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DEMAND BASED RELIABILITY: A PROPOSED MEASUREMENT APPROACH

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ABSTRACT:

Significant change is taking place in the power generation market. We are witnessing structural change as we move to a deregulated and competitive global market. And we can also see significant technological change, as new products are driven towards improved efficiencies, greater output and environmental friendliness. Measuring the impact of these changes in terms of efficiency, output and reduced emissions is a straightforward exercise, and the ability to judge if the change has been positive is relatively objective.

However, these structural and technological changes have created challenges in terms of reliability and availability measurements.

- First, our measurement approach is obsolete and has no consideration for duty cycle... The demand, the mission profile, which must be achieved for the unit to meet its economic contribution value, is the single most important issue for power producers today.
- Second, if the measurements have no consideration for the demand that the unit must meet, then the measure is not tied to the profitability of the plant, and therefore the operators are forced to use non-standard measures to accommodate management reporting.
- And third, the strong relationship between effective plant operations and profitability demands "real time" data gathering from the unit control or plant DCS, and transformation of the data points into meaningful information for effective decision support, specifically related to the availability and reliability of systems, components, and the full plant, with a specific focus on measuring "demand" based availability and reliability.

This paper addresses the issue and the opportunities associated with developing both new standard for measuring demand related reliability and availability, as well as the focus on "real time" data capture.

BACKGROUND & ISSUES:

1. **The standard measures of availability and reliability are not suitable or specific enough to characterize today's gas turbine usage or capability.**

Simply put, the measures of reliability, availability, and maintainability, as defined by IEEE Standard 762 and ISO 3977, do not reflect the varying levels of operating demand which a given unit or plant must fulfill. The measures are calculated and presented as indicators of time or capacity, and do not reflect actual performance against a given level of demand. Nor were the measures intended to reflect demand considerations.

If we look to the data available from the North American Electric Reliability Council (NERC), seen on Chart A, the perceived profile of a gas turbine unit, whether a heavy duty frame type or an aeroderivative, is a low service factor electric utility peaking unit. The NERC data does provide a review of combined cycle units which operate in more of a cycling mode of duty, however, the availability and reliability levels appear consistent with the peaking duty units as shown on Chart A. The essential issue is, does the data provide a meaningful set of expectations for the current achievable level of gas turbine availability and reliability? What objective reference is available relative to the next generation gas turbine design? And how do these values influence the increasing focus on and requirement for availability and reliability guarantees?

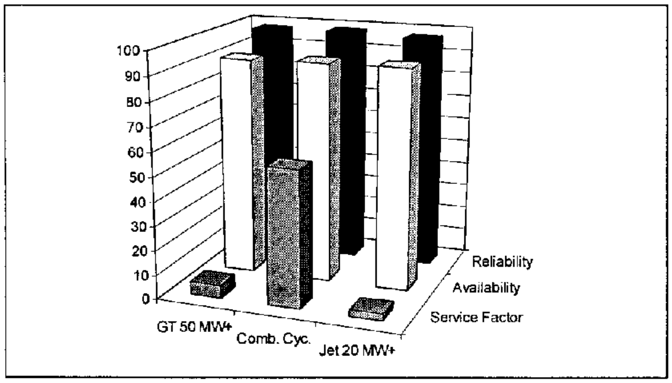


Chart A. NERC Data - 1995 to 1999

The rules of the game have changed and gas turbine driven plants are more than just "peakers". Today, gas turbine driven plants have a broad range of operating missions; peaking, cycling, baseload, and continuous duty. This is substantiated by the information shown on Chart B. Chart B provides a review of data available from the Operational Reliability Analysis Program (ORAP®), which is maintained by the authors' company. It is clear that the ORAP® data can be segmented into more classes of duty cycle. The information shows that a cycling mode of service is more severe relative to the effect on availability.

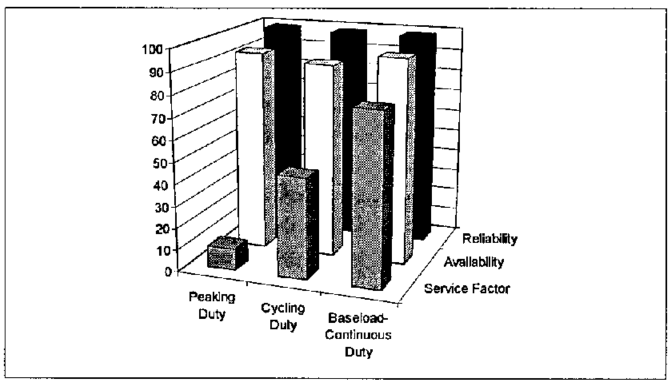


Chart B. ORAP® Data (70-125 Mw) - 1995 to 1999

Chart C provides a review of the typical number of starts and the fired hours per start ratio across the various duty cycles. If a peaking unit has less than twenty (20) starts per year and must operate about ten to twelve (12) hours per start, how relevant is a 90% availability? Regardless of duty, the critical issue is the likelihood that the unit will successfully complete its operating mission. This information available on Chart C provides an indication of the specific mission that a unit must fulfill, given a specific duty cycle. This may be the basis for beginning to describe aggregate demand. And since the explicit mission for a given unit and plant are normally different, the measures must reflect how the unit or plant performed against its pre-defined demand profile.

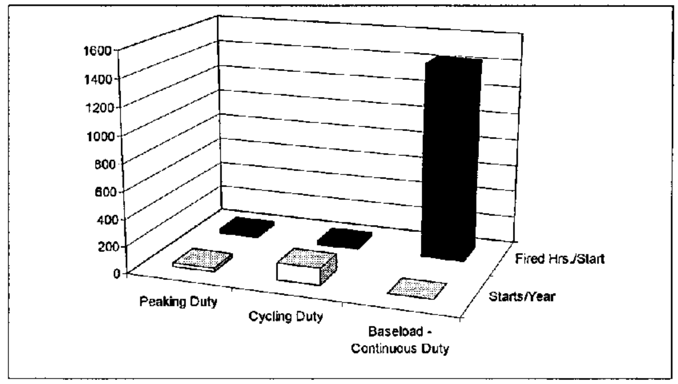


Chart C. ORAP® Data (70-125 Mw) - 1995 to 1999

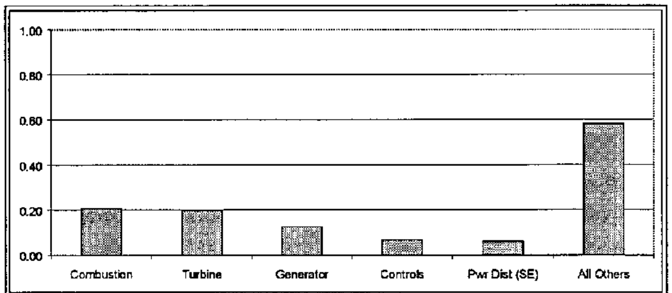
Additionally, demand on today's gas turbine simple and combined cycle plants can change dynamically, irrespective of mission. Bid rates for peaking power can change every hour, or in some cases every fifteen (15) minutes in some regions of the world. In times of peak demand, power can be sold at a significant premium. An outage during these periods would have a major impact on profitability, and opportunity for maximizing margin would be eliminated. Today's approach for measuring and reporting this loss would not reflect the severity and consequence of the outage. Tracking actual performance against a pre-established demand goal, whether time based or energy based, would provide a better picture of the capability or performance of the unit or plant.

It's time to change the standards. The concept of monitoring performance relative to unit demand is not new. Knowing that a specific plant had an availability of 90% to 95% has little value if when the unit was called on to serve it was unable to complete its mission effectively. With the market focus on competitiveness and profitability, there is a need to understand how a given unit performs (or worse, fails to perform) relative to an operating mission. Knowing when a unit does not perform provides a view of lost opportunity which is an essential requirement of risk and asset management.

2. Detailed site recording and reporting is inadequate because it is labor intensive.

There is absolutely no doubt that in a competitive environment, where resources are stretched and pulled in many different directions, where reductions in staffing levels are occurring, where more contract labor is utilized to direct and perform major maintenance, that site reporting is a significant burden. The task of reporting operating data, recording and classifying forced outages, as well as providing sufficient detail on a scheduled maintenance activity is a constraint which is normally minimized in the data recording and reporting process.

This problem is reflected in the lack of essential detail which typically exists in the history files to varying degrees, including; plant records, computerized maintenance management systems (MMS), manufacturer field service reporting systems, NERC's Generating Availability Data System (GADS), as well as ORAP®. The old adage of "garbage in, garbage out" is exacerbated when the quality of the reported operating, failure, and maintenance experience is insufficient for effective maintenance planning, addressing inventory requirements based on parts usage, understanding the causes and effects of unreliability, as well as for supporting product improvement and development efforts. Also, it is clear that detailed data must be captured at the time an event takes place. Attempts to reconstruct important detail after the fact often fail.



	Combustion	Turbine	Generator	Controls	Pwr Dist (SE)	All Others
70 to 125 MW	0.21	0.20	0.13	0.07	0.06	0.58

Chart D. ORAP® Data (70-125 MW – Baseload/Continuous Duty) 1995 to 1999 (Top System Contributors to Forced Outage Factor)

As an example, Chart D shows the data by system. The chart reflects the contribution made to Simple Cycle Plant Forced Outage Factor. Further breakdown of the outage details by component is essential for a more precise understanding of what drives the levels of plant unavailability. Similar charts could be developed for event frequency as well.

The issue and effect of under-reporting is heightened by the fact that the "rules of reporting" are not consistent from plant to plant. Readiness to serve rules and curtailment periods provide opportunity for maintenance to be performed at some plants when the unit known to be "not required" for some period of time. The elapsed time associated with these activities is typically not recorded as outage time (either forced, unscheduled, or scheduled). A legitimate rationalization and belief is that if the unit can be restored to a state of readiness in a certain acceptable period of time, if maintenance is performed when the unit is curtailed and will not be called upon to serve, that the maintenance which is performed should not be charged against the unit as unavailable time. The logic is, "it wasn't needed, why should the unit be penalized," and "Our availability guarantees exclude periods of curtailment." These are sound arguments. However, these "rules" do not apply across all plants, making the standard data recording processes and measurements more susceptible to individual interpretation.

There is no doubt that these activities are meant to ensure the operational readiness of a unit, and in fact are approaches for optimizing the performance of maintenance. However, the issue is that the details associated with the maintenance are typically not recorded simply because the activities are perceived to be outside the "reporting rules" of unit unavailability. This process will make the availability and reliability values artificially higher, and in fact support the perspective that the standard measures need to be more directly related to unit demand.

It's time to make the rules of reporting more uniform and improve the process. What is important is to consider the fact that limited plant resources must be deployed in a manner which is productive and cost effective. The burden of data capture and processing must be moved as much as possible to the plant and unit level controls. This will improve the quality of the operational data and serve as the basis for the event driven data. This feedback will provide the opportunity to assess the capability of the unit to start successfully when called upon and to remain on-line until a normal shutdown process is initiated. Each successful or interrupted run cycle can be captured and evaluated, with the intent of assessing the impact on economic viability of the unit and plant. If a trip occurs, at any load, the control system will provide the initial reference point for the beginning of an outage. However, additional detail relating to the cause and the disposition requires input which only plant personnel staff can provide.

While the value and use of the control system will improve data accuracy and reduce manual effort, human input and knowledge is still required and essential. The recording of outage and maintenance activities requires discipline and commitment. Identifying and reporting to the lowest level of detail is essential for understanding of the reliability of the various component and systems.

The Electric Power Research Institute (EPRI) implemented a more uniform equipment coding structure to standardize and facilitate event recording and reporting from plant personnel. The coding structure was designed to be flexible, allowing for additional "growth" as advanced technology equipment, new emissions controls, and more complex combined cycle plants are introduced to the market. The coding structure design provides a uniform basis for categorizing the outage and maintenance events. The primary objective is to assist the plant in accurately attributing frequency of events, event duration, and corrective actions to specific components in the plant. The utilization of the standard coding structure allows for a cross-reference between manufacturers and the various turbine models.

PROPOSED APPROACHES:

The ASME B133 Sub-Committee 5 has been investigating approaches for calculating demand based reliability measurements. The preferred approach is calculating the performance based upon actual unit demand periods, on either a time or energy basis. If the actual demand periods are not known, the Markov approach is one methodology that provides a reasonable approximation for demand based performance, expressed in terms of an Equivalent Forced Outage Rate (EFOR).

Calculating Performance Against Actual Demand:

When the actual demand for a unit is known on either a time or energy basis, the calculation of the unit's performance relative to the demand becomes a straightforward exercise. The outage time during the periods of demand and the demand period are utilized as input to the standard equations of availability and reliability. This provides an accurate picture of how well the unit meets its required demand.

The advantages of tracking a unit's performance against its actual demand are obvious - it provides a true measure of the unit's ability to generate revenue. This information allows accurate planning and projections to be made to maximize profitability. The major impediment to calculating performance against demand in this manner is the additional data collection required to document when demand for the unit occurs. Computers can be utilized to alleviate this burden by linking information from the control system, the MMS and even electronic operator logs.

Markov Approach:

If the actual periods of demand are not known for a particular unit, the Markov approach can be utilized to develop an estimation of the unit's performance relative to demand. The Markov approach was originally introduced in the 1970's (reference 1 & 2) and is currently in use by several utilities.

The methodology approximates demand for a unit through the use of a 'discount factor'. The discount factor is based upon the average length of forced outages, the average reserve time, and the average demand period estimated by the service hours per start. The basic equation to determine EFOR is as follows:

$$\text{EFOR}=\frac{(f \times \text{FOH})+(\text{EFDH}-\text{EFDHRS})}{\text{SH}+(f\ \text{FOH})}\times 100$$

where:

FOH = (Full) forced outage hours

EFDH = Equivalent forced derated hours

EFDHRS = Equivalent forced derated hours during reserve shutdown

SH = Service hours

f = Discount factor for FOH

f = (1/r + 1/T)/(1/r + 1/T + 1/D) — Reference (1)

r = Average forced outage duration

r = FOH/number of forced outages

T = Average reserve shutdown time

D = Average demand time (duty cycle time)

D = SH/number of successful starts (SS)

T+D Available hours/number of starts

Table 1 presents examples of the Markov Calculations based on duty cycles. The impact of the 'discount factor' can be clearly seen in the cycling duty case. In this example, the Markov demand based estimation of Forced Outage Rate is less than the IEEE Std. 762 Forced Outage Rate.

	Peaking Duty	Cycling Duty	Baseload/ Continuous Duty
Period Hours	8760.00	8760.00	8760.00
Service Hours	220.00	2232.45	8373.67
Reserve Hours	8444.34	5165.13	83.33
Successful Starts	48	198	13
Forced Outage Hours	4.44	691.94	57.50
# Forced Outage Events	4	30	3
Scheduled Outage Hours	91.22	670.48	245.50
Markov Calculation of Demand Based Forced Outage Rate (FORd)			
r	1.11	23.06	19.17
T	175.92	26.09	6.41
D	4.58	11.28	644.13
f	0.81	0.48	0.99
FORd	**1.60**	**12.94**	**0.68**
IEEE Std. 762 Calculation of Forced Outage Rate (FOR)			
FOR	**1.98**	**23.66**	**0.68**

Table 1: Example Markov Calculations

As with any approximation methodology, there are certain advantages and disadvantages in the utilization of the approximation. These must be understood in order to draw meaningful conclusions and make valid comparisons from the results of the approximation. The following are considered as advantages of using the above equation to calculate EFOR.

1. The approach provides an approximate demand-related EFOR, which is a popular index for planning, production, and design studies in the U.S. and other countries.
2. It is applicable to units with any duty cycles. For truly base-load units (continuous demand) the discount factor would approach 1.
3. It discounts the reported forced outage time for those non demand-related periods when there is little (or no) urgency to repair. The non demand-related periods, by definition, are not applicable to a demand-related EFOR.

Likewise, the following are the disadvantages of the Markov approach.

1. The equation appears complex. It is more complex that the current IEEE Standard 762 EFOR equation. However, it requires no additional data-reporting burden. Computers can be programmed to perform the calculations.
2. It is an approximation. However, it is a major improvement over the current EFOR equation to estimate a demand related EFOR. It uses **average** and **relative** forced-outage event durations, duty durations, and reserve shutdown event durations to approximate the forced outage discount factor. The only exact way to calculate a demand-related EFOR would be to report the demand time for each generating unit along with the unit's events.

"Real Time" Monitoring, Measurement and Evaluation... ORAP LINK

Remote monitoring is an effective vehicle for capitalizing on the flow of on going "process" related data from various microprocessor based control systems; whether unit level controls or plant distributed control systems:

- ➢ In the past, stand-alone systems have been implemented by plant management to complement the existing plant control, and to enhance the information available for tracking unit "health"; vibration analysis (trends and polar plots), exhaust temperature monitoring (spread), and oil analysis (particulate and contamination). An issue with these systems is related to the level of expertise required to interpret and effectively use the information provided for timely and effective decision-making.
- ➢ Today, the market views remote monitoring systems either as intrusive, or as a way to mitigate the risk associated with new technology deployments. The typical approach is to allow the equipment manufacturer to monitor the plant, specifically the turbine-generator, to "hopefully" intervene on "out of normal" condition situations during the warranty period, or through the term of an O&M agreement. These systems are utilized for cost containment as opposed to assisting in driving top line growth.

The opportunity exists to utilize the capability of modern microprocessor based control systems to improve the profitability of the plant. The vision is to make availability and reliability something that isn't just calculated after the fact, but rather something that is evaluated in a real-time manner, the pulse of plant performance. The availability and reliability of components, systems and the total plant can be monitored with information available to all levels; in the control room, the trading floor, and executive offices. This allows a specific focus to be placed upon measuring the unit's performance relative to demand.

The authors' company has developed a non-intrusive product, ORAP LINK, that interfaces with the unit level control and/or the plant DCS (Distributed Control System) to obtain real-time process data values for transformation and display as site management information. The data points that are collected are transformed into "data views" which are focused on Reliability, Availability, Maintainability and Durability (RAM-D) trends and real-time operating experience. The objective is to strengthen the emphasis on plant profitability.

- ✓ Transforms process data into RAM-D business information.
- ✓ Improves the accuracy and quality of information.
- ✓ Automates reporting and eliminates redundancy.
- ✓ Supports Availability & Reliability guarantees.
- ✓ Reduces manual effort required for plant reporting.

The program automatically retrieves control system data and transforms this information real-time into data that can then be utilized to track the actual performance of the unit relative to demand. This alleviates the need for manual data capture and for the use of estimation techniques to calculate demand based performance. Specifically capturing the following mission based information necessary for calculating demand-based performance.

- ✓ Starting times, including timestamps for initiation of the start, establishment of primary flame, and breaker closure for each mission.
- ✓ Operating time from breaker closure to breaker opening for each mission.
- ✓ The actual energy produced (MWH) for each mission.
- ✓ How the mission was terminated - normal shutdown or trip (either automatic or manual), which provides an indication of unfulfilled missions.

This information provides an accurate picture of how the unit meets its demand. Since the actual on-line time, output and mission termination are known, the performance against the demand can be calculated directly. In addition, the detailed information available from the program allows further demand related assessments to be made, which estimation techniques such as the Markov Approach do not. For example;

- ✓ Since the actual start times - from start initiation, engagement of starting means, flame establishment, breaker closure to when the pre-selected load is achieved –are known, the time to reach load can be compared to requirements.
- ✓ Actual generation can be compared to requirements.
- ✓ Since the data is available on an individual mission basis, the units actual demand profile can be developed.

This provides a valuable planning tool for projecting unit performance and more importantly, profitability. As an example, assume that a unit has a requirement to operate weekdays from June through August from 9:00 AM to 5:00PM. Chart E represents a plot of actual operating time for this unit.

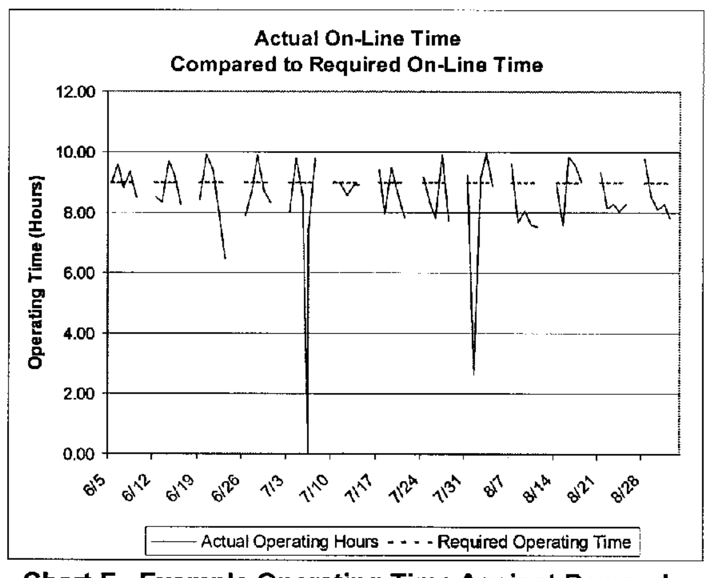


Chart E. Example Operating Time Against Demand

As can be seen from the figure, this unit failed to meet its theoretical demand in many cases during the period. Calculating the Demand Reliability for this case is as follows.

Total Demand Time: 594.00 hrs
Actual Operating Time: 558.73 hrs

Demand Reliability = Actual Operating Time/Required Operating Time
= 558.73/594 = 94.06%

However, since the focus is on profitability, operating time in excess of the demanded period can be just as bad as a production shortfall. Therefore the demand performance can be calculated based upon the absolute difference between demanded time and actual operating time. As can be seen in Figure 1, this unit operated beyond its required demand time frequently. Summing the absolute difference between the actual and required operating times for each mission yields the following results.

Total Demand Time: 594.0 hrs
Sum of the Difference between Actual and Required Operating Time: 59.81 hrs
Demand Unreliability = Σ(Δ Actual & Required Operating Time)/Total Required Operating Time
= 59.81/594 = 10.07%
Demand Reliability = 100 – Demand Unreliability = 89.93%

These values compare with the Markov Estimation based upon this example of Demand based Foreced Outage Rate, FORd = 2.34%, which is ~1/2 the FOR of 5.094% calculated based upon the actual demand period (FOR = FOH/SH+FOH = (594.00 – 558.73)/594.00). Similar calculations could be performed based upon the energy produced. Tracking the data from the control system allows the demand profile to be established and predictions made based upon empirical data as opposed to estimations. Statistical bounds can then be placed upon the data allowing more meaningful probabilistic calculations of future performance. The following table provides a summary of the statistics from this example, including the probability of successfully completing a mission.

	Start Time (Min)	On-Line Hours	Average Load	Outage Hours
Total	1783.11	558.73	9894.10	21.29
Average	27.02	8.47	149.91	7.10
Min	12.00	0.00	0.00	1.02
Max	29.96	9.98	164.41	13.02
Standard Dev	2.47	1.50	19.93	6.00
Numer of Trips		2		
Number of Failures to Start		1		
Total # of Missions		65		
Successful Missions		62		
Probability of Successfully Completing Mission		95.38		

Table 2: Summary of Example Performance

As further example of the benefits of utilizing control system data to track unit performance relative to demand, Chart F presents the start times for the individual missions compared to the required start time. The figure assumed that the unit has a requirement to start and reach the preselected load within 30 minutes. In this example there were eight (8) cases where the unit failed to achieve this goal in 65 Missions (7 starts with a length greater than 30 minutes and 1 failed start). Based upon this information, the probability of starting within the specified time period (starting reliability) is 87.7%. Tracking the data from the control system in this manner eliminates the ambiguity associated with tracking starting reliability against defined starting time requirements.

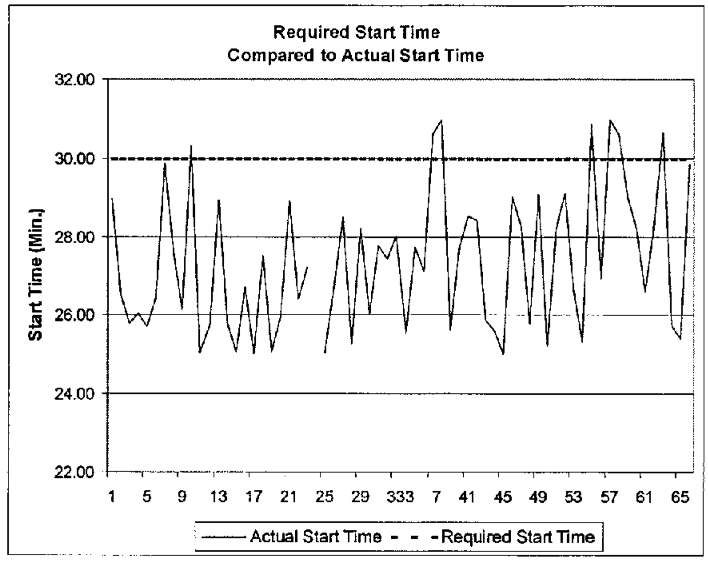


Chart F. Example Starting Times Against Requirements

In addition to the capability to accurately track performance relative to demand, ORAP LINK enables operations and maintenance personnel to record meaningful event detail concerning symptoms, corrective actions, and root causes of events. This capability is provided through a tight coupling of ORAP LINK with ORAP Data Entry. Together, these products provide the maximum focus on RAM-D, and include such valuable measures as:

- ✓ Plant availability and reliability factors.
- ✓ Service factor and starting reliability.
- ✓ Equipment outage factors down to the component level.
- ✓ Symptoms, corrective actions, and root cause of failures.

These important RAM-D metrics allow rigorous, yet achievable goals for "best in class" performance to be established, while considering each unit's unique and specific mission profile.

Interfaces with the Maintenance Management Systems can be provided to acquire additional data relating to outage event reporting, as well as for other useful logistical support information. Also a flow of data from ORAP LINK to the MMS may be established for automatic generation of work orders based on an indicator(s) from the control system.

The information available in ORAP LINK can be accessible through output views on Web pages over a secure Intranet. This ensures that the output is controlled and secure, and it is fully accessible from the control room, the trading floor, and by executive management.

Several examples of views and features are provided below.

- ✓ Summary views of each mission which display the percentage of time in each starting, on-line and shutdown state. The actual begin and end times for starting, breaker closure, flame established/extinguished, as well as total and average output are displayed. This information provides input to the unit performance relative to demand
- ✓ Calculated "life consumption" based upon equivalent operating hours and starts accumulated by the unit. The program will display both the expended life (based on the calculation of Equivalent Hours and/or Starts), as well as the variable values that were used to develop the current "life consumption". Calculating life consumption, and tracking the variables that influence it, is an impossible manual process. Automation makes the process easy and relieves a significant manual burden from operations.
- ✓ Recommended inspection or maintenance period (combustion, hot gas path, major overhaul). The recommendation as well as the last inspection or maintenance period will be displayed.
- ✓ Compressor efficiency monitoring. A user flag is provided, indicating time to perform a compressor water wash.
- ✓ Direct interface with ORAP Data Entry for RAM-D tracking. The process values such as; run time, trips, load, starts, and shutdowns will be transformed into the key input for RAM-D reporting. ORAP Data Entry will provide the opportunity to add information (manually) from the knowledgeable operations/maintenance personnel. This complete process provides the basis for the RAM-D database to be maintained.

  Another important feature of the ORAP Data Entry system, is the ability to enter part replacement information and perform parts life tracking. This feature should support the plants' logistics planning process. More importantly, parts' tracking is essential for performing effective inventory management and controlling parts costs.

  Data sharing (participation) with ORAP provides the plant with the opportunity to obtain "fleet" level comparisons on a frequent basis. These "fleet" level comparisons should support logistics planning process.
- ✓ Other RAM-D data views such as; starting timeline events (important for starting reliability issues), record of operating trips (important for tracking running reliability issues), and others…
- ✓ Data views (output) presented in a "statistical process control" format (as much as possible) to provide easy to view information, highlighting operations that are "outside" the normal envelope. The ability to highlight specific "data view" points is also provided to let the user gain access to the details at a lower level.

CONCLUSION:

Changes in the power generation market are resulting in the need for standard methodologies for measuring a unit's performance relative to demand, which can be directly related to the unit's profitability. When the actual demand of a unit is not known, there are techniques that can be utilized to estimate the demand related performance. The Markov Approach is one such technique that provides reasonable estimates of demand performance in terms of a Forced Outage Rate. However, the most accurate method for calculating demand-based performance is to utilize data collected from the control system to track each mission on a real time basis.

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