Annex M

Reliability/Availability Guarantees of Gas Turbines and Combined Cycle Generating Units

By
Thomas E. Ekstrom

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***Abstract*— This paper is an updated and revised version of the 1992 ASME paper 92-GT-208 "Reliability measurements for gas turbine warranty situations." It recognizes that reliability performance is receiving significant and increasing attention in the bid requests for new gas turbine generating units. Reliability guarantees backed by liquidated damages clauses are becoming more the rule rather than the exception. But the power generation industry does not have a universally accepted set of reliability measurements, and the more commonly used measurements are not always used appropriately, nor are they sufficiently refined for the warranty situation.**

This paper is intended to provide the guidance, structure, and refinement needed for meaningful reliability measurements and reliability warranties.

Four key areas of reliability measurement: starting reliability, running reliability, availability and equivalent availability are separately explored. Within each of these areas there is the flexibility and the need to adapt the measurement system to the varied operating regimes and philosophies encountered such as: peaking versus continuous service, limited scopes of supply, different levels of maintenance intensity, chargeable versus nonchargeable outage events and emotional/political/optical acceptability (i.e., 3% Forced Outage Factor versus 40% Forced Outage Rate). Warranty structuring rationale and suggested contract language are provided to address such needs as a rigorous and explicit operating log, certification of data, measurement uncertainty, assurance of readiness, and risk assessment.

The suggestions presented herein have been constructed with logic and fairness. They have been applied with good acceptance to over 30 contracts in the past three years. This paper will be beneficial to all architect engineers, utilities, independent power producers, and OEM's that become involved with the measurement of reliability or the structuring of reliability warranties.

I. Introduction

IT HAS been said that gas turbine value is measured in terms of performance and reliability. And to insure the receipt of that value, the electric utility industry is increasingly seeking warranties on both performance and reliability in its contracts for new gas turbine power plants. But common practices and the available standards for measuring reliability are inadequately structured for warranty situations. This paper addresses these needs. In this paper the word "reliability" is frequently used in the broad sense. Reliability warranties may typically apply to any of the following specific measurements:

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The author is with GE Power Generation Engineering, Gas Turbine Applications Engineering, Schenectady, NY, 12345-6001 USA.

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1) Starting Reliability: The expected likelihood that a generating unit can successfully start on demand and/or within a given time period.

2) Running Reliability: The expected likelihood that a generating unit can provide electricity when requested. Measurements of running reliability deal with unplanned events and generally exclude all outages associated with scheduled maintenance activities.

3) Availability: The expected portion of period time (typically a year) that a generating unit is capable of providing electricity. Availability considers all outage activity, both planned and unplanned, forced and scheduled.

4) Equivalent Availability: Similar to availability but further refined by capacity adjustments to reflect the cumulative energy production capability. It becomes the expected portion of *energy output* available over a period of time (typically one year) and is applied where the availability measurement must also reflect the effect of reduced capacity operating modes. The concept of "Equivalent . . . " can also be applied to running reliability measurements.

II. Current Standards and Data Collection Systems

Technically speaking, the domestic (USA) electric utility industry has one formal standard for reliability terminology. It is ANSI/IEEE Standard 762-1987, entitled "IEEE Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity" [1]. It was written for base-loaded power plants and defines no less than 66 reliability-related terms plus some 25 performance indexes (none of which are explicitly named "reliability" or "running reliability.") IEEE Std 762 is fairly new and to the author's current knowledge, there are no industry databases or operator data collection systems that are strictly based on the IEEE Std 762 definitions. The more commonly used definitions in the United States are those of the North American Electric Reliability Council (NERC), as applicable to its Generating Availability Data System (GADS). A significant number of domestic (USA) utilities supply annual operating data to the GADS data base. The NERC GADS definitions are slightly different from the IEEE Std 762 definitions but NERC is gradually changing its definitions to be more in line with the IEEE standard. And despite the IEEE and NERC definitions, the majority of utilities still use their own "home-grown" traditional measures which tend to combine classical reliability theory with specific system configuration, operating or administrative needs.

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The objectives of IEEE and NERC relate to the gathering and presenting of *broad system operational data* on a consistent basis. But component failure rate data and failure cause data have not been rigorously kept and no effort has been made to assess maintenance intensity effect. *Force majeure* events are not subtracted. Downtime is not segregated into active repair effort, waiting time, or unapplied time. Consequently, the IEEE and NERC definitions structures have not been adequate to support the needs of equipment reliability engineers nor to support real-world reliability/availability warranties. Nonetheless, the concepts, definitions, and formulas of IEEE Std 762 and NERC GADS still provide an excellent starting point. The terms and recommendations in this paper utilize, expand upon, and generally flow with these "standards."

Another database receiving increasing attention is the Operational Reliability Analysis Program (ORAP) which was devised by GE in 1976 and is currently managed by Strategic Power Systems Inc., a private company in Albany, NY. It utilizes the old standard terminology of Edison Electric Institute but was set up as an "events-based" database to specifically serve reliability engineering needs. It presently includes more than 4500 unit-years of comprehensive gas turbine operating data and provides fleet performance reports and failure rate data to the users, EPRI, architect engineers and the OEM's. Today, with the ever-increasing flexibility of computers, systems such as the ORAP system have the capability to support the most detailed categorization of events and then provide for multiple analysis and reporting. From one set of operating data, the computer can generate the standard fleet performance reports, the appropriately categorized NERC GADS data (or results), the utility's preferred internal performance report and a unit or plant warranty performance level measurement set under custom-tailored warranty conditions.

III. Starting Reliability

Starting Reliability (SR) is easily understood as the ratio of the number of successful starts to the number of attempted starts.

$$\text{Starting Reliability} = \frac{\text{successful starts}}{\text{attempted starts}} \quad \text{(NERC)}. \quad (1)$$

However, when starting reliability is to be measured carefully, there are a number of "special situations" that must be considered, adjusted for, and sometimes contractually qualified. The most typical are:

- multiple initiations of the "start" command without intervening corrective action(s),
- "test" starts and "maintenance" starts,
- starting failures caused by other than contract-furnished equipment,
- starting time allowance period,
- operator or procedural errors,
- start sequence aborts by operator or dispatcher discretion with no equipment failure,
- load level reached for a "successful start," and
- starting reliability measurements for components, subsystems and partial plants.

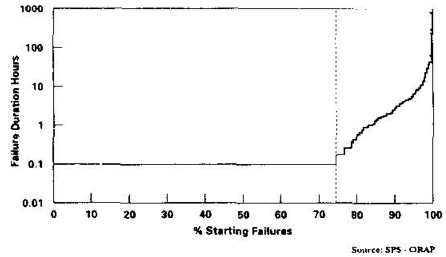


Fig. 1. Starting failure outage times. Cumulative distribution—MS7001E/EA units 1978–1989.

To illustrate the importance of the above "special considerations," consider the concept of the starting time allowance period as incorporated in the IEEE standard but not in the NERC GADS or standard ORAP definitions. The IEEE standard allows that repeated initiations of the starting sequence, within a user-specified period (typically 20 or 30 min) be counted as a single attempt. The significance of this distinction is evident by the fact that 74% of the starting failures (see Fig. 1) reported in the ORAP data base under the NERC definition are followed by a successful start within six minutes time of the "failure" and have minimal impact to the service demand request. When a five-year ORAP history of GE MS7001E/EA units was assessed the starting reliability averaged 93% by the NERC definition but 98.2% by the IEEE Std 762 definition!

The IEEE Std 762 formula for starting reliability basically enables fair treatment of all the "special situations" described previously by focusing only on the number of chargeable failures to start. This is accomplished by making a subtle formula change to

$$\text{Starting Reliability} = \frac{SS}{SS + SF} \quad \text{(IEEE)} \qquad (2)$$

where SS = [Chargeable] Starting Successes, and SF = [Chargeable] Starting Failures.

IEEE Std 762 then offers some basic qualifications through its definitions. But warranty situations require expanded qualification as suggested here along the lines of IEEE Std 762.

A *Qualifying Starting Attempt* is the action intended to bring a unit from shutdown to the in-service state under conditions that qualify for inclusion in the warranty. Repeated initiations of the starting sequence within the allowable specified starting time period or without accomplishing corrective repairs are counted as a single attempt.

A *Chargeable Starting Success* is the occurrence of bringing a unit through a qualifying starting attempt to the in-service state within a specified period, as evidenced by maintained closure of the generator breaker to the system.

A *Chargeable Starting Failure* is the inability to bring a unit through a qualifying starting attempt to the in-service state within a specified period for failure reasons chargeable to the warranty. Repeated failures within the specified starting period are to be counted as a single starting failure.

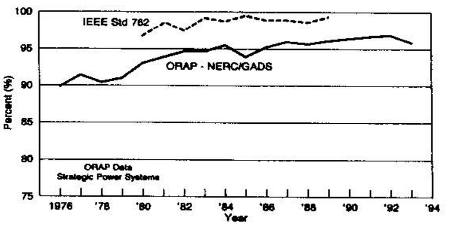


Fig. 2. Starting reliability MS7001 domestic units.

A third formula for starting reliability is used in the ORAP system for engineering analysis of component and subsystem performance.

$$\text{Starting Reliability} = \frac{\text{SA} - \text{SF}}{\text{SA}} \quad \text{(Engineer's)} \qquad (3)$$

where SA = Qualifying Starting Attempt, and SF = [Chargeable] Starting Failures.

This "Engineer's" formula, like the IEEE formula, accommodates the "special situations" fairly well and actually offers the most representative measure of equipment performance. But it tends to err on the optimistic side while the NERC-GADS and IEEE formulas tend to err on the pessimistic side. For example, a starting attempt aborted midway through the start sequence by the operator, but not associated with any equipment failure, would be counted as a failed start by NERC-GADS, would not be counted at all under IEEE Std 762, and would be counted as a successful start by this ORAP formula.

When selecting a measurement formula and warranty context for starting reliability guarantees, there need to be rules: What is chargeable, and what is not? The maintenance-readiness environment should be addressed. And the measurement should statistically reflect the inherent starting reliability of the equipment. Financial penalties should not be incurred in a warranty situation simply due to the *natural randomness* of starting failures. Here are some examples of SR warranty considerations:

1) Repair verification starts and failures-to-start from equipment not furnished under the contract should not be chargeable to the warranty.
2) If the equipment has not been successfully started within a reasonable period (e.g., 30 days) then, for compromise of readiness, the next starting attempt should not be considered a qualifying start attempt.
3) In order to realize the significantly higher SR levels associated with the IEEE starting time allowance clause, there should be technically competent supervision and appropriate maintenance personnel available at site to expeditiously facilitate correction of the minor and "procedural" errors that typically account for the five-minute start-up delays. Remotely dispatched sites typically do not have this benefit. Fig. 2 illustrates the numeric magnitude of this difference.

A good measure of starting reliability considers measurement precision and representativeness, commonly referred to as measurement uncertainty. It takes 100 start attempts for the data alone to be precise to the nearest one percent. And it takes 1000 start attempts for the measurement to statistically represent the true-inherent equipment SR with one-percent accuracy at the 90% confidence level! Therefore it is always recommended to combine the starts data from all similar units at the same site and maybe for multiple years to obtain a better and more representative data set. Obviously a machine that is started less than 50 times per year is a poor candidate for a single unit starting reliability warranty. Here is a way, however, that this measurement uncertainty can be fairly addressed.

If the starting reliability measurement must be made with an accumulation of less than 500 start attempts, the statistical measurement uncertainty shall be recognized by providing an allowance from the guarantee level. The Measurement Uncertainty Allowance shall adjust the point of damages initiation based on the cumulative binomial probability function and the actual number of start attempts so as to assure with 75% confidence that the indicated (measured) shortfall is due to equipment deficiency rather than the random nature of failure occurrences.

The author recommends that the IEEE Std 762 formula be used for starting reliability guarantees since it is most universally acceptable, allows focus on only the chargeable starting failure events, and is already set up as a published national standard. Starting reliability guarantees are not recommended for base load and continuous service units that experience infrequent starting. Appendix A provides a suggested generic write-up for a multi-unit Starting Reliability warranty.

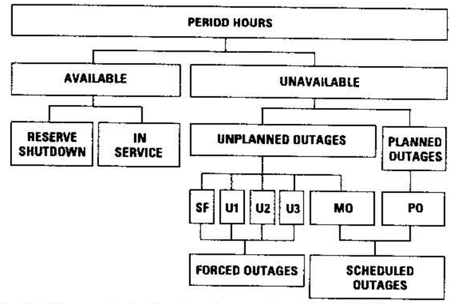


Fig. 3. Conceptual classification of outage time (NERC GADS).

IV. Outage Classifications

Before discussing running reliability and availability, which are primarily time-based measurements, one should review the principal classifications of outage time. For this, a picture is worth a multitude of words and this "picture" (see Fig. 3) is based on the familiar NERC GADS definitions.

1) SF = *Starting Failure*. Under IEEE Std 762, this is called a Class 0 Unplanned Outage.
2) U1 = *Immediate Unplanned Outage*. IEEE Std 762 calls this a Class 1 Unplanned Outage and both NERC and IEEE allow assignment to this classification from

either the in-service (running) state or from the shutdown (nonrunning) state. IEEE additionally permits scheduled outage extension time to be reclassified as Class 1 depending on the cause of the extension. The ORAP reporting system takes a different approach to U1, U2, and U3 forced outages which will be discussed later. U1 failures are obviously the most critical failure events.

3) U2 = *Delayed Unplanned Outage*. Similar to U1 but less urgent; NERC-GADS generally allows the machine to delay the outage to the end of its daily run. IEEE Std 762 calls this a Class 2 Unplanned Outage and more specifically requires that unit be removed from the in-service state within six hours.
4) U3 = *Postponed Unplanned Outage*. Both NERC GADS and IEEE identify this as an outage that can be postponed beyond the U2 level of urgency but must be removed from the in-service state before the end of the next weekend. IEEE Std 762 identifies U3 outages as Class 3 Unplanned Outages.
5) MO = *Maintenance Outages*. IEEE Std 762 identifies maintenance outages as Class 4 Unplanned Outages and with NERC GADS qualifies these outages as those that can be delayed beyond the next weekend but must be attended to before the next [long-lead] planned outage. The ORAP definition of maintenance outage is slightly broader as it picks up a few of the U2 outages and many of the U3 outages. Note that maintenance outages occur for unplanned reasons but can be sufficiently delayed to be classed as "scheduled" outages.
6) PO = *Planned Outages*. Both IEEE Std 762 and NERC GADS identify planned outages as those that are scheduled well in advance and have a predetermined duration. Extensions of planned outage are noted as such under NERC GADS and continue to be counted as more planned (and scheduled) outage hours. But according to IEEE, planned outage extensions may be retained as unplanned outage extensions or reassigned to Class 1 or Class 0 unplanned outages depending upon extension cause.

Administrative Outage Hours (AOH) are a category not identified under either IEEE Std 762 or NERC GADS but very necessary for warranty situations. It provides a charging category (or location) for outage hours that might not be chargeable under the warranty such as *force majeure* events, waiting time, nonapplied time, noncovered equipment outages, etc. Furthermore, it can also be used to separate the service intensity/effectiveness aspects from the nominal inherent equipment aspects in cases where the warrantor is not responsible for providing the maintenance service. In application, the AOH hours are removed from the IEEE or NERC unplanned outage hours and then either removed totally from the measurement or credited as available hours.

As mentioned previously, the basic ORAP reporting system treats the forced outage categories differently from the NERC GADS and IEEE classifications. The distinction primarily relates to whether the unit was running or in the shutdown state at the time of initiation of the outage state. The four standard ORAP forced outage categories are:

1) FS–*Starting Failure*
2) FOA–*Automatic Trip* from the running state
3) FOM–*Manual Trip* from the running state
4) FU–*Forced Unavailability* from the shutdown state.

The ORAP maintenance outage categories roughly correspond to the NERC GADS' MO and PO and are:

1) MU–*Maintenance Unscheduled*
2) MS–*Maintenance Scheduled*.

The ORAP outage classifications plus identification of noncurtailing events particularly serve the reliability engineering needs and enable the measurement of failure rate from the running state. MTBF data for gas turbines are generally more appropriate when based on service time and failures from the running state. The ORAP system also reports concurrent maintenance activities to assist design engineers and to better support MTTR assessments. NERC GADS is planning to pick up these capabilities.

As can be seen from above, the NERC GADS, SPS-ORAP, and IEEE outage classification systems are somewhat similar, *but not identical*. The variations in outage classification definitions plus operator judgement on classifications are quite minor in the aggregate of many unit-years of data. But in the context of measuring performance for a single unit for a single year, and then considering financial penalty or "liquidated damages," such variations can be extremely important. A well-written warranty contract document will greatly reduce future conflict over rules and operator interpretations.

V. Running Reliability

Reliability is defined (in essence) as "the probability that the equipment, or system, can fulfill its function *for the planned period of need*." But while there is widespread general agreement with this concept, there is unfortunately a large number of significantly different measurement formulas being applied to quantify "reliability." This group is often referred to as "Running Reliability" (RR) measurements (to distinguish them from starting reliability measurements) and their one point of commonality is that they all generally exclude planned shutdowns from the measurement.

For the sake of reliability understanding, and to more quickly relate to the *many* formulas faced by users, A/Es and OEM's; some of the more commonly used formulas will be defined, explained and compared for different operating service profiles. Please note that some formulas are better suited to specific warranty or engineering situations than are other formulas.

A. RR = (1 − FOF) [GT traditional formula] (4)

where FOF is the Forced Outage Factor and

$$\text{FOF} = \frac{\text{Forced Outage Hours}}{\text{Period Hours}}. \qquad (5)$$

The author's company has traditionally used this formula for reliability because: 1) the Forced Outage Factor tends to be somewhat independent of service duty, and 2) the FOF can

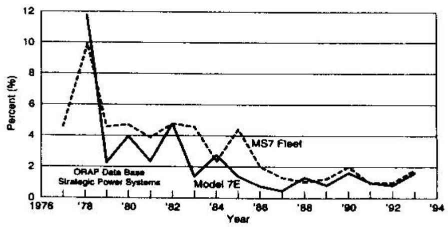


Fig. 4. Forced outage factor. MS7001 domestic (USA) units.

be directly subdivided to the contributing elements. Forced Outage Factor is formally defined by both NERC GADS and IEEE Std 762; it typically runs in the 1% to 4% range (see Fig. 4) and is a reasonably well accepted reliability measure for high use machines. It is the reliability measure used in ORAP. The minor problem with this measure is that while an FOF of 2% yields a good reliability number of 98%, most users/operators are not impressed with the thought of 175 forced outage hours per year on machines used only 100 to 500 service hours per year. The more common and preferred form of this traditional GT formula, is as follows:

$$RR = \frac{\text{Period Hours} - \text{FOH}}{\text{Period Hours}}. \qquad (6)$$

For warranty situations, FOH are *chargeable* forced outage hours.

B. RR = (1 − UOF) ["UOF" formula] (7)
where UOF is the Unplanned Outage Factor and

$$\text{UOF} = \frac{\text{FOH} + \text{MOH}}{\text{PH}} \qquad (8)$$

FOH	Forced Outage Hours,
MOH	unplanned Maintenance Outage Hours, and
PH	Period Hours.

This UOF formula is similar to the traditional GT formula (4) except that it includes all unplanned outages (forced plus maintenance). Some ORAP historical data has shown that the Maintenance Outage Factor runs at about two-thirds of the Forced Outage Factor. So the "example" machine with a 2% FOF might have 1.3% MOF for a total of 3.33% Unplanned Outage Factor and a "UOF Reliability" of 96.7%.

C. RR = (1 − FOR) [utility FOR formula] (9)
where FOR is the Forced Outage Rate and

$$\text{FOR} = \frac{\text{Forced Outage Hours}}{\text{Forced Outage Hours} + \text{Service Hours}}. \qquad (10)$$

The Forced Outage Rate (FOR) is a long established utility industry measurement formally defined by both NERC GADS and IEEE. It works fairly well on high use machines and it is often used for utility reliability calculations including loss of load probability planning. It loses its appropriateness and attractiveness when applied to low usage machines in standby or traditional "peaking" service. The "example" machine with 175 forced outage hours and 100 service hours per year has an FOR of 63.6% and a reliability of 36.4%! The optics are bad. Part of the problem with FOR, as a measurement, is that no credit is given for reserve shutdown time when the unit is fully available on standby. Another part of the problem is that *all elapsed time* forced outage hours (FOH) are debited even though a large percentage of the FOH might occur during periods of nondemand.

D.
$$RR = \frac{\text{PH} - \text{FOH} - \text{SOH} - \text{AOH}}{\text{PH} - \text{SOH} - \text{AOH}} \qquad (11)$$
[European formula]

where

PH	Period Hours (one year—8760 h),
FOF	Forced Outage Hours,
SOH	Scheduled Outage Hours, and
AOH	Administrative Outage Hours.

This formula, seen frequently in European bid specs, is variously called "Forced Outage Availability" or "Running Availability" or just plain "Availability." It is the truest measure of the time-based probability for avoidance of forced outages and it is fully suitable as a warranty measure for units of any service application whether peaking or continuous service. The "Administrative Outage Hours" (AOH) category admirably covers any number of "stop-the-clock" provisions for outage events that should not be charged against the equipment. To continue the example: If the machine with 175 forced outage hours and 100 service hours also had 200 scheduled outage hours plus 20 administrative outage hours, its annual "running reliability" would be 97.95%. The European formula also has alternate forms that sometime appear in bid specifications

$$RR = \frac{\text{SH} + \text{RSH}}{\text{SH} + \text{RSH} + \text{FOH}} \quad \text{[European Version 2]} \qquad (12)$$

where SH = In Service Hours (fired hours), RSH = Reserve Shutdown Hours, and FOH = Forced Outage Hours, and also

$$RR = \frac{\text{Available Hours}}{\text{Available Hours} + \text{FOH}} \quad \text{[European Vers. 3].} \qquad (13)$$

E. $\text{Reliability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$ [textbook formula](14)

where MTBF = Mean Time Between Failures, and MTTR = Mean Time To Repair. This classical textbook formula [2] is used in the EPRI UNIRAM program and is often applied to components or subsystems. It originated as a measurement of reliability for systems that were expected to be in continuous service such as telephone and communications systems. If the MTBF is measured in period time (clock/calendar hours), the result numerically approximates the GT traditional formula (4). If the MTBF is measured in service hours, the result numerically approximates the utility FOR formula (9). This formula and the terms MTBF and MTTR are more often tools of the reliability engineer than the power plant operator. There are at least two reasons why this is not a good formula, or measure, for warranty purposes: 1) The terms MTBF and

MTTR are derived, rather than directly-measured values, and 2) it tends to be overly sensitive to event rate.

F. RR = (1 - CFOR) [corrected FOR formula] (15)

where

$$\text{CFOR} = \text{Corrected Forced Outage Rate}$$

$$\text{CFOR} = \frac{(\text{FOH})(\text{DDF})}{(\text{FOH})(\text{DDF}) + \text{SH}} \tag{16}$$

and

FOH Forced Outage Hours,
DDF Daily Duty Factor,
(Fired Hours per Start)/24, and
SH Service Hours.

The Corrected Forced Outage Rate (CFOR) is an attempt to more fairly apply the concept of Forced Outage Rate (FOR) to low usage situations such as "peaking" duty. See [3] for a complete discussion of this approach. This formula is purported to be an applied approximation of a four-state Markov model (with which some utilities are experimenting), and through the Daily Duty Factor (DDF) it recognizes that much of the forced outage repair time is accrued when the unit is not in demand (and maybe not even being worked on). For the original example machine of 175 forced outage hours and 100 service hours, we might ascertain that the average fired hours per start is 4.0. That gives a daily duty factor of 0.167, a CFOR of 6.8%, and a reliability of 93.2%. Not as optically pleasing a number as the GT and European formulas produce but tremendously better than the 36.4% associated with the uncorrected forced outage rate formula (9). This is a fair reliability warranty measurement for peaking units but it depends on a derived (or arbitrary) correction factor. It has seen little exposure and even less acceptance.

G. $\text{RR} = e^{-(\lambda)t}$ [mission reliability] (17)

where e = the base of the natural log (2.71828), λ = the failure rate in events per hour which is also equivalent to 1/MTBF, and t = mission time in hours. Mission reliability is a classical reliability measurement tool and represents the probability that a mission of time (t) will be successfully completed once started. Mission reliability is extensively used in military and aerospace design and is most applicable to continuously functioning components or systems where there is no opportunity for in-service repair. Unlike all of the foregoing reliability definitions (or formulas), mission reliability is oblivious to the repair or outage time. But it is still useful to estimate the probability of completing a run or to predict component failures. If the "example" machine has a 250-service-hour MTBF in peaking service, then the probability of completing a 4-h run is 98.4%, and that would be called the mission reliability. Mission reliability is an excellent design or system planning tool but a poor warranty measurement device.

H. $\text{RR} = 1 - \dfrac{\text{SF} + \text{FOE}}{\text{SF} + \text{SS}}$ [P.R. Index-1] (18)

where SF = Starting Failures, FOE = Forced Outage Events (from the running state), and SS = Starting Successes. The "Peaking Reliability Index" (PRI) is a fairly new approach that is quite attractive as a single, simple, fair, and overall measure for peaking or cycling duty units. It is strictly an "events" based extension of starting reliability that views the probability of not only starting, but completing a run. The simplicity of the measurement offers strong argument, particularly for warranty purposes. In the continuing example: As the peaking "example" machine sees 25 successful starts and 100 service hours, it likely endured one starting failure and maybe one forced outage event (a trip) from the running condition. The corresponding PRI Reliability is easily calculated at 92.3%.

I. $\text{RR} = 1 - \dfrac{\text{UOE}}{\text{SF} + \text{SS}}$ [P.R. Index-2] (19)

where

UOE Unplanned Outage Events,
SF Starting Failures, and
SS Starting Successes.

This alternate "Peaking Reliability Index" is a little broader than the first version, (18) above, in that it relates all unplanned planned outage events to the number of attempted runs. It is an excellent general measure of the freedom from unplanned outages. As the peaking "example" machine sees 25 successful starts, 100 service hours, one starting failure, one forced outage (trip) event, and one unplanned maintenance outage repair event accomplished during a period of no demand, the corresponding PRI-2 Reliability is calculated at 88.5%.

J. $\text{RR} = (\text{P}_{\text{avail}})(\text{SR})(\text{P}_{\text{mission}})$ [demand rel.] (20)

where P_{avail} = probability of being available using the European formula (11), SR = Starting Reliability, and $\text{P}_{\text{mission}}$ = probability of completing the mission using the Mission Reliability formula (17). This demand reliability formula is receiving increased usage by utilities as a planning tool for peaking and daily cycling units. See [4], which is both specific and encompassing in nature, and is an excellent *collective* measure for most generating units. It has a disadvantage of producing poor appearing numbers for units that target for very long continuous runs (thousands of hours). It is also somewhat complex for implementation as a warranty measurement. If the base case "example" machine has a starting reliability of 96%, then the demand reliability is (0.9795)(0.96)(0.984) = 92.5%. This is perhaps the best measure of the probability that a generating unit in peaking service will provide electricity for a period of demand.

The dilemma of the existence and usage of so many formulas is tacitly acknowledged by the two leading USA norms, ANSI/IEEE Std 762 and NERC GADS, in that neither attempts to provide a specific mathematical formula for the terms reliability or running reliability.

The author has provided his rating of the applicability of the different running reliability formulas for use in different warranty and engineering situations (see Fig. 5). The basic criteria for the ratings on warranty measurements are as follows:

1) The measure should have a tangible feeling; that is, it should be a simple measure calculated directly from counting hours and/or events.

Formula for Running Reliability		Warranty Measurements: Peaking < 20 FH/start	Mid-Range <6,000 FH/year	Base >6,000 FH/year	Reliab. Engrg. & Systems Planning
A. Trad. GT	1 - FOF	Fair	Good	V.G.	V.G.
B. "UOF"	1 - UOF	Fair	Good	V.G.	V.G.
C. Utility FOR	1 - FOR	V.P.	Poor	Good	Limited
D. European	$\frac{SH + RSH}{SH + RSH + FOH}$	V.G.	V.G.	V.G.	Fair
E. Textbook	$\frac{MTBF}{MTBF + MTTR}$	V.P.	Poor	Fair	Limited
F. Corrected	1 - CFOR	Fair	Poor	N.A.	Limited
G. Mission	$e^{-(lambda)t}$	V.P.	V.P.	Poor	V.G.
H. P.R.I.-1	$1 - \frac{SF + FOE}{SF + SS}$	V.G.	Fair	Poor	Fair
I. P.R.I.-2	$1 - \frac{UOE}{SF + SS}$	V.G.	Fair	Poor	Fair
J. Demand	$(P_{avail})(SR)(P_{miss})$	V.P.	V.P.	V.P.	V.G.

Abbreviations:

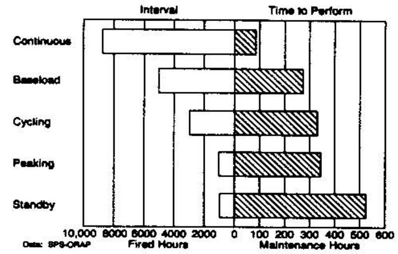
V.G. = Very Good
V.P. = Very Poor
N.A. = Not Applicable

Fig. 5.

2) The measure should closely describe the probability of the machine being able to deliver service when it is expected to be in service.
3) There should be zero or minimum dependence on arbitrary or approximated factors.
4) The resulting number should have political and emotional acceptability; i.e., if it is a measure of reliability, it should read above 90%.

Warranties on running reliability are reasonable for all service applications from peaking to continuous duty if the proper formula is selected. Warranty structuring for running reliability guarantees is concerned with good recordkeeping and careful outage management (including correct categorization of the forced outage events and the elements of restoration time). Furthermore, it is good to decide when writing the warranty terms whether the warranty is basically intended to nominally cover the equipment only or the equipment plus the user's and/or manufacturer's service system. Most manufacturers are not keen to pay liquidated damages for downtime hours where the user applied his limited maintenance resources to other projects because of other priorities.

Appendix B includes a generic sample warranty statement (plus qualifying clauses) for a running reliability warranty based on the "European" formula.



SERVICE APPLICATION

Duty	Service Factor %	FH per Start	# of Insp.	Insp. Interval	Outage Hours
Continuous	80-100	>120	28	8675	88
Base Load	30-80	>60	178	5048	276
Cycling	10-50	10-20	160	3206	339
Peaking	2-10	3-10	120	1072	355
Standby	0-2	<4	2	1073	529

Fig. 6.

VI. Maintenance Intensity

The time-based measurements of availability and running reliability generally count the grand total elapsed outage hours without differentiating actual applied repair time from unapplied time or planned tasks from ad hoc inspection activities. Some critical peaking or cycling units are overly maintained. And some minor two-hour repair tasks are logged at over a hundred outage hours because of low maintenance priority and idle time. Waiting time for replacement parts can have an even more serious effect. Availability can become more a measure of the service system than the inherent disposition of the equipment to perform. In reviewing ORAP data for many machines, it becomes obvious that the maintenance intensity effect is a very significant factor, it is driven by the operators's need for the equipment and it can be correlated to the service application. Fig. 6 exquisitely illustrates this effect.

The combustion inspection is a fairly standard gas turbine maintenance inspection, yet some operators perform it more often than others, and the *average* elapsed period hours taken to accomplish this inspection vary by 6 to 1 across the service application categories! From all 488 inspections the average amount of hours to complete is 306. But is the "average" representative? How about the manufacturer's instruction book? Reference [5] estimates 12 eight-hour shifts (or as little as 96 clock/period hours) for the MS7001 combustion inspection. The data indicate that this is reasonably demonstrated by the continuous duty units where the need and maintenance intensity are high, where three-shift maintenance is often employed, and where an offline, "replace-then-repair," parts correction technique is applied.

Maintenance intensity effect is such a significant factor that it must be addressed with every time-based availability or running reliability warranty situation. All maintenance may be performed by the equipment supplier, or agreement reached on specific maintenance conduct, or a warranty qualification set up to exclude excessive inspection events and excessive waiting time. The additional subclassifications of outage time necessitate more detailed recordkeeping and a separate set of warranty performance measurements that will be numerically different from the normal ORAP or NERC GADS measurements. Two (or even three) "sets of books" will have to be kept.

VII. Availability

Availability is the popular measure of the *portion of time* that a unit is available to serve load because it is not on forced outage, maintenance outage, or planned outage. NERC GADS, ANSI/IEEE Std 762-1987 and ORAP recognize Availability as a key performance index and more specifically call it the "Availability Factor" (AF).

$$\text{Availability Factor} = \frac{\text{Available Hours}}{\text{Period Hours}} \tag{21}$$

where

$$\text{Available Hours (AH)} = \text{PH} - \text{FOH} - \text{MOH} - \text{POH}$$

and

PH Period Hours (one year—8760 h),
FOH Forced Outage Hours,
MOH (unplanned) Maintenance Outage Hours, and
POH Planned Outage Hours scheduled well in advance).

Sometimes the "availability" label is applied to a more limited measurement, one that removes scheduled outage hours or some other element. These situations have been addressed in Section V. And when "availability" becomes concerned with capacity levels or deratings or plant-level ratings (as it should with multi-shaft combined cycle units) it belongs to Section VIII.

It should also be pointed out that while availability is an excellent measure for high usage machines, it is a relatively poor measure to be applied to low usage machines. In periods of low equipment need there is usually little incentive to accomplish scheduled or even essential maintenance in an expeditious manner. The inevitable stretch of outage time accrues unfavorably to the measurement. If the service application is low usage peaking service, it is advisable to consider a more appropriate running reliability guarantee along the lines of the "European" formula (11) or the "Peaking Reliability Indexes" (18), (19) or perhaps just a Starting Reliability guarantee.

The structuring of availability warranties is similar to the structuring of running reliability warranties. For both, the focus is on the management of outage time, but for availability there must also be some control over the conduct of planned maintenance. And, in recognition of the fact that there will be nonchargeable outage time, the warranty version of the availability formula is preferably written as follows:

$$\text{Availability of Warranty} = \frac{\text{AH}}{\text{PH} - \text{AOH}} \tag{22}$$

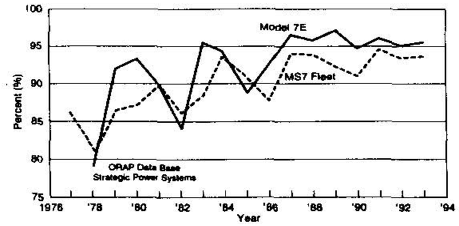


Fig. 7. Availability. MS7001 domestic (USA) units.

where Available Hours (AH) also equals PH − FOH − MOH − POH − AOH and

PH Period Hours (one year—8760 h),
FOH Forced Outage Hours,
MOH (unplanned) Maintenance Outage Hours,
POH Planned Outage Hours (scheduled well in advance), and
AOH Administrative Outage Hours (nonchargeable hours).

Fig. 7 traces the average annual availability performance of the domestic (USA) MS7001E/EA units participating in the SPS-ORAP data system. Appendix C includes a generic sample of an availability warranty statement with qualifying terms.

VIII. Equivalent Availability

When the term "Equivalent" is applied to availability or reliability it could mean several things. Under IEEE Std 762-1987 and NERC GADS it extends the concept of availability or reliability to account for varying capacity levels and in effect becomes a measure of *energy production availability*. This is the context advocated by this author. In other uses, the term "equivalent" is sometimes associated with an approximation type measurement that may have nothing to do with capacity. Sometimes, the term "equivalent" might be used to distinguish the subsystem level or component level from the full system generation level. For example, the reliability performance of a problematic limit switch might be described in terms of its Equivalent Forced Outage Rate (EFOR) which was deduced from its MTTR divided by its (MTTR + MTBF). This paper, with its focus on warranty conditions, will look at three types (or levels) of "system" equivalent availability measurements which increasingly accommodate the capacity element.

A. Equivalent Availability (EA)—Level 1 "Block Method"

The SPS-ORAP system has for many years been measuring the equivalent availability of combined cycle plants by merely extending the traditional time-based availability measurements to the full (multi-unit) plant. If one gas turbine of a four-unit combined cycle plant is unavailable, the plant may still be operated at about 3/4 capacity. If only the steam turbine is unavailable, and there are provisions (e.g., HRSG bypass stacks) for operating the gas turbines simple cycle, then about 2/3 of the plant capacity is available. During these periods of partial equipment unavailability the plant is respectively considered to be at 75% or 66.7% equivalent availability. This measurement system is fully described by [6]. By this measurement method, each major generating block is treated as being either available or not available to contribute a pre-established percentage of the plant's output. This block method of equivalent availability measurement can also be calculated using the NERC and IEEE suggested procedures outlined later.

The IEEE Std 762-1987 procedure for calculating the Equivalent Availability Factor (EAF) first establishes the normal time-based availability factor then provides a deduct in the form of equivalent derated hours for operation at derated capacity levels.

$$\mathrm{EAF} = \frac{\text{available hours} - \text{equiv. derated hours}}{\text{period hours}} \tag{23}$$

where

Available Hours

$$(\mathrm{AH}) = \mathrm{PH} - \mathrm{FOH} - \mathrm{MOH} - \mathrm{POH}$$

Equiv. Derated Hours

$$(\mathrm{EDH}) = \mathrm{EUDH} + \mathrm{EPDH} + \mathrm{ESEDH}$$

and

PH	Period Hours (one year – 8760 h),
FOH	Forced Outage Hours,
MOH	unplanned Maintenance Outage Hours,
POH	Planned Outage Hours (scheduled well in advance),
EUDH	Equivalent Unplanned Derated Hours,
EPDH	Equivalent Planned Derated Hours, and
ESEDH	Equivalent Seasonal Derated Hours.

The Equivalent Derated Hours are determined by multiplying the derated operating time (hours) by the percentage of derating. If a four-unit combined cycle plant experienced unplanned unavailability of one gas turbine for 100 period (clock-time) hours, it is treated as a 25% "block" derating of the plant. For calculation purposes the *plant* available hours are still 100 hours (100%) but there would be the accumulation of (0.25) × (100 h) = 25 equivalent unplanned derated hours (100 AH – 25 EUDH)/100 PH = 75% EAF. When the equipment capacity is limited, all hours are derated including not only the service hours, but also the reserve shutdown hours. Seasonal derated hours, as defined by IEEE and NERC and discussed later, are excluded or set to zero in the block method.

B. Equivalent Availability—Level 2 "Proportional Block Derating"

A second example illustrates the "proportional" derating method which goes beyond the previous block method by considering deratings due to partial equipment failures. If another gas turbine generator in the same four-unit combined cycle plant had a generator rotor heating problem that prescribed a limit on output power to 92% of its rated capability for a period of 1000 h, then that gas turbine generating set would be operating with an 8% shortfall of capacity. By the proportional derating method, the *plant* would accumulate (0.08)(0.25)(1000) = 20 equivalent planned derated hours for the 1000 period hours of this generator shortfall. These 20 EPDH would not have been counted under the previous block derating method, but here at level 2 they are counted together with the other equivalent derated hours.

Using the Level 2 Proportional Block Derating Method, the plant is considered 100% available except when equipment failure reduces generating capacity. Then the amount of equivalent derating is established based upon engineering logic and negotiation. Accurately measuring the true amount of capacity shortfall is difficult as will become evident in the discussion of level 3 EAF. (Note: Appendix D provides a sample equivalent availability warranty based on the proportional block derating method).

C. Equivalent Availability—Level 3 "Full Energy Measurement"

The IEEE and NERC standards strive for a good measure of energy availability but have not fully addressed the significant (and nonfailure) factors influencing gas turbine output power levels such as:

- *Ambient Climatic Conditions:* Temperature, barometric pressure, and humidity can cause gas turbine output capability to vary by 10% or more in a 24-h period without any equipment failures or faults chargeable to unreliability. And seasonal variations can be worth as much as 30% change in output power capability.
- *Compressor and Turbine Cleanliness Levels:* The state of cleanliness of the gas turbine's compressor and turbine sections can impact output capability by up 10% in extreme cases. This is a site environment/maintenance issue; it is not a reliability issue, but should it be counted as equivalent unavailability?
- *Compressor and Turbine Degradation:* Aging and wear cause clearances to increase and flow path surfaces to roughen, ultimately decreasing output capability by 5% or more in a normally unrecoverable manner. This is not usually categorized as equipment failure but some would have it be counted as equivalent unavailability.

So, the measure of equivalent availability, on a full energy production capability measurement basis, is not just one of reliability or equipment failure, but also how to deal with the other major performance factors. An equivalent availability guarantee especially needs a very clear and explicit set of warranty terms and conditions. Despite the complexity, the full energy measurement basis of EAF is exactly what some independent power producers and nonutility generators are seeking in order to insure the profitability of their ventures.

One technical solution suggested by the author is to utilize a small computer model to first calculate the theoretical "new-and clean" performance on an average hourly basis from the manufacturer's plant performance algorithms. Then, *actual hourly output capability* would be calculated by subtracting a cleanliness (fouling) correction, a degradation correction and an equipment failure correction (derating). Negotiation would determine which corrections would be included in the

TABLE I

Number of Start Attempts	85% Confidence Levels on 95% inherent SR to Favor or Protect	
	Seller	Buyer
20	90	Not Possible
50	92	98
100	93	97
400	93.75	96.0
1000	94.3	95.7

EAF measurement. The value of each of the corrections is determined by regularly pressing the generating machinery to maximum operating level and recording the actual output power. Since most of these measurements would not have equipment failure deratings in effect, it is possible to determine the average deterioration of performance due to long term degradation, the rate of deterioration due to fouling, and the amount of recovery associated with cleaning. The derating due to equipment failure can also be tested, or even measured on an hourly basis. Those corrections that had been agreed to be included in the EAF measurement would then be integrated to equivalent derated hours for use in the EAF equation (23).

Unfortunately, several known projects have been committed to EAF guaranties without preestablishing the measurement system, measurement formulas, or rules. When the equipment finally enters commercial operation, the dilemma of the measurement system becomes clear and the warranties have defaulted to compromise positions such as negotiated seasonal (monthly or quarterly) production quotas with associated bonus/penalty conditions. EAF has become the percent achievement of the quota and it has sometimes exceeded 100% (defying all traditional reliability theory). Even the variance of the weather has been passed back to the equipment manufacturer! When IEEE and NERC standards invoke the "Seasonal Derating" term for gas turbines, it effectively offers the same compromise position and the same problems for gas turbine power plants.

Thinking broadly about all equivalent availability guarantees, they can be applied for simple cycle gas turbines up through the most complex combined cycle plants, but the measurement system and warranty structure must be very carefully thought out and agreed upon between all parties to the contract. The simple time-based measures of availability and block method EAF are often more appropriate, and more easily measured and preferred for their simplicity. And like availability, the EAF is a good measure for high usage plants and a poor (undesirable) measure for low usage machines.

In recognition of the fact that there will be nonchargeable outage time, the warranty version of the equivalent availability formula is suggested as follows:

$$\text{EAF Under Warranty} = \frac{\text{AH} - \text{EDH}}{\text{PH} - \text{AOH}} \qquad (24)$$

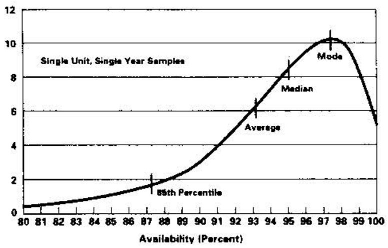


Fig. 8. Typical availability distribution. Percent samples per percent availability.

where Available Hours (AH) = PH − FOH − MOH − POH − AOH and Equivalent Derated Hours (EDH) = EUDH + EPDH + ESEDH and

PH	Period Hours (one year − 8760 h),
FOH	Forced Outage Hours,
MOH	unplanned Maintenance Outage Hours,
POH	Planned Outage Hours (scheduled well in advance),
AOH	Administrative Outage Hours,
EUDH	Equivalent Unplanned Derated Hours,
EPDH	Equivalent Planned Derated Hours, and
ESEDH	Equivalent Seasonal Derated Hours.

IX. Measurement Uncertainty

When money or reputation are at stake, it is important that the measurement system be both accurate and representative. The accuracy of the data is accomplished through a "rigorous and explicit" logging system that identifies the nature of each operating event (and outage) together with the starting and stopping times to the nearest minute or tenth of an hour. Representativeness of the data is a little tougher to deal with because of the randomness of occurrence of failure events and the widely distributed spacing of planned maintenance events.

The term "representativeness" is used here to relate the actual measured value to the inherent long-term operating norm of the equipment. This was partially addressed under starting reliability with reference to the number of start attempts required in the measurement to be statistically representative of the real, inherent mean. Table I illustrates the 85% confidence band around 95% inherent starting reliability to protect seller and buyer.

A similar situation of randomness exists with Running Reliability and Availability measurements. The statistician will advise that at least 25 to 30 unplanned outage events are needed in the measurement set in order for the MTTR and MTBF to be considered representative of the inherent performance level of the equipment. Once again it is appropriate to average multiple units and even multiple years of operating data.

Fig. 8 shows the smoothed probability distribution function of a sample set of availability data for simple cycle gas turbine generating sets taken on a single unit, single year basis. It nicely shows the "mode" units which the sales personnel love to tout: the fleet "average" (mean) data which is commonly shown as the collective performance statistic, and then a couple of distribution statistics. To the author, the "median" machine performance is a better indicator of expectations for single units than the "average" fleet performance, but the important number for warranty situations should be somewhere near the 85th percentile. At that point there is about 85% probability of successful achievement and only 15% probability of failure. By averaging multiple units and multiple years of data in the measurement, the gap between the 85th percentile and the "average" can be significantly closed. Bonus/penalty arrangements can also drive the guarantee point closer to the "average."

It should therefore be recognized by all parties that guarantee points will normally be more pessimistic than fleet average performance, median machine performance or the mode example machines.

X. Warranty Terms

A contractual warranty requires not only a measurement formula, definition of factors, and a guarantee number, but a set of terms to qualify the environment. Here is a reasonably full house of terms to choose from:

For all Reliability Warranties:

1) The reliability warranty is fully separate and independent from the equipment warranty. The warranties may have separate starting times, ending times, and commercial remedies.
2) A rigorous and explicit operating log shall be maintained from which the performance under warranty is to be determined. The log shall clearly identify the time, the cause, the capacity reduction, the amount of waiting time and/or idle maintenance time associated with each and every outage event and be periodically reviewed and jointly certified with the warrantor's technical representative.
3) With the seller's assistance and concurrence, the equipment operator shall have a documented maintenance program which covers scheduled maintenance plans, a work schedule agreement, and well planned replacement parts support.
4) The equipment shall be operated and maintained in accordance with the suppliers' recommended procedures with particular attention to maintenance inspection intervals and preventative maintenance activities.
5) A two-week (minimum) reliability demonstration period including no less than 5 start-stop cycles, 50 fired hours and mutually acceptable results shall precede the warranty measurement period.
6) Outage hours or events not directly chargeable to failure of equipment furnished under the contract shall not be chargeable to the warranty.

Additional Clauses for Starting Reliability Warranties:

7) Test starts and failures to start from equipment not furnished by the seller shall not be counted as start attempts, failures, or successes.
8) As a general assurance of readiness: If a unit has not experienced a successful start during the prior thirty days, then the start attempt shall be considered as a nonwarranty-qualifying "test start" and shall not be counted.
9) Measurement blocks of at least 500 unit start attempts are desired to ensure that the measured SR is statistically representative of the inherent (true) SR. Where liquidated damages without bonus provisions are associated with the measurement of SR, and the measurement block has less than 500 start attempts, then a measurement tolerance band shall be inserted between the guarantee point and the point of damages assessment. The measurement tolerance shall consider the actual number of start attempts and relate the measured SR to guaranteed SR with 85% statistical confidence.

Additional Clauses for Running Reliability, Availability and Equivalent Availability Warranties (as Applicable):

10) For purposes of the warranty measurement: Inspections, maintenance, and repair shall be gauged on a high priority, high need basis. To achieve this, waiting time and inactive maintenance time in excess of four hours per outage event shall be charged to administrative outage hours and not charged against the warranty.
11) Equipment outages shall be considered on a "block" basis. Each individual major piece of equipment (gas turbine, generator, HRSG, or steam turbine) shall be treated as either available or unavailable at any point in time. Equivalent outage hours shall be accumulated for "block" outages but not for reductions in capacity of the individual major pieces of equipment.
12) Planned outage inspections shall be performed on a "replace then repair" basis with all needed replacement parts on hand at the start of the inspection. NDE inspections, repairs and cleaning up of removed components are to be done separately from the outage/inspection activities.
13) Planning for outage inspections shall address all major equipment on a concurrent maintenance basis to be consistent with the basis of formulation of the guarantee level. If concurrent maintenance cannot be practiced, then the nonconcurrent planned outage hours for nongas turbine equipment shall not be chargeable as either outage hours or period hours, but as administrative outage hours.
14) Whereas seasonal deratings (due to ambient conditions) do not constitute any form of equipment failure, the Equivalent Seasonal Derated Hours (ESEDH) shall be set to zero and not factored into the measurement.

XI. Conclusion

In the author's experience of writing and negotiating reliability warranties, there was much new ground to break. There are also several major steps in the process of reaching an equitable warranty structure:

Step 1: Recognize the value of reliability to the point that it must be insured during the contracting process.

Step 2: Realize the fact that there are no commonly accepted standards and definitions that can be directly and solely used to establish the warranty measurement.

The current "standards," including IEEE Std 762, NERC GADS, ORAP, and the German VDEW, take a total plant operation approach. There are no provisions for dealing with nonchargeable outages or for separating nominal equipment restoration aspects from service system aspects.

Different site applications require different treatment. Single unit peakers operating 200 fired hours per year should be under warranty by different measurements than base-loaded, multi-unit, combined cycle plants.

Step 3: Reconcile the "real-life" warranty consideration factors and determination of the appropriate measurement for the specific application.

Part of this process is to "rough in" the qualifications concerning which outage events or hours shall be chargeable to the warranty, or fully excluded from the warranty or handled on a "stop-the-clock" basis. To aid this process, Appendix E contains a Worksheet for Allocation of Outage Hours.

Step 4: Capture the ideas of step 3 in suitable contract language.

Step 5: Implement the measuring system with log sheet forms (hopefully computerized) to semi-automatically track each machine covered by the warranty. The degree of detail or categorization afforded by the log shall support multiple reporting needs including the qualified warranty performance, NERC GADS reporting data, traditional performance measures (e.g., ORAP) and engineering-desired events data.

As reliability gets more widely and properly measured, so will its value become more appreciated and sought after on a tangible basis.

APPENDIX A

Starting Reliability Guarantee

[Project/Contract Title]

[Date]

A. Starting Reliability Statement

The average Starting Reliability of the [Model/Type] gas turbine-generator units furnished under this contract is guaranteed to be not less than [96.7%] over the warranty measurement period as measured in accordance with the definitions and concepts of ANSI/IEEE Std.762-1987. The warranty measurement period for each machine shall commence on the date of first commercial operation and expire [three years] from that date.

B. Starting Reliability Warranty Context

1. The ANSI/IEEE Std.762-1987 provides definitions and a formula for Starting Reliability that allow for the fact that not all failures-to-start or incomplete start attempts are chargeable to equipment failure or to the warranty. Starting Reliability is to be measured by the IEEE formula as follows:

$$\textbf{Starting Reliability} = \frac{SS}{SS + SF}$$

Where:

SS = Chargeable Starting Successes
SF = Chargeable Starting Failures

And:

A Qualifying Starting Attempt is the action intended to bring a unit from shutdown to the in-service state under conditions that qualify for inclusion in the warranty. Repeated initiations of the starting sequence within the allowable specified starting time period or without accomplishing corrective repairs are counted as a single attempt.

A Chargeable Starting Success (SS) is the occurrence of bringing a unit through a qualifying starting attempt to the in-service state within a specified period, as evidenced by maintained closure of the generator breaker to the system.

A Chargeable Starting Failure (SF) is the inability to bring a unit through a qualifying starting attempt to the in-service state within a specified period for failure reasons chargeable to the warranty. Repeated failures within the specified starting period are to be counted as a single starting failure.

2. On an annual basis or at each accumulation of 500 qualifying start attempts (whichever is greater), the Starting Reliability shall be calculated collectively as a single average measurement of all of the contract units that are within the warranty measurement period. If the calculated average Starting Reliability falls below the guarantee level, it shall be remedied in accordance with the terms set forth [in the Commercial section].

If the measurement must be made with an accumulation of less than 500 start attempts, the statistical measurement uncertainty shall be recognized by providing an allowance from the guarantee level. The Measurement Uncertainty Allowance shall adjust the point of damages initiation based on the cumulative binomial probability function and the actual number of start attempts to assure with 75% confidence that the indicated (measured) shortfall is due to equipment deficiency rather than the random nature of failure occurrences.

3. A rigorous and explicit operating log shall be maintained from which the starting reliability measurement is to be determined. The log shall be periodically reviewed and jointly certified with a [Supplier] technical representative.

4. Test Starts and failures to start from equipment not furnished under this contract by [Supplier] shall not be counted as start attempts, failures or successes.

5. As a general assurance of readiness; if a unit has not experienced a successful start during the prior thirty (30) days, then the start attempt shall be considered as a non-warranty "test start" and shall not be counted.

6. Procedural errors that do not constitute equipment failure involving repair shall not be counted as failures-to-start.

7. The units shall be operated within the design conditions specified in the contract and maintained in accordance with [Supplier] recommended procedures with particular attention to maintenance inspection intervals and preventative maintenance activities.

APPENDIX B
Running Reliability Guarantee
[Project/Contract Title]
[Date]

A. Running Reliability Statement

Running Reliability shall be guaranteed in terms of the ratio of actual available hours to planned available hours. The Running Reliability for the gas turbine-generator units furnished under this contract is guaranteed to average not less than [97.2%] over the warranty measurement period. The measurement period shall commence on successful completion of the two-week reliability readiness test. It shall expire [two years] after the date of first commercial operation.

B. Running Reliability Warranty Context

1. In recognition of the fact that there will be non-chargeable outage time, the warranty version of the running reliability formula shall be as follows:

$$\textbf{Running Reliability} = \frac{AH}{PH - POH - AOH}$$

where: Available Hours (AH) also equals
PH-FOH-MOH-POH-AOH

and: PH = Period Hours (usually one year - 8760 hours)
FOH = Forced Outage Hours
MOH = (unplanned) Maintenance Outage Hours
POH = Planned Outage Hours (scheduled well in advance)
AOH = Administrative Outage Hours (non-chargeable)

and: The above terms (except AOH) are more fully conceptualized and defined by ANSI/IEEE Std 762-1987

2. A rigorous and explicit operating log shall be maintained from which the Running Reliability measurement is to be determined. The log shall clearly identify the cause and the amount of waiting time and/or idle maintenance time associated with each and every outage event and be periodically reviewed and jointly certified with a [Supplier] technical representative.

3. With [Supplier] assistance and concurrence, the equipment operator shall have a documented maintenance program which covers scheduled maintenance plans, a work schedule agreement and well-planned replacement parts support.

4. The unit shall be operated and maintained in accordance with [Supplier] recommended procedures with particular attention to maintenance inspection intervals and preventative maintenance activities.

5. A two-week (minimum) reliability demonstration period including no less than 5 start-stop cycles, 50 fired hours and mutually acceptable results shall precede the Running Reliability warranty measurement period.

6. For purposes of the warranty measurement; inspections, maintenance and repair shall be gauged on a high priority, high need basis. To achieve this, waiting time and inactive maintenance time in excess of four hours per outage event shall be considered as Administrative Outage Hours (AOH). As such, they shall have "stop-the-clock" treatment and effectively not be counted as outage hours, derated hours or included in the period hours base.

7. Outage hours associated with the [Supplier] furnished equipment but not directly chargeable to equipment failure shall be considered as Administrative Outage Hours (AOH).

8. Operator shall operate the gas turbine unit within the design conditions specified in the contract.

APPENDIX C
Availability Guarantee
[Project/Contract Title]
[Date]

A. Availability Statement

Availability shall be guaranteed in terms of the Availability Factor as described in the definitions and concepts of ANSI/IEEE Std 762-1987. The average Availability Factor for the [#/model] gas turbines generator sets furnished under this contract is guaranteed to average not less than [95]% over the warranty measurement period. The measurement period shall commence on successful completion of the two-week reliability readiness test. It shall expire [three] years after the date of first commercial operation.

B. Availability Warranty Context

1. In recognition of the fact that there will be non-chargeable outage time, the warranty version of the availability formula shall be as follows:

$$\textbf{Warranted Availability Factor} = \frac{\textbf{AH}}{\textbf{PH - AOH}}$$

where: Available Hours (AH) also equals PH-FOH-MOH-POH-AOH

and: PH = Period Hours (usually one year - 8760 hours)

FOH = Forced Outage Hours

MOH = (unplanned) Maintenance Outage Hours

POH = Planned Outage Hours (scheduled well in advance)

AOH = Administrative Outage Hours (non-chargeable)

2. A rigorous and explicit operating log shall be maintained from which the Availability measurement is to be determined. The log shall clearly identify the cause and the amount of waiting time and/or idle maintenance time associated with each and every outage event and be periodically reviewed and jointly certified with a [Supplier] technical representative.

3. On an annual basis the Availability Factor shall be calculated collectively as a single average measurement of all the contract units that are within the availability warranty measurement period. If the calculated average Availability Factor falls below the guarantee level, it shall be remedied in accordance with the terms set forth in the [Commercial] agreements.

4. With [Supplier] assistance and concurrence, the equipment operator shall have a documented maintenance program which covers scheduled maintenance plans, a work schedule agreement and well-planned replacement parts support.

5. The unit shall be operated and maintained in accordance with [Supplier] recommended procedures with particular attention to maintenance inspection intervals and preventative maintenance activities.

6. A two-week (minimum) reliability demonstration period including no less than 5 start-stop cycles, 50 fired hours and mutually acceptable results shall precede the availability warranty measurement period.

7. For purposes of the warranty measurement; inspections, maintenance and repair shall be gauged on a high priority, high need basis. To achieve this, waiting time and inactive maintenance time in excess of four hours per outage event shall be considered as Administrative Outage Hours (AOH). As such, they shall have "stop-the-clock" treatment and effectively not be counted as outage hours, derated hours or included in the period hours base.

8. Outage hours associated with the [Supplier] furnished equipment but not directly chargeable to equipment failure shall be considered as Administrative Outage Hours (AOH).

9. Planned outage inspections shall be performed on a "replace then repair" basis with all needed replacement parts on hand at the start of the inspection. NDE inspections, repairs and cleaning up of removed components is to be done separately from the outage/ inspection activities.

10. Operator shall operate the gas turbine unit within the design conditions specified in the contract.

APPENDIX D
Equivalent Availability Guarantee
(Proportional Block Derating Method)
[Project/Contract Title]
[Date]

A. Availability Statement

Availability shall be guaranteed in terms of the Equivalent Availability Factor as generally described in the definitions and concepts for the ANSI/IEEE Std 762-1987. The average Equivalent Availability Factor for the contract-furnished gas turbines, generators and supporting controls and accessories is guaranteed to average not less than [90%] over the warranty measurement period. The measurement period for each generating set shall commence on successful completion of the two-week reliability readiness test. It shall expire two years after the date of first commercial operation.

B. Availability Warranty Context

1. In order to reflect capacity reductions due to equipment failures and deal with non-chargeable outage time, the warranty version of the equivalent availability formula shall be as follows:

$$\textbf{Warranted Equivalent Availability Factor} = \frac{AH - EDH}{PH - AOH}$$

where: Available Hours (AH) also equals
PH - FOH - MOH - POH - AOH by the
conventional, time-based, IEEE 762 definition

Equivalent Derated Hours (EDH) equals EUDH + EPDH calculated for periods of derating due to specific equipment failure and excluding seasonal derating and nominal degradation of performance

and: PH = Period Hours (usually one year-8760 hours)
FOH = Forced Outage Hours
MOH = (unplanned) Maintenance Outage Hours
POH = Planned Outage Hours (scheduled well in advance)
AOH = Administrative Outage Hours (non-chargeable)
EUDH = Equivalent Unplanned Derated Hours
EPDH = Equivalent Planned Derated Hours

2. A rigorous and explicit operating log shall be maintained from which the Equivalent Availability measurement is to be determined. The log shall clearly identify the cause and the amount of waiting time and/or idle maintenance time associated with each and every outage event plus all data required to calculate EDH including minimum and maximum ambient temperatures and the effective reduction in dispatchable dependable capacity. The log will be periodically reviewed and jointly certified with a [supplier] technical representative

3. The Equivalent Derated Hours (EDH) shall be calculated on a daily basis as follows:

a. For days wherein generating capacity is not limited by specific failure of contract-furnished equipment, the EDH shall be taken as zero (0).

b. For days that generating capacity is partially derated due to specific failure of the contract-furnished equipment, the EDH shall be calculated as the ratio of the capacity shortfall to the daily dependable capacity multiplied by the number of hours the derating was in effect. General degradation shall not be considered as specific failure.

For example; for each day with some capacity derating, the minimum and maximum ambient temperatures for the operating period are noted, recorded and averaged to determine the median daily operating temperature. Utilizing performance curves from the manufacturer, a "new and clean" plant capacity level is determined for that median temperature. Then that capacity is reduced by a nominal predicted degradation amount to arrive at the median daily dependable capacity. Now, because of the impact of the specific component failure, a maximum dispatchable capacity level will exist which must be rationally determined. (If the plant is fully dispatched for the full day, then the full day's generation in kWh divided by 24 hours is the maximum dispatchable capacity.) The difference between the median daily dependable capacity and the maximum dispatchable capacity is the shortfall.

The ratio of the shortfall to the median daily dependable capacity is the degree of derating. Then multiplying the degree of derating by the number of hours that the derating was in effect that day, yields the Equivalent Derated Hours.

4. With [Supplier's] assistance and concurrence, the equipment operator shall have a documented maintenance program which covers scheduled maintenance plans, a work schedule agreement and well-planned replacement parts support.

5. The unit shall be operated and maintained in accordance with [Supplier] recommended procedures with particular attention to maintenance inspection intervals and preventative maintenance activities.

6. A two-week (minimum) reliability demonstration period including no less than 5 start-stop cycles, 50 fired hours and mutually acceptable results shall precede the Equivalent Availability warranty measurement period.

7. For purposes of the warranty measurement; inspections, maintenance and repair shall be gauged on a high priority, high need basis. To achieve this, waiting time and inactive maintenance time in excess of four hours per outage event shall be considered as Administrative Outage Hours (AOH). As such, they shall have "stop-the-clock" treatment and effectively not be counted as outage hours, derated hours or included in the period hours base.

8. Outage hours associated with the [Supplier] - furnished equipment but not directly chargeable to equipment failure shall be considered as Administrative Outage Hours (AOH).

9. Planned outage inspections shall be performed on a "replace then repair" basis with all needed replacement parts on hand at the start of the inspection. NDE inspections, repairs and cleaning up of removed components is to be done separately from the outage/ inspection activities.

10. Operator shall operate the gas turbine unit within the design conditions specified in the contract.

APPENDIX E
Worksheet for Allocation of Outage Hours

A = warranty chargeable hours
B = non-chargeable "stop-the-clock" hours
C = non-chargeable fully-excluded hours

	A	B	C
Classifications by Event Cause			
Clearly covered equipment			
Forced outage	(X)		
Maintenance (delayed) outage	( )	( )	( )
Planned Outage	( )	( )	( )
Unplanned Extension of planned outage	( )	( )	( )
Non-covered equipment outages			(X)
Buyer-stipulated outage time			
Equipment modifications		( )	( )
Special tests or inspections		( )	( )
Force Majeuere events			
Flood - hurricane		(X)	
Externally caused fire		(X)	
Labor problems, strike			(X)
System problems			
Excessive frequency swings			(X)
Lack of proper (in spec.) fuel			(X)
Inadequate cooling water supply	( )	( )	( )
Site specific contract exclusion events			
Cement dust fouling of inlet		( )	( )
Planned outages for residual fuel		( )	( )
Service Interruption Outage Hours			
Waiting time or idle maintenance time in excess of (4) hours per outage event considering:	( )	( )	( )
Delays for replacement parts			
Buyer stocking responsibility	( )	( )	( )
Supplier stocking responsibility	( )	( )	( )
Carrier (transportation) mishap	( )	( )	( )
Delayed in Customs	( )	( )	( )
Delays of technical advisory service			
Notification delay	( )	( )	( )
Delayed arrival	( )	( )	( )
Unapplied crafts or labor time			
2nd shift not working	( )	( )	( )
3rd shift not working	( )	( )	( )
Weekend day or holiday	( )	( )	( )
Higher priority elsewhere	( )	( )	( )
Work stretch-out labor problem	( )	( )	( )
Necessary tools/equipment not available			
Traveling cranes or lifting gear	( )	( )	( )
Special welding equipment	( )	( )	( )
Oil conditioning equipment	( )	( )	( )
Other Considerations			
______________________	( )	( )	( )
______________________	( )	( )	( )
______________________	( )	( )	( )
______________________	( )	( )	( )
______________________	( )	( )	( )

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IEEE Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity, ANSI/IEEE Standard 762, 1987.
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Thomas E. Ekstrom received the B.S.M.E. from Northeastern University, Boston, MA.

He has worked for over 30 years in GE's Industrial and Power Systems businesses, Schenectady, NY, as an installation engineer, applications engineer, quality systems engineer, quality manager and engineering programs manager. He is currently a Senior Gas Turbine Application Engineer, in which his work includes the reliability analysis of all GE gas turbine power plant systems that involve reliability estimates or guarantees. He evaluates and structures about 60 reliability guarantees per year. He holds two patent awards and is an author of more than 20 technical papers.

Mr. Ekstrom is a member of ASQC and a recipient of numerous GE Engineering and Management awards. He is a Registered Professional Engineer in the state of New York.

