Utility Advanced Turbine Systems (ATS) Technology Readiness Testing Phase 3 Restructured (3R)

Predicted Reliability, Availability, Maintainability For The General Electric 7H Gas Turbine

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Reliability Expectations for GE’s New “H” Technology Power Generation Equipment

Summary

Much of the “H” technology design is based on proven, established technologies. The major technologies of the combined cycle powertrain, including the bearing designs, the evaluation methods for rotor dynamics, the compressor and turbine blading designs, and the generator field construction methods are all either direct applications of proven design technology or evolutionary refinement of existing designs. It is for these reasons that GE expects that the reliability of the new “H” Class generating system will be fully commensurate with the levels associated with today’s “F” Class combined cycle power plants. With maintenance and operations performed at “best practice” levels, the new “H” Class plant should reach its full reliability potential of 97.0% or better.

Introduction

GE’s new “H” technology design is the latest development in the evolution toward more efficient, more reliable, (and therefore more productive), electric power generation equipment offerings. This design is in its initial offering stage and no full plant operating data is yet available to bear out the engineering predictions for specific power output capability, net plant heat rate, emissions performance, reliability, and availability, which are the principal measures of the long-term “value” of a power plant.

The engineering advancement of the “H” technology has been a joint effort between GE and the US Department of Energy (DOE). GE’s target levels of reliability and availability are consistent with the current industry expectations for large combined cycle plants.

Furthermore, as technology has advanced to provide higher performance equipment, the engineering tools have advanced to provide better analysis of the hardware component performance. The Engineering Design Standards (of an experienced manufacturer such as GE) have evolved to provide better and more comprehensive design guidance. The design of the new “H” technology has particularly benefited from a validation strategy utilized as a best practice in GE’s Aircraft Engine (GEAE) business. The result is that the H technology has a higher probability of rapidly achieving its design expectations than the “new technology” offerings of past decades.

Discussion

The H New Product Introduction (NPI) team has followed a comprehensive design and technology validation plan that will, when complete, have spanned almost 10 years from concept to power plant commissioning. The first phase in the H System™ development process was a thorough assessment of product options and corresponding design concepts and system requirements. Also crucial in the first phase was careful selection of materials, components and subsystems. These were sorted into categories of existing capabilities or required technology advancements. The technical risk for each component and subsystem was assessed and abatement analyses, testing, and data requirements were specified. The plans to abate risk and facilitate design were arranged, funded and executed. The second development phase covered
product conceptual and preliminary designs. This phase included the introduction of knowledge gained through experience, materials data, and analytical codes from GEPS and GEAE. The H System development program is currently in its third and final phase, technology readiness demonstration. This phase includes execution of detailed design and product validation through technology rig and full scale component testing. A high degree of confidence has been gained during the third phase through this component and subsystem testing and subsequent validation of analysis codes. The development program will conclude with full-scale gas turbine testing at GE’s factory test stand in Greenville, SC followed by combined cycle power plant testing at the Baglan Energy Park launch site in the United Kingdom for the 9H (50 Hz) machine, and later at Sithe Energies Heritage Station site in upstate New York for the 7H (60 Hz) machine.

That new and more complex models can be introduced and rapidly meet on-target performance is borne out by field data collected since the early 1970s. The introduction of the GE MS6001B in the late 1970s showed better availability and less new model introduction impact than the introduction of the GE MS7001B in the early 1970s. The introduction of the far-more-complex MS7001F in the early 1990s was even better than the introduction of the MS6001B, and suffered only one-third the new model introduction impact to availability of the MS7001B. By the latter half of the 1990s, the introduction of the new MS6001FA gas turbines occurred with virtually immediate on-target performance and negligible new model introduction impact. GE’s installed fleet of “F Class” gas turbine generators has now logged over 2,620,000 service hours of experience with the majority of units normally operated at full base load. Therefore, with this experience base and proven design and technology validation plan, GE believes that the new “H” Class power generation equipment will meet its performance, reliability, availability, and maintainability objectives.

For yet a deeper focus on reliability, it should first be recognized that the controls and accessories support systems typically account for 60% to 80% of a plant’s unplanned outage events and 50% to 60% of the unplanned outage time. As the new “H” Technology machines go into production, the supporting controls and accessories systems are being assembled from the same class of components in the same proven system structures that currently serve the “E” Class and “F” Class product offerings. Much of the “H” Technology design is based on proven, established technologies. Designs for the major components of the combined cycle powertrain, including the bearing designs, the evaluation methods for rotor dynamics, the compressor and turbine blading designs, and the generator field construction methods are all either direct applications of proven design technology or evolutionary refinement of existing designs. It is for these reasons that GE expects that the reliability of the new “H” Class generating system will be fully commensurate with the levels associated with today’s “F” Class combined cycle power plants. With maintenance and operations performed at “best practice” levels, the new “H” Class plant should reach its full reliability potential of 97.0% or better. GE’s estimate of the individual component group reliability levels is as follows:
The gas turbine industry measures reliability in terms of the ratio of actual machine available time to the total period time, with an exclusion for the scheduled outage time. More specifically, “reliability” is measured as one minus the unreliability, where the “unreliability” is the industry-recognized “Forced Outage Factor”. Availability is a broader measure than “reliability” because it includes the effects of all outage categories including scheduled outages. In general, GE and the power generation industry expect availability levels of 90% and better for all gas turbine combined cycle plants, no matter how complex.

Starting Reliability is an important measure for peaking duty or daily start machines, and achievement of 95% or better starting reliability is expected for a single shaft combined cycle unit started regularly. Starting Reliability is a less important measure for base loaded generating sets. It should also be noted that the majority of failure-to-start events are the result of minor, procedural type errors that are remedied in less than 15 minutes without a bonafide “repair”.

In recent years, the reliability and availability of large gas turbine and combined cycle plants have far surpassed that of other generating plant types. The new “H” technology machines are being designed to achieve the same or higher levels of reliability as the industry currently expects from large combined cycle plants.

The following Appendix gives supporting reliability and availability data from both the US Government sponsored North American Electric Reliability Council (NERC), and the privately held Strategic Power Systems (SPS). Also included are terms and definitions used in the Appendix.
APPENDIX
RELIABILITY AND AVAILABILITY SUPPORTING DATA

There are two organizations in the United States that collect reliability-related operating data from utility-size generating plants. The older and more broadly recognized is the US Government sponsored North American Electric Reliability Council (NERC), which has been collecting this data under government mandate from regulated utilities since the 1970s. NERC data is collected in their Generating Availability Data System (GADS). The second organization is the privately-held firm, Strategic Power Systems, Inc. (SPS), which focuses on the reliability of gas turbine electrical generation plants, worldwide and application-wide, using their Operational Reliability Analysis Program (ORAP) data system. While the two organizations collect and report their data on slightly different bases, they share several common traits. First, they rigorously seek to record and classify each and every outage event so that the reliability and availability measures are complete, comprehensive and accurate. Second, they look at the complete plant operations from an operations point of view rather than from an equipment point of view (as would be preferred by the OEMs and is necessary where equipment reliability guarantees are involved). For example, the charging and recording of outage time for any particular event is the total elapsed clock time independent of the cause of the event, the availability of replacement parts, the amount of unapplied time or the applied maintenance intensity. A week of downtime is sometimes charged for a two-hour repair issue because of maintenance scheduling priorities. A third common trait is a high regard for the confidentiality of the individual unit data. Both organizations go to great lengths to thwart the cross-flow of competitive data. All data is reported in groupings such that no individual unit data, plant data or operator/owner data can flow or be deduced by another owner/operator. Similarly, the performance of one OEM’s equipment is obscured from the other OEMs.

Using the NERC’s on-line website report system (called EGADS), GE collected the following data:

<table>
<thead>
<tr>
<th>YEAR</th>
<th># units</th>
<th>Capacity Fact. (%)</th>
<th>Service Fact. (%)</th>
<th>Avail. (%)</th>
<th>Equiv. Avail (%)</th>
<th>FOF (%)</th>
<th>FOR (%)</th>
<th>EFOR (%)</th>
<th>Start Rel. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>35</td>
<td>33.14</td>
<td>46.65</td>
<td>91.16</td>
<td>80.60</td>
<td>1.09</td>
<td>2.29</td>
<td>5.45</td>
<td>98.11</td>
</tr>
<tr>
<td>1995</td>
<td>39</td>
<td>38.15</td>
<td>50.71</td>
<td>90.36</td>
<td>80.45</td>
<td>1.32</td>
<td>2.54</td>
<td>6.28</td>
<td>98.13</td>
</tr>
<tr>
<td>1996</td>
<td>54</td>
<td>41.24</td>
<td>55.12</td>
<td>92.12</td>
<td>86.16</td>
<td>1.40</td>
<td>2.48</td>
<td>5.20</td>
<td>98.28</td>
</tr>
<tr>
<td>1997</td>
<td>57</td>
<td>41.31</td>
<td>54.92</td>
<td>91.69</td>
<td>86.32</td>
<td>1.06</td>
<td>1.89</td>
<td>4.60</td>
<td>98.75</td>
</tr>
<tr>
<td>1998</td>
<td>57</td>
<td>44.24</td>
<td>58.20</td>
<td>91.66</td>
<td>85.52</td>
<td>2.41</td>
<td>3.98</td>
<td>6.99</td>
<td>98.38</td>
</tr>
<tr>
<td>94 – 98</td>
<td>58</td>
<td>40.15</td>
<td>53.86</td>
<td>91.49</td>
<td>84.33</td>
<td>1.50</td>
<td>2.71</td>
<td>5.71</td>
<td>98.35</td>
</tr>
</tbody>
</table>

NERC uses (and emphasizes) the energy-based equivalent availability and equivalent forced outage rate (EFOR) measures which are the preferred NERC measures for multi-gas-turbine combined cycle plants. When NERC applies the IEEE Std 762 time-based measurements (Availability, FOF, FOR and Starting Reliability) to combined cycle plants with multiple gas turbine generating sets, an unrealistically favorable bias results. With NERC, the whole plant is considered to be “available” when any one generating set is available to synchronize and produce any level (above zero) of commercial power. Similarly, if any of the multiple generating sets can be brought on line at dispatch request, the start attempt is considered to be successful. From a
reliability point of view, the multiple generating sets of most combined cycle plants are incorrectly treated as if they are redundant. Another point to be considered with NERC data is that the degradation of output power due to temporary fouling of the inlet filters and compressor blading, and the longer term degradation of output power due to wear, roughening of the airfoil surfaces and opening of clearances, is charged to “unit derating” and counts against equivalent availability. To the manufacturers, degradation is not usually considered a reliability issue. The average age of the NERC combined cycle units in the above data tabulation is about 14 years and general degradation is probably depressing the equivalent availability numbers by four or more points.

For the 1994 to 1998 period, the NERC data provides useful summary statistics by component for the combined cycle plants described in the table above:

<table>
<thead>
<tr>
<th>Component Group</th>
<th>Avail. (%)</th>
<th>Equiv. Avail (%)</th>
<th>FOF (%)</th>
<th>FOR (%)</th>
<th>EFOR (%)</th>
<th>SOF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler(s)</td>
<td>98.86</td>
<td>95.66</td>
<td>0.26</td>
<td>0.48</td>
<td>0.77</td>
<td>0.87</td>
</tr>
<tr>
<td>Balance of plant</td>
<td>98.95</td>
<td>95.62</td>
<td>0.24</td>
<td>0.45</td>
<td>1.18</td>
<td>0.80</td>
</tr>
<tr>
<td>Steam Turbine</td>
<td>99.07</td>
<td>95.98</td>
<td>0.18</td>
<td>0.33</td>
<td>0.44</td>
<td>0.75</td>
</tr>
<tr>
<td>Generator(s)</td>
<td>98.89</td>
<td>95.88</td>
<td>0.19</td>
<td>0.35</td>
<td>0.57</td>
<td>0.92</td>
</tr>
<tr>
<td>Gas Turbine(s)</td>
<td>96.44</td>
<td>91.88</td>
<td>0.42</td>
<td>0.78</td>
<td>1.58</td>
<td>3.14</td>
</tr>
<tr>
<td>Combined Cycle</td>
<td>99.89</td>
<td>97.04</td>
<td>0.02</td>
<td>0.03</td>
<td>0.07</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Using the same NERC website, the reliability characteristics of large, simple cycle, gas turbine generator sets (over 50 MW) were tabulated. Unfortunately, NERC separates simple cycle plants from combined cycle plants and does not break out the gas turbine portion of the combined cycle plants for inclusion with simple cycle units. The resulting table of gas turbine generating sets represents only low service factor, simple cycle, units; and the NERC sample turns out to be a group of peaking units that are on average over 15 years old.

<table>
<thead>
<tr>
<th>YEAR</th>
<th># units</th>
<th>Capacity Fact. (%)</th>
<th>Service Fact. (%)</th>
<th>Avail. (%)</th>
<th>Equiv. Avail (%)</th>
<th>FOF (%)</th>
<th>FOR (%)</th>
<th>EFOR (%)</th>
<th>Start Rel. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>250</td>
<td>2.55</td>
<td>3.44</td>
<td>89.33</td>
<td>84.68</td>
<td>2.12</td>
<td>38.12</td>
<td>38.91</td>
<td>93.85</td>
</tr>
<tr>
<td>1995</td>
<td>273</td>
<td>3.44</td>
<td>4.33</td>
<td>88.41</td>
<td>84.02</td>
<td>2.72</td>
<td>38.62</td>
<td>40.03</td>
<td>94.84</td>
</tr>
<tr>
<td>1996</td>
<td>283</td>
<td>2.04</td>
<td>3.08</td>
<td>90.95</td>
<td>87.74</td>
<td>2.07</td>
<td>40.18</td>
<td>41.90</td>
<td>95.75</td>
</tr>
<tr>
<td>1997</td>
<td>292</td>
<td>2.80</td>
<td>3.88</td>
<td>91.74</td>
<td>88.60</td>
<td>1.91</td>
<td>32.98</td>
<td>33.05</td>
<td>95.95</td>
</tr>
<tr>
<td>1998</td>
<td>288</td>
<td>5.08</td>
<td>7.44</td>
<td>91.25</td>
<td>88.02</td>
<td>1.85</td>
<td>19.90</td>
<td>20.01</td>
<td>97.18</td>
</tr>
<tr>
<td>94 – 98</td>
<td>4</td>
<td>3.21</td>
<td>4.47</td>
<td>90.40</td>
<td>86.72</td>
<td>2.12</td>
<td>32.18</td>
<td>32.92</td>
<td>95.80</td>
</tr>
</tbody>
</table>

This table of data points out the industry-recognized problem of using FOR and EFOR as a metric for low service factor units (as compared to using FOF). The FOR and EFOR measurements basically compare forced outage hours to service hours (see definitions). There is no credit for available standby reserve time; and worse, all forced outage hours (nights, weekends, holidays, unapplied time, etc.) are counted in the measurement. The usual result is an unrealistic, optically poor, misleading measurement. To counter this problem, the gas turbine industry focuses on the Forced Outage Factor (FOF) rather than the Forced Outage Rate (FOR).
By means of a manufacturer’s version of NERC’s “PC-GAR” program, GE has been able to extract the fleet performance data for its own gas turbine generator sets over 50MW. [GE was not able to make this work for combine cycle plants.]

<table>
<thead>
<tr>
<th>YEAR</th>
<th># units</th>
<th>Capacity Fact. (%)</th>
<th>Service Fact. (%)</th>
<th>Avail. (%)</th>
<th>Equiv. Avail (%)</th>
<th>FOF (%)</th>
<th>FOR (%)</th>
<th>EFOR (%)</th>
<th>Start Rel. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>147</td>
<td>3.18</td>
<td>4.12</td>
<td>90.27</td>
<td>84.32</td>
<td>1.71</td>
<td>29.33</td>
<td>30.22</td>
<td>96.80</td>
</tr>
<tr>
<td>1995</td>
<td>170</td>
<td>4.10</td>
<td>5.27</td>
<td>89.56</td>
<td>84.11</td>
<td>1.81</td>
<td>25.54</td>
<td>26.45</td>
<td>98.02</td>
</tr>
<tr>
<td>1996</td>
<td>171</td>
<td>2.11</td>
<td>3.35</td>
<td>91.43</td>
<td>88.26</td>
<td>1.84</td>
<td>35.39</td>
<td>37.12</td>
<td>98.00</td>
</tr>
<tr>
<td>1997</td>
<td>173</td>
<td>2.77</td>
<td>3.94</td>
<td>91.52</td>
<td>88.43</td>
<td>2.05</td>
<td>34.25</td>
<td>34.28</td>
<td>97.37</td>
</tr>
<tr>
<td>1998</td>
<td>173</td>
<td>4.89</td>
<td>7.46</td>
<td>91.70</td>
<td>88.65</td>
<td>1.53</td>
<td>16.96</td>
<td>16.98</td>
<td>98.54</td>
</tr>
</tbody>
</table>

When this data on GE units is compared to the NERC data for all manufacturer’s gas turbine generating sets over 50MW in the previous table, it can be seen that GE units generally perform more reliably.

Strategic Power Systems collects its reliability data from a broader field than just regulated utilities, but collects the data only in the manner of the traditional time-based measurement methods. The energy-based measures of equivalent availability and equivalent forced outage rate are not pursued. FOF is generally used instead of FOR. “Reliability” is reported as Rel. = (1 – FOF)x100. Fortunately, SPS specifically reports on “F” class gas turbines and breaks out individual gas turbine generating set performance within combined cycle plant operations. As a starting point, the SPS-ORAP data provide a look at “industry data” for the past five years for “F”-class gas turbine generating sets that, in general, are associated with combined cycle operations. It should also be pointed out that SPS collects data from only three of the four manufacturers of “F”-class machines. The “industry data” is then compared to the performance of seven GE frame 7 “F”-class gas turbine generator sets being operated at three different sites in the USA.

<table>
<thead>
<tr>
<th>Group</th>
<th># units</th>
<th>Service Factor (%)</th>
<th>Availability (%)</th>
<th>FOF (%)</th>
<th>SOF (%)</th>
<th>Starting Rel. (%)</th>
<th>Reliability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Industry Average”</td>
<td>73</td>
<td>58.1</td>
<td>86.1</td>
<td>2.5</td>
<td>11.4</td>
<td>N/A</td>
<td>97.5</td>
</tr>
<tr>
<td>GE 7FA Units</td>
<td>7</td>
<td>64.0</td>
<td>95.0</td>
<td>1.5</td>
<td>3.5</td>
<td>91.6</td>
<td>98.5</td>
</tr>
</tbody>
</table>

For the above GE 7FA units, the annual statistics are shown below:

<table>
<thead>
<tr>
<th>Period</th>
<th># units</th>
<th>Service Factor (%)</th>
<th>Availability (%)</th>
<th>FOF (%)</th>
<th>SOF (%)</th>
<th>Starting Rel. (%)</th>
<th>Reliability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>6</td>
<td>65.4</td>
<td>94.7</td>
<td>1.5</td>
<td>3.8</td>
<td>90.3</td>
<td>98.5</td>
</tr>
<tr>
<td>1996</td>
<td>6</td>
<td>59.4</td>
<td>95.7</td>
<td>0.4</td>
<td>4.0</td>
<td>87.4</td>
<td>99.6</td>
</tr>
<tr>
<td>1997</td>
<td>7</td>
<td>63.1</td>
<td>94.2</td>
<td>0.9</td>
<td>4.9</td>
<td>89.6</td>
<td>99.1</td>
</tr>
<tr>
<td>1998</td>
<td>7</td>
<td>65.6</td>
<td>93.6</td>
<td>3.8</td>
<td>2.6</td>
<td>93.0</td>
<td>96.2</td>
</tr>
<tr>
<td>1999</td>
<td>7</td>
<td>67.5</td>
<td>98.3</td>
<td>0.4</td>
<td>1.3</td>
<td>94.3</td>
<td>99.6</td>
</tr>
<tr>
<td>1995 – 1999</td>
<td>7</td>
<td>64.0</td>
<td>95.0</td>
<td>1.5</td>
<td>3.5</td>
<td>91.6</td>
<td>98.5</td>
</tr>
</tbody>
</table>
Predicted 7H Availability

As a final summary to this collection of data, it should first be recognized that the new GE 7H System is in itself a full combined cycle plant and should be compared against full combined cycle plants. The NERC summary of combined cycle plant experience suggests an industry average equivalent availability of about 84%, which should be corrected upward to about 88% or 89% to eliminate the inappropriately included effects of fouling and long-term degradation. Both the NERC data and the SPS-ORAP data demonstrate that GE equipment performs with better reliability and availability than power generating equipment provided by its competitors. If this GE advantage is equivalent to two to four percentage points of equivalent availability, it places the GE combined cycle norm above 90% equivalent availability, and that is GE’s goal and expectation for the new 7H System.

BASIC TERMS & DEFINITIONS

The Operational Reliability Analysis Program (ORAP) utilizes a traditional set of reliability and availability metrics that have their roots in the old Edison Electric Institute (EEI), go back to at least the 1960s, and for the most part are incorporated in the current ANSI/IEEE Std 762-1987 “IEEE Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity”. But the IEEE Std 762 goes further with additional definitions that include levels of capacity and degrees of urgency. It contains definitions for 66 terms and 25 performance indices, but does not define or provide measurements with the names “Reliability” or “Productivity”. The NERC-GADS system follows the IEEE Std 762 definitions and performance indices.

1. AVAILABILITY

Availability is a very broad measure in that it accounts for (or deducts) all outage types whether forced or scheduled, planned or unplanned. Availability is the proportion of clock/calendar time that the unit is available for commercial service regardless of whether the unit was placed in service or not and regardless of whether it was forced to operate in a derated mode or not. Simply said, if the unit is available to synchronize to the line and produce some billable level of electric power, it is available. The most simple formula for availability is:

\[
\text{Availability} = \frac{\text{Available } \cdot \text{Hours}}{\text{Period } \cdot \text{Hours}} \times 100
\]

Available Hours are most often calculated by subtracting the outage hours from the period hours which leads to writing the formula this way:

\[
\text{Availability} = \frac{\text{Period } \cdot \text{Hours} - \text{Forced } \cdot \text{Outage } \cdot \text{Hours} - \text{Scheduled } \cdot \text{Outage } \cdot \text{Hours}}{\text{Period } \cdot \text{Hours}} \times 100
\]
2. OUTAGE CATEGORIES

Outages can be subdivided into those that are Planned and those that are Unplanned. The Unplanned outages can be further subdivided into those that require immediate or somewhat urgent shutdown of equipment (the Forced Outages) and those for which the equipment shutdown can be deferred or postponed for several days or several weeks (called Maintenance Outages). While the Europeans tend to work with two groupings: Planned and Unplanned; the IEEE Std 762 and the NERC-GADS data system use three groupings: Forced, Maintenance and Planned; and, the ORAP system works with two groupings: Forced and Scheduled (where, “Scheduled” outages are the combination of Maintenance outages and Planned outages).

FORCED OUTAGE FACTOR (FOF)

When the forced outage time is shown as a ratio (or percent) of period time, it is called the Forced Outage Factor (FOF).

\[
Forced\ Outage\ Factor = \frac{Forced\ Outage\ Hours}{Period\ Hours} \times 100
\]

SCHEDULED OUTAGE FACTOR (SOF)

When the scheduled outage time is shown as a ratio (or percent) of period time, it is called the Scheduled Outage Factor (SOF).

\[
Scheduled\ Outage\ Factor = \frac{Scheduled\ Outage\ Hours}{Period\ Hours} \times 100
\]

3. AVAILABILITY FACTOR

The Availability described in item 1 (above) is also (more appropriately) called the Availability Factor. The Availability formula can also be written in terms of the outage factors:

\[
Availability\ [factor] = 1 - (FOF + SOF)
\]

4. RELIABILITY

Whereas Availability is a measurement that considers all outage types, Reliability [or Running Reliability] is a measurement that focuses on only the forced outages. The ORAP system definition (and long time GE Power Systems standard) for Reliability is:

\[
Reliability = 1 - FOF
\]
5. **STARTING RELIABILITY**

This is a totally different measurement (from the previous running reliability measurement). Starting Reliability compares the number of starting successes to the number of start attempts:

\[
Starting \cdot Re\text{liability} = \frac{Starting \cdot Successes}{Start \cdot Attempts} \times 100
\]

6. **SERVICE FACTOR**

This is a measure to show what percentage of time the unit or units were actually in service:

\[
Service \cdot Factor = \frac{Service \cdot Hours}{Period \cdot Hours} \times 100
\]

7. **FORCED OUTAGE RATE (FOR)**

The Forced Outage Rate (FOR) is a common utility measurement which is generally not used with gas turbines because of the poor optics of that measurement which generally accompanies low service factor units (i.e. peakers). The ORAP system does not report the FOR, but everyone working with NERC – GADS data, or with reliability performance indices in general, should be aware of the distortions it introduces. The FOR compares the forced outage hours to the service hours in a formula that is rigged so that it cannot go above 100% or be divided by zero.

\[
Forced \cdot Outage \cdot Rate = \frac{Forced \cdot Outage \cdot Hours}{Service \cdot Hours + Forced \cdot Outage \cdot Hours} \times 100
\]

The problem with the FOR on low service factor units is that no credit is given for being available in the reserve mode. As soon as a forced outage commences, all time (including nights, weekends, holidays, etc.) is accrued as forced outage time (whether the unit would have been placed in service, or not). On low service factor units with a low priority on corrective maintenance, it is very easy for the FOR to rise to undesirable levels of 30%, 40%, 50%, or more.

8. **EQUIVALENT AVAILABILITY**

This is another measurement not tracked or reported by the ORAP system but is becoming increasingly popular. It should not be confused with the traditional time-based availability measurement. It is also covered by the IEEE STD 762 and it is reported in the NERC-GADS reporting system. Equivalent availability considers the lost capacity effects of partial equipment deratings and reports those effects as Equivalent Unavailable Hours. For example, if a unit operated for 100 hours with an equipment limitation at 80% of nominal rated capacity, it would be considered to have accrued 100 Hours x 20% derating = 20 equivalent derated hours. For that 100 hours the traditional (time-based) Availability would show as 100%; but, the Equivalent Availability would equal 100 available hours minus the 20 equivalent derated hours for a measure of 80%.
EDOF is the Equivalent Derated Outage Factor and it typically runs from 0.5% to 2.0% on our gas turbine generator sets and combined cycle plants. The term “Equivalent” implies a capacity basis of measurement and can be worked up as Equivalent Forced Outage Factor, Equivalent Maintenance Outage Factor, Equivalent Forced Outage Rate, etc.

9. **CAPACITY FACTOR**

The SPS-ORAP system does not track the energy-based measures or the megawatt-hours of production but most utilities and the NERC-GADS data system do track this data. Whereas the service factor, described in section 6 above, considers the utilization of the generating equipment on a percentage-of-time basis, the Capacity Factor considers the utilization on a capacity or energy basis.

\[
\text{Capacity} \cdot \text{Factor} = \frac{\text{MWh} \cdot \text{produced}}{(\text{Period} \cdot \text{Hours}) \times (\text{Nameplate} \cdot \text{Capacity})}
\]

When the data is reported, comparisons will be made. Since the capacity factor is based against a fixed “nameplate capacity” there is always the question with gas turbine plants of how well the nameplate capacity reflects the seasonal, daily and hourly available capacity considering the significant affect of ambient temperature conditions on the available output power. The IEEE STD 762 solution to this is to let the nameplate capacity be equal to the maximum “New and Clean” capacity that the generator set can produce (usually on the coldest day). This method has the problem of prejudicing the gas turbine generator sets by as much as 10 to 20 percent when the weather is hot, even though all of the equipment is working normally and properly. Consequently, gas turbine plant operators and gas turbine manufacturers tend to use the time-based service factor more frequently than the capacity factor.

10. **EQUIVALENT FORCED OUTAGE RATE (EFOR)**

This popular measurement is the energy-based (capacity sensitive) version of the Forced Outage Rate (FOR) measurement described in section 7 above. It includes the distortions associated with low service factor operations as described in section 7. Limitations in capacity (deratings) are accounted for in the manner described in section 8, Equivalent Availability.

\[
\text{EFOR} = \frac{\text{FOH} + \text{EFDH}}{\text{SH} + \text{FOH} + \text{ERSFDH}}
\]

EFOR uses IEEE Std 762 terms as follows:
- FOH = Forced Outage Hours (with the generating unit fully off-line)
- EFDH = Equivalent Forced Derated Hours (due to equipment limitations)
- SH = Service Hours
- ERSFDH = Equivalent Reserve Shutdown Forced Derated Hours