EXHIBIT
#90
DE 16-576

Development of New Alternative Net Metering Tariffs
and/or Other Regulatory Mechanisms and
Tariffs for Customer-Generators
Docket No. DE 16-576
Eversource Set 1 Data Requests on Rebuttal Testimony to Commission Staff

Received: January 6, 2017
Request Number: Eversource 1-3

Date of Response: January 20, 2017
Witness: Stan Faryniarz

Request:

Reference Bates Page 46 lines 6-17 where Staff suggests that it is important to collect more data on distribution equipment for all utilities to analyze wear and tear on distribution system equipment caused by DG resource reverse power flows, and the ability of DG resources to reduce the need to replace and/or upgrade distribution equipment and system capacity, and describes some potential methods of collecting and using such data.

a. Please provide details on the type of data needed and the timeframe for data collection.

b. Is Staff aware of any studies that examine wear and tear on equipment caused by reverse power flow? Please provide references to these studies.

c. Is Staff aware of any studies that examine the ability of DG to reduce the need to replace or upgrade distribution equipment? Please provide references to these studies.

d. Is Staff aware of a model (i.e. from another state) for the coordination of utility capital replacement plans with DG deployment? Please provide a reference to these models.

Response:

(a) The types of data needed were largely identified and requested of the utilities and other parties in both direct prefiled testimony and discovery promulgated in this proceeding, though studies prepared in other jurisdictions and by other organizations could prove useful in determining the type of data needed. In order to help monitor the effects of reverse power flows on substation equipment, as well as evaluate wear and tear on circuit equipment from the deployment of DG, the system managers should develop and monitor Asset Health Indexes ("AHI"), if not already being done as part of the normal asset management process. Although not intended as an exhaustive treatment of the topic, as a supplement to this response, attached is an IEEE paper that discusses the development of AHIs on distribution equipment. In addition to any approaches the utility's engineering department may have identified for reverse power flow study, I have been made aware of Section 2.4 of the NREL High-Penetration PV Integration Handbook for Distribution

Engineers (January 2016).[1] This Handbook discusses possible reverse flow impacts and identifies a number of them related to system protection and voltage profile.

(b) As one example of such a study or analysis, refer to a series of technical workshops and work products associated with this issue in the Hawaii PUC DER Docket 2014-0192 as listed under the "Documents" tab for the proceeding: http://dms.puc.hawaii.gov/dms/DocketSearch?V_DocketNumber=2014-0192&QuickLink=1

(c) See previous responses (a) and (b) above.

(d) The coordination of utility capital replacement plans and DG deployment would entail recognition of the effects on equipment from DG in the current asset management process, and opening the capital planning process to allow for consideration of DG alternatives to system needs. While Staff anticipates that a follow-on collaborative process would help develop the appropriate program approaches that recognize the characteristics of New Hampshire utilities, a general example of an open system planning process at the bulk power system level can be found in the ISO New England Regional Transmission Planning process, and the California Public Utility Commission distributed resource plan initiative (Docket R.14-08-013) addresses locational aspects of planning and DG deployment.

ISO-NE Planning: https://www.iso-ne.com/system-planning/system-plans-studies/rsp

CA Distribution Resource Plan Order: http://www.cpuc.ca.gov/General.aspx?id=5071

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[1] *High-Penetration PV Integration Handbook for Distribution Engineers*, Rich Seguin, Jeremy Woyak, David Costyk, and Josh Hambrick, *National Renewable Energy Laboratory* Technical Report NREL/TP-5D00-63114 (January 2016).

Development of Health Indices for Asset Condition Assessment

T. Hjartarson, *Member, IEEE*, B. Jesus, D.T. Hughes and R.M. Godfrey

***Abstract*—The drive to continuous improvement in Transmission and Distribution businesses, fueled by sectoral reform and Performance Based Regulation, demands new and innovative approaches to asset planning decisions. Costs must be reduced, and spending needs to be optimized, without jeopardizing vital business values such as safety and reliability. Among the new and innovative approaches that have been utilized by asset owners are Health Indices and risk management techniques. Composite Health Indices represent a novel way of utilizing findings from Preventive Maintenance activities and Asset Condition Assessment surveys to develop an overall picture of the health of the asset. With risk factors included in the index, a Composite Risk Index can be developed, which provides a powerful tool in identifying requirements for changes in investment and maintenance programs, and for prioritizing identified investment and maintenance initiatives.**

***Index Terms*—Decision-making, Indexes, Life estimation, Power distribution, Power transmission, Reliability management, Risk analysis, Substations, Testing**

I. INTRODUCTION

THROUGHOUT the world, electricity companies are undergoing major change due to privatization or deregulation. While the detail of these processes varies from country to country, some of the effects are almost universal. Essentially, the engineering activities of utility companies have been subject to much closer scrutiny and there is great pressure to reduce cost while maintaining or improving network performance. As a consequence of this, there is greater need to provide technical and economic justification for engineering decisions and spending plans. The analysis outlined in this paper specifically focuses on the technical justification.

II. ASSET CONDITION ASSESSMENTS

Electricity distribution and transmission systems are made up of a very large number of individual components, which are widely distributed. Conventionally, in order to make a decision about the future of an individual asset, relatively detailed condition information is required. This immediately raises a very significant practical problem for electricity companies. To attempt to gather detailed condition information about every individual asset would be both practically and economically infeasible. In order to overcome this situation, a hierarchical approach to condition assessment must be applied, to enable prioritization and focused gathering of detailed condition information.

A. Asset Deterioration and Degradation

It is important to understand the differences between defect management and regular 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 end-of-life. These 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 maintenance activities to repair or replace failed components to ensure continued operation of the asset.

Long term degradation is generally less well defined and it is not easily determined by routine inspection. The purpose of asset condition assessment is to detect and quantify long-term degradation and to provide some 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 asset.

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.

B. The Concept of Health Indices

Health Indices provide a basis for assessing the overall health of an asset. Health Indices are based on identification of the modes of failure for the asset and its subsystems, and then developing measures of generalized degradation or degradation of key subsystems that can lead to end-of-life for the entire asset.

A composite Health Index is a very useful tool for representing the overall health of a complex asset.

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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 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.

C. Development of Health Indices

For a typical asset class, a wide range of diagnostic tests and visual inspections are undertaken as part of the maintenance program or 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 could 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 main functions of the asset. With a clear understanding of asset functionality, the various condition ratings 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 differing degrees of asset health.

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

Development of a condition-based Health Index requires an assessment of the relative degree of importance of the different condition factors in determining the health of the asset. Each condition factor must be assessed as falling into categories as shown in Table 1:

TABLE I
RELATIVE DEGREE OF IMPORTANCE OF CONDITION FACTORS

No impact	Indicator reflects defects or deterioration measures that have no impact on overall asset health
Contributing Factor	Indicator reflects defects or deterioration measures that range from low to high in importance, but typically in combination with other measures as part of a formulation of generalized deterioration
Combinatorial Factor	Indicator reflects a measure which does not represent asset condition in isolation, but is a critical component in a complex logical and/or mathematical formulation of asset health
Dominant Factor	Indicator reflects the health of dominant subsystem that makes up the asset, and end-of-life based on this single factor represents end-of-life for the entire asset

By using a multi-criteria analysis approach, the various factors can be combined into an idealized condition- based Health Index. This involves grouping together the various factors, crafting the mathematical and/or logical formulations, and establishing the importance weightings of all the factors to allow combining them into a single Health Index.

Next a quantified scoring system can be developed to appropriately represent the asset health consistent with this philosophical approach. The steps are as follows:

1. "Deterioration" assessments or scores are converted to health scores in a defined range from "perfect health" to "end-of-life".
2. Importance weighting is assigned to each factor in a range from "modest importance" to "very high importance".
3. General deterioration index is formulated by calculating the maximum possible score by summing the multiples of steps 1 and 2 for each factor.
4. The general deterioration index is normalized to a maximum score of 100 based on having a defined acceptable/minimum number of condition criteria available.
5. Normalize the dominant factors to a maximum score of 100.
6. Calculation of the overall Health Index as the lesser of step 4 or 5, where 100% is excellent health and 0% is "poor" health.

Finally the continuum of asset health scores is correlated into discrete categories of asset health from "Very Poor" to "Very Good". This conversion into discrete categories for a condition index requires fine-tuning of the health scoring system, since it is necessary that the relative degree of severity of the scores due to "dominant" factors and those due to generalized degradation match up at the boundaries between each category. This may require iteration of the individual steps to ensure that the resulting index is rational and coherent, and reasonably reflects field condition.

D. Development of Risk Indices

The preceding discussion has focused on Health Indices that are focused on objectively verifiable measures of asset condition, and for some classes of assets, degradation occurs in an organic fashion, with predictable rates of deterioration. However, risk is a factor in all asset management decisions, since it is not possible to predict with certainty when any given asset will fail. For some assets, which are not characterized by steady and predictable rates of degradation, effective asset management depends on risk factors which are either unrelated to present asset condition or only indirectly related. These additional risk factors can be incorporated into the condition assessment, in the form of a "Composite Risk Index".

A Composite Risk Factor can be viewed in two equally valid ways: as a Composite Health Index coupled with a Composite Non-Condition Risk Index, suitably weighted to reflect the degrees of confidence imparted by each index; or as a reformulation of the Composite Health Index, with additional Non-Condition risk factors added to the list of factors considered and each factor assigned a weighting according to importance and degree of confidence. In our work, we have opted for the latter view, because the expanded formulation allows weighting of each Condition Factor and each Non-Condition factor in a single formulation. This provides greater visibility for the importance of each factor.

Some examples of Non-Condition risk factors include: specific makes and vintages of equipment which have been identified by the owner or the industry at large as having particular problems; material used in manufacture of asset; or the age of the asset.

In contrast with Condition Factors, Non-Condition factors may only be considered as "Contributing Factors" or "Combinatorial Factors", but should never be treated as "Dominant Factors". As an example, the type of insulation used in an underground cable and the age of the cable would each be considered "Combinatorial Factors" in the overall risk of failure, and even the combination of insulation type and age would only be considered a "Contributing Factor" to the risk of failure. Most utilities would also insist on a pattern of historical failures before they would reach definitive conclusions about the health of a particular family of underground cables.

E. Typical Examples of Health and Risk Indices

The following example relates to the Health Index formulation for a distribution wood pole, which is then extended to a Health Index formulation for a wood pole structure, and then further extended to a a health index formulation for an overhead line section. These formulations are based exclusively on measurable and observable asset condition information.

The Health Index of the wood pole is determined from a combination of a remaining strength calculation (which is the outcome of a mathematical formulation of several combinatorial factors) and other degradation factors such as woodpecker damage and pole top rot. Each of these factors is a dominant factor, meaning that each of these factors can independently bring the pole to end-of-life. Each is assigned a health rating from 0 to 3. For instance a remaining strength determination below a defined level (for example 70%) would assign a pole a health rating of 0 (end-of-life). Because each of these factors is a dominant factor, the overall Health Index for the pole is equal to the lowest of the health ratings of the various dominant factors.

At each pole structure position, the condition of each sub-component is similarly assigned a health rating from 0 to 3. Different weightings are applied to the different components reflecting their relative importance to the overall structure. In this case, only the wood pole is a dominant factor. The cross arm is a combinatorial factor, which can only degrade the overall health index of the structure in comparison with the health rating of the pole. The insulators, guys and fittings are treated as contributing factors. The condition values (the product of the condition value and the weighting) for the different components are summed to give a Condition Score for each wood pole structure.

TABLE 2
EXAMPLE OF COMPOSITE HEALTH INDEX FORMULATION FOR DISTRIBUTION WOOD POLE STRUCTURE

Condition Criteria	**Weighting**	**Maximum Score**
Wood Pole	8	24
Cross Arm	3	9
Insulators	2	6
Guys	2	6
Fittings	2	6

Maximum score is 51; health index for the wood pole structure is therefore (total score/51) X 100.

A composite score of the inclusive structure scores is then calculated where varying types of structures (intermediate, section or terminal) have different weighing. Also structures determined at or near end-of-life are weighed higher for an increased effect on the overall line section.

The Conductor is assessed in a similar way as the section structures, with condition rating from 0 to 3.

The Health Index (0-100) for the line section is then a composite of the aggregated structure scores and the conductor score, and provides a measure of the level and extent of degradation of the components.

Another example can be given of a combined Health Index with risk contribution for an unnamed substation asset.

TABLE 3
EXAMPLE OF COMPOSITE HEALTH RISK INDEX FOR A SUBSTATION ASSET

Condition or Risk Criteria	Weighting	Maximum Score
Visual Condition	3	9
Dissolved Gas Analysis	4	12
Doble Test	3	9
Risk Type Insulators	3	9
Bearings not been changed	2	6

The maximum score is 45; Health Index is therefore (Total Score/45) X 100.

An example of a Composite Health Index with a risk contribution results for such a Substation Asset is shown in Figure 1.

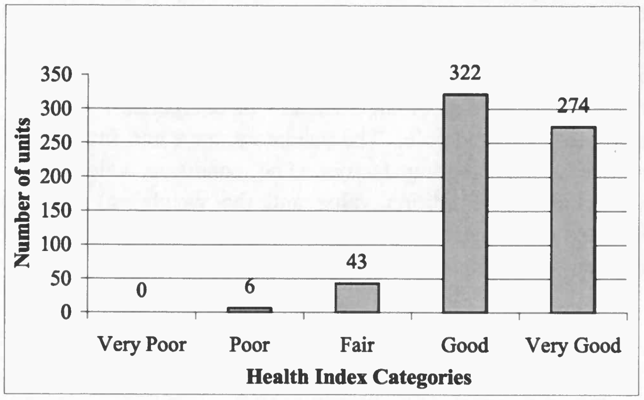

Fig. 1. Actual Health Index Results for a Typical Substation Asset

Based on these results assessments can be made on the required maintenance, refurbishment or replacement levels needed over a defined time period for this particular asset. However, the interpretation of the Health Index results has to take into account the nature of the asset being rated; for example, end-of-life has a different meaning for a transmission right-of-way than for an air-blast circuit breaker.

F. Conclusion

Health Indices provide a basis for assessing the overall health of an asset. Health Indices are based on identification of the modes of failure for the asset and its subsystems, and then developing measures of generalized degradation or degradation of key subsystems that can lead to end-of-life for the entire asset. This approach is a valuable method of justifying the need for capital expenditures on T&D assets based on condition of the assets and not on their age alone.

III. ACKNOWLEDGMENT

The authors gratefully acknowledge the contributions of Hussein El-Hennawy (Hydro One Inc.) and Neil Reid and Hans Ziemann (Acres), plus all of the Investment Planners and Asset Managers of Hydro One Inc, who played a pivotal role in the success of the project that forms a large part of the background for this paper.

IV. REFERENCES

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[1] B. Cozzens, "Seven principles of highly effective T&D asset management, moving toward best practices in information-based T&D condition assessment," Energy Pulse, Energy Central, Feb. 2003.

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[2] D. T. Hughes and T. Richards, "The use of condition information in strategic risk management,", presented at EuroTechCon, Birmingham (UK), October 2002.

[3] D. T. Hughes, The use of health Indices for determining EOL and estimating remnant life for distribution assets', presented at CIGRE 17th International Conference on Electricity Distribution, Barcelona, May 2003.

V. BIOGRAPHIES

Thorhallur Hjartarson (M'1996) was born in Akureyri, Iceland, in 1965. He graduated from the University of Iceland, Reykjavik, and received a M.A.Sc degree in Electrical Engineering from the University of British Columbia, Vancouver, B.C., Canada.

His employment experience includes the Iceland State Electricity, Reykjavik, L4 Solutions Inc, Philadelphia, and Acres International Ltd, Oakville, Ontario. His special fields are within Asset Management of Electrical Power Transmission and Distribution.

Bruno Jesus received his B.A.Sc. degree in Electrical Engineering from the University of Toronto in 1987. He is a registered Professional Engineer in the Province of Ontario. He has been with Hydro One and its predecessor, Ontario Hydro, for 15 years. He is currently a Team Leader in the Network Strategy Division responsible for developing customer and asset strategies.

David Hughes is material scientist with a BSc and PHd from the University of Birmingham , UK, (1972-8). For the past 25years he has worked for EATechnology (formerly part of the UK nationalized electricity industry) studying the degradation and failure of electricity distribution and transmission assets.

In recent years he has specialized in the development and application of condition based management processes for distribution and transmission networks based around an understanding of the critical degradation and failure processes.

Myles Godfrey graduated in 1981 with a degree in Electrical Engineering from the University of Saskatchewan in Saskatoon Saskatchewan. His employment history includes 8 years with the former Ontario Hydro, and he has been with Acres International since 1989.

He is the Manager of the Transmission and Distribution Division at Acres, and his specialties include planning, design, construction management and asset management for T&D facilities.