PREDICTING FUTURE ASSET CONDITION BASED ON CURRENT HEALTH INDEX AND MAINTENANCE LEVELS

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With restructuring of the electricity sector into profit oriented business models, an increasing number of electric utilities are adopting Health Indices to measure and monitor the condition of their assets.

The Health Indices represent a novel way for capturing and quantifying the results of operating observations, field inspections, in situ and laboratory testing into an objective and quantitative picture, providing the overall health of the assets. Asset Health Indices become a powerful tool in managing assets and identifying investment needs and prioritizing investments into capital and maintenance programs.

When appropriately developed, Health Indices provide an accurate indication of the probability of asset failures and associated risks. Having established the Asset Health Index under current conditions, Health Index values in future can be predicted by taking into account the impact of environmental and operating conditions along with the preventative maintenance practices. This article describes the techniques to account for impact of preventative maintenance on Health Indices and for predicting future asset condition based on the current Health Index and maintenance practices.

The techniques can be used for evaluating future risks associated with an asset or in selecting optimal maintenance levels that would provide the right balance between risk and investment costs.

Table 1
Example of a Health Index for a Distribution Asset

Condition or Risk Criteria	Weighting	Maximum Score
Bushing Condition	2	8
Oil Leaks	2	8
Tank/Cabinet and Controls	2	8
Foundation/Support Steel/Grounding	2	8
General Condition	2	8
Thermograph Test (IR)	2	8
Winding Doble Test	4	16
Dissolved Gas Analysis Test (DGA)	4	16
Oil Quality Test	3	12

ANALYSIS, STRATEGIC PLANNING, TRANSFORMERS

1. Introduction

Increased demands for improved financial and technical performance by electric power companies throughout the world are resulting in much closer scrutiny of capital investments.

There is also significant pressure to control operating and maintenance costs while maintaining or improving system performance. In order to achieve the optimal balance among capital investments, asset maintenance costs and operating performance, there is a need to provide economic and technical justifications for engineering decisions and spending plans. The analysis outlined in this paper specifically focuses on the technical justifications for proposed expenditures.

Electric utility transmission and distribution systems are made up of a large number of individual system components with different characteristics and different importance. Assets such as transformers, circuit breakers, reclosers, overhead lines, underground cables, switches, rights-of-way, and civil works are a few typical examples of the type of components that make up the asset base of an electric transmission or distribution utility. Conventionally, in order to make decisions on the maintenance and replacement needs for such assets, relatively detailed information on each asset would be required. This immediately raises a very significant practical problem. Firstly, an attempt to gather detailed information on each individual asset would be both practically and economically infeasible. Secondly, there are no standard interpretations of the various tests and inspections that may be carried out on each asset, therefore, requiring reliance on engineering judgment, which may be difficult to apply uniformly over

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Asset Condition

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an entire asset group or for different asset groups. In order to overcome these problems, a statistical sampling method can be used which would result in accurate evaluation of the overall asset class, providing a hierarchical approach to condition assessment.

2. Asset Degradation and Health Indices

It is important to understand the differences between defect management and reactive maintenance versus long-term asset degradation and asset condition assessment. Defects are usually well defined and associated with failed or defective components in the ancillary systems that affect operation and reliability of the asset well before its end-of-life. These defects do not normally affect the life of the asset itself, if detected early and corrected. Defects are routinely identified during inspection and dealt with by corrective maintenance activities to ensure continued operation of the asset.

Long-term degradation is generally less well defined and it is not easily determined by routine inspections. The purpose of asset condition assessment is to detect and quantify long-term degradation and to provide a means of quantifying remaining asset life. This includes identifying assets that are at or near end-of-life and assets that are at high risk of generalized failure that will require major capital expenditures to either refurbish or replace the assets.

A good understanding of the asset degradation and failure processes is vital if condition assessment procedures are to be effectively applied. It is important to identify the critical modes of degradation, the nature and consequences of asset failure, and, if possible, the time remaining until the asset is degraded to the point of failure. Unless there is a reasonable understanding of the degradation and failure processes, it is impossible to establish sensible assessment criteria or to define appropriate end-of-life criteria.

A composite Health Index is a very useful tool for repre-

Table 2
Design Criteria for Health Index Formulation

Health Index	Cond-ition	Probability of failure (pof)	Equivalent status on life curve	Requirements
85-100	Very Good	Low	First half of mean life expectancy (Green in Fig 2)	Normal maintenance
70-85	Good	Low but slightly increasing	Second one-third of mean life expectancy (Pale Blue in Fig 2)	Normal maintenance
50-70	Fair	Rapidly Increasing but lower than pof at mean age	Final one-third of mean life expectancy (Yellow in Fig 2)	Increase diagnostic testing, possible remedial work or replacement depending on criticality
30-50	Poor	Higher than pof at mean age and increasing	First one-third after the mean life expectancy (Brown in Fig 2)	Start planning process to replace or rebuild considering risk and consequences of failure
0-30	Very Poor	Very High, more than double the pof at mean age	Second one-third after the mean life expectancy (Red in Fig 2)	Immediately assess risk, replace or rebuild based on assessment

senting the overall health of a complex asset. Transmission and distribution assets are seldom characterized by a single subsystem with a single mode of degradation and failure. Rather, most assets are made up of multiple subsystems, and each subsystem may be characterized by multiple modes of degradation and failure. Depending on the nature of the asset, there may be one dominant mode of failure, or there may be several independent failure modes. In some cases, an asset may be considered to have reached its end-of-life only when several subsystems have reached a state of deterioration that precludes continued service. The composite Health Index combines all of these condition factors using a multi-criteria assessment approach into a single indicator of the health of the asset.

For a typical asset class, a wide range of diagnostic tests and visual inspections may be undertaken, either as part of the ongoing maintenance program or as special-purpose Asset Condition Assessment (ACA) surveys. In some cases, a poor condition rating value will represent a failure of a subsystem, which can be repaired through replacement of that subsystem, with no resultant impact on the serviceability of the overall asset. However, it should be recognized that generalized deterioration of many or all of the subsystems that make up an asset can also be a valid indication of the overall health of the asset. A composite Health Index captures generalized deterioration of asset subsystems, as well as fatal deterioration of a dominant subsystem.

In developing a composite Health Index for an asset, it is very important to understand the functionality of the asset, and the manner in which the various subsystems work together to perform the key asset functions. With a clear understanding of asset functionality, condition ratings of different asset components and subsystems can be combined to create a composite "score" for the asset, and the continuum of asset scores can be subdivided into ranges of scores that represent varying degrees of asset health.

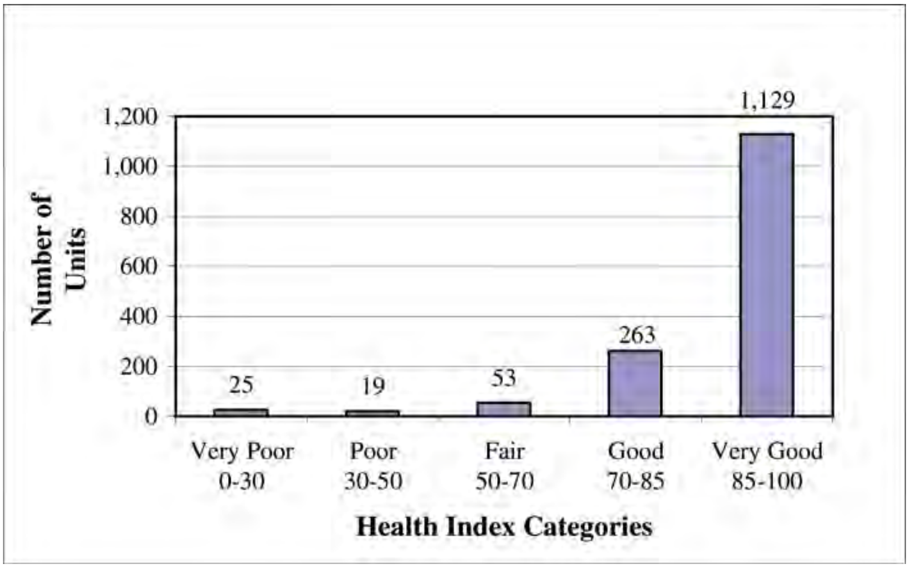

Figure 1
Actual Health Index Results for a Typical Distribution Asset

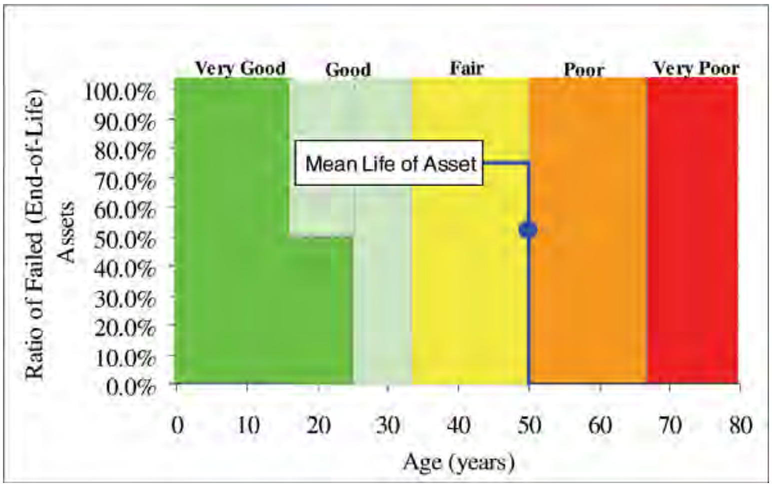

Figure 2
Health Index scaling categories as reflected to the age curve

The critical objectives in the formulation of a composite Health Index are:

- The index should be indicative of the suitability of the asset for continued service and representative of the overall asset health

- The index should contain objective and verifiable measures of asset condition, as opposed to subjective observations

- The index should be understandable and readily interpreted

Table 1 shows an example of a combined Health Index for Voltage Regulators (see previous page).

In this example, the maximum score is 92; Health Index is therefore (Total Score/92) X 100 (0-100) and provides a measure of the level and extent of degradation of the asset components.

Finally assets with a health index within a specific range can be assigned appropriate rankings (i.e. poor, fair, good etc., as shown in Figure 1).

3. Relationship among Health Index, Asset Condition and Probability of Failure

The targeted design criteria for assigning asset condition to a health index range and relating it to the failure probability of an asset is shown in Table 2 and illustrated in Figure 2 and Figure 3. This asset is assumed to have a median life expectancy of 50 years. The life expectancy curves for the asset are initially developed through careful evaluation of the design and manufacturing standards for the asset, results of accelerating aging tests where available and utilizing industry's collective experience with historic performance and failure rates through expert judgment. By applying actual condition data to a large enough population and studying failure rates over a period of time, the initial formulation can be revisited and, if necessary, adjusted towards the design criteria.

The asset health scaling categories would correspond to probability of failure rates on the asset life expectancy curve as illustrated in Figure 2 and can be utilized to assess effective age of the asset based upon its condition. Similarly, Figure 3 illustrates the probabilities of failure for these health scaling categories.

Based on these results, decisions for this particular asset can now be made on the most appropriate level of investments into maintenance, refurbishment or replacement over a defined time period. As such, the Health Index can be considered a key performance indicator (KPI) in a corporate performance management and decision making setting where its interpretation takes into account the nature of the asset being rated; e.g., end-of-life has a different meaning for a substation drainage system than for an distribution wood pole.

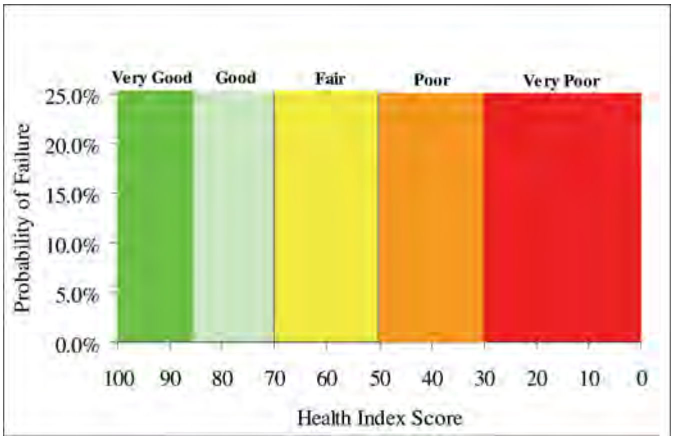

Figure 3
Health Index scaling categories and probabilities of failure

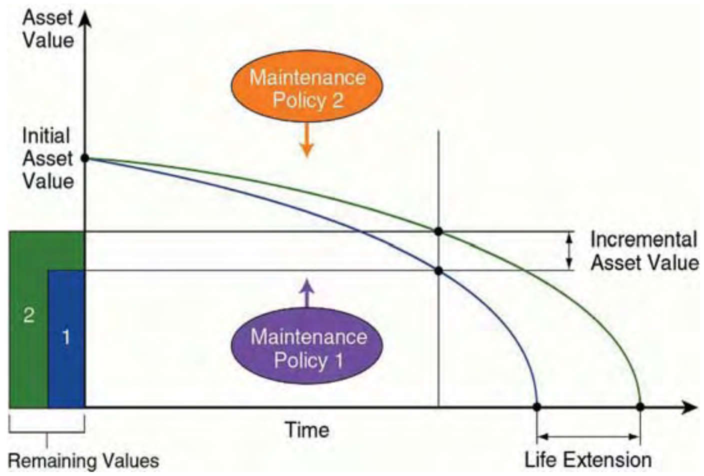

Figure 4
Two life curves for the same equipment under two different maintenance scenarios (Operating conditions are assumed to be the same)

4. Future Asset Health Condition and Effect of Maintenance

The scope and frequency of asset maintenance activities significantly impact asset life expectancy and asset health at any time during asset's lifespan. Different types of assets require different preventative maintenance routines, which have varying levels of impact on asset health and condition and probability of failure.

Figure 4 shows an example of two life curves for the same type of equipment under two different maintenance scenarios. If a comprehensive scope of maintenance activities is selected and these maintenance activities are carried out with greater frequency, as indicated by "Policy 2" in Figure 4, it would result in an increase in asset's life expectancy and the health index at any particular time (represented as asset value in the graph) will be higher. On the other hand, if maintenance policy 1 selected, which consists of fewer maintenance activities and carried out less frequently, it would result in shorter asset life expectancy and a lower value of health index at any time during asset's life. We can observe that the life curves in Figure 4 are equivalent to those in Figure 2.

The time period over which a certain maintenance policy is applied is, of course, of equal importance. For example, if the comprehensive maintenance policy 2 is applied from the beginning, the life expectancy would be significantly extended. However, if Policy 2 is applied late in the asset life cycle, the life extension may be minimal.

While the curves in Figure 3 allow derivation of the current effective age of an asset based on the present health index, Figure 4 provides means of taking into account the effect of the current maintenance policy and predicting expected aging and deterioration of the asset in future years. Thus, future asset health and condition can be predicted. Similarly, a change in the maintenance policy can be evaluated and its effect on the overall asset's life assessed.

It is important to note that accurate depiction of maintenance impacts on health and condition of assets and development of curves indicated in Figure 4, is not a trivial task, but requires extensive experience and knowledge in maintaining and operating assets to determine accurate cause-and-effect algorithms which are used in deriving these curves.

5. Conclusion

Health Indices provide a basis for assessing the overall health of an asset and risk of failure and are, therefore, a key performance indicator (KPI) on the asset condition. Health Indices are based on aging and degradation modes of assets and their subsystems under different environmental and operating conditions.

Use of health indices in establishing the level of investment levels into capital and maintenance activities allows the selection of optimal risk mitigation initiatives for implementation. A key factor in such integration is using the information available to assess the expected asset failure rates and the corresponding remaining life. This can be done by utilizing demographic, performance and condition information through health index analysis.

The effect of different maintenance options can then be analyzed for the optimal life extension of the assets.