component	29	Fuel oil transfer pump	Safety-related	Non safety-related, other manufacture, different spec.
	30	Starting air valve	Safety-related	N/A
	31	Fuel day tank	Safety-related	Non safety-related, other manufacture, different spec.
	32	Fuel storage tank	Safety-related	Non safety-related, other manufacture, different spec.
	33	Fuel system piping	Safety-related	Non safety-related, other manufacture, different spec.
	34	Exhaust duct	Safety-related	Non safety-related, other manufacture, different spec.
	35	Inlet duct	Safety-related	Non safety-related, other manufacture, different spec.
	36	Ventilation fan	Safety-related	Non safety-related, other manufacture, different spec.
	37	Generator	Class 1E	Non Class 1E, other manufacture, different spec.
	38	Generator excitation circuit	Class 1E	Non Class 1E, other manufacture, different spec.
	39	AVR	Class 1E	Non Class 1E
	40	GTG control panel (hardwired)	Class 1E	Non Class 1E, other manufacture
	41	GTG control panel (DDC)	Class 1E	Non Class 1E, other manufacture
	42	AC power supply	Class 1E bus	Non Class 1E bus
	43	DC power supply	Class 1E bus	Non Class 1E bus