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A Study of the Implementation of an Improved Transformer Reliability Program

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SUMMARY

The paper will present the main aspects of a successful program implemented at American Electric Power (hereafter called Utility) between 2012 and 2016, in partnership with partner company and solution provider. The aim of the program was to detect and minimize transformer failures, optimize maintenance resources, prioritize asset renewal, and enhance safety. The authors will present several aspects associated with the program implementation – such as challenges related to data acquisition, disparate sources of data, data quality and availability, existing and newly employed online sensors; the need for multiple algorithms to handle offline (as well as online sensor data); the IT platform and software tools; and preparing and cultivating the resources. Although early detection of asset failure provides a strong business case to justify the adoption of such a program, it can also show that there are a number of other aspects that have a significant impact on company's asset management. Several use cases will be presented to illustrate the actual effectiveness of the program, not only with respect to failure prevention and cost avoidance, but also to demonstrate the paradigm change that the program brought to the Utility's operations, maintenance, planning, and safety programs. The paper will describe the benefits of the program including the creation of new data structures and templates, smart data management, and the formation of an internal task force to support the project. It will also examine the various internal issues – such as how to move from a multitude of non-standardized data sources to a central standardized data repository to easily facilitate transformer reporting, analysis, and condition assessment.

KEYWORDS

Asset management, Reliability, Transformers, Condition-based, predictive maintenance

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1. Historical Background

1.1 Asset Health Analysis

Electric power transmission and distribution utilities have long been tasked with upgrading, replacing, and maintaining an interconnected fleet of substation equipment. Whether batteries, switches, circuit breakers, regulators, transformers, or any other numerous assets, utilities have to balance the competing criteria of customer reliability, safety, Operations and Maintenance (O&M) expenses, and capital investments to manage their fleet effectively. In the past, during times of rapid electrical grid expansion, much of this fleet was in a younger, healthier state. Currently, many utilities are facing both an aging fleet and downward pressure on O&M expenses. For instance, at the Utility, 33% of transformers are 50 years or older, and nearly 18% are 60 years or older [1]. The obvious implication is that utilities now must operate a program of asset management in the most effective way possible. Historically, asset managers were able to operate at a local level. With years of experience and a deep knowledge of the equipment at a relatively small collection of substations, an asset manager was able to effectively administer the maintenance and replacement of his or her assets. As utilities have merged with one another, total assets have increased, operations have become centralized, and the control of the funding for asset management activities has moved further from those who interact with the assets on a daily basis. These factors create the need for a centralized asset management program that includes asset health analysis, condition based maintenance, and dynamic rationalization of capital and O&M spend [2].

The concept of asset health analysis is not a new one. Utilities have been recording measurements of asset health indicators for years, particularly on transformers, for the purposes of ranking replacements and maintenance. These practices have relied on manual inspection and analysis of the data by a trained engineer. The concept of using a calculated health index is discussed in [3]. New programs, such as the asset health solution at the Utility, aim to reduce human involvement with the initial assessment of incoming data, predict equipment failures and required maintenance, and provide evidence and visibility for the case to renew the grid. The asset health solution (co-developed with the solution provider) provides analysis on top of several data sources including: nameplate and population databases, historical test records, and SCADA trends (as well as data from real time health monitoring systems). The asset health solution attempts to solve the problem of ineffective asset management practices by employing intelligent data feeds and algorithms that combine expert level knowledge and predictive capability [2].

1.2 Transitioning Data Collection Practices

As previously mentioned, utilities traditionally have not had a primary concern for collecting and storing substation equipment data in a way that would allow for much automatic analysis. Early methods included handwritten notes stored with the technicians, who took measurements or notes kept in a file cabinet at a central office. Substation and equipment routine inspections were recorded in substation control building logbooks. Even with the advancement of computing technology and the availability of spreadsheets and databases, data was still hand recorded and manually digitized, allowing greater opportunity for error. As more and more data was digitized, separate, disconnected databases created silos of data that could not be corroborated against one another [2]. It was not uncommon for original SCADA (Supervisory Control and Data Acquisition) databases and inspection record databases to use different names for the same substation, given the unique bandwidth and size limitations of SCADA data.

Even the advancement of connectivity and bandwidth has not guaranteed easy access and interpretation of data. Cloud storage now allows for the Utility data to be directly uploaded from test equipment to vendor websites and databases, which can greatly complicate the issue of automatic aggregation back to the Utility. To confound the issue further, utilities are now beginning to augment the historical records with the implementation of online sensors [4].

Without current and up-to-date inputs, decisions made to maintain, replace, or remove assets from service may not be the most timely or efficient. Historically, data that was collected for analysis by asset managers was done on a routine basis. This method would miss any fast acting catastrophic failures on a piece of equipment, and would not alert field personnel to the possibility of failure. As part of the Utility's Asset Health Center program, critical assets are equipped with smart monitors that collect significant data assets. These smart monitors measure data in real time, specific to asset health, and either replicate or imitate traditional equipment testing on an asset, while providing on-board intelligence [3].

2. Architecture of the Solution

The asset health solution is constructed to bring the IT (Information Technology) and the OT (Operations Technology) together for the organization, as illustrated in Figure 1. By combining the two, the customer is able to bring a more complete picture of the assets into one common view. The asset health solution allows both online and offline data from many different systems and databases to be combined in an automated way, to allow the Utility to take advantage of the many features and functions within the tool.

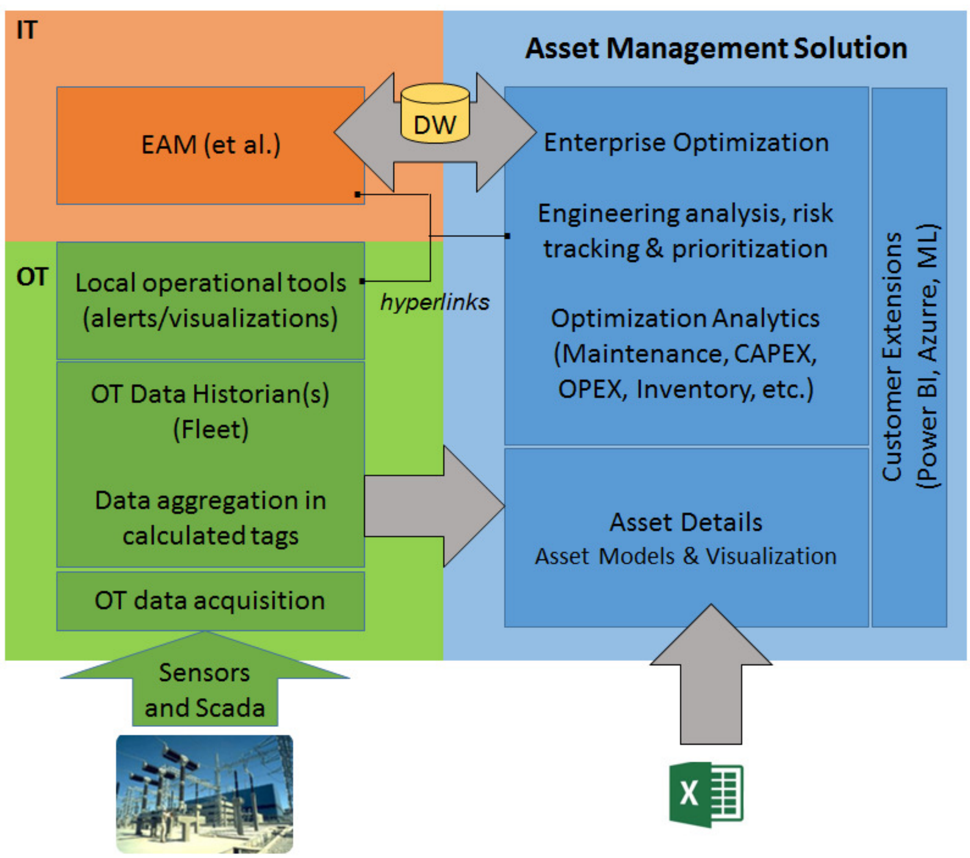

Figure 1 – General architecture of the asset health solution with integration of IT and OT

The asset health solution provides this bridge between IT and OT by bringing Enterprise Asset Management (EAM) data, historian data, acquired sensor, and SCADA data together from throughout the enterprise to one common place. This allows stakeholders to dynamically see the status across the organization's assets on a timely basis. From there, the asset health solution applies multiple asset models to the data to significantly deepen the understanding of the health and status of each asset. This information feeds multiple dashboards that include overall Health Status, Maintenance Recommendations and Priority, Replacement Priority, and others. In addition, this information can also feed a Work Management system that will take the recommendations to the next step, and create Work Orders to perform the actions recommended by the system. Once complete, that information can feed right back into the asset health solution to update the information for each asset. Then the cycle continues.

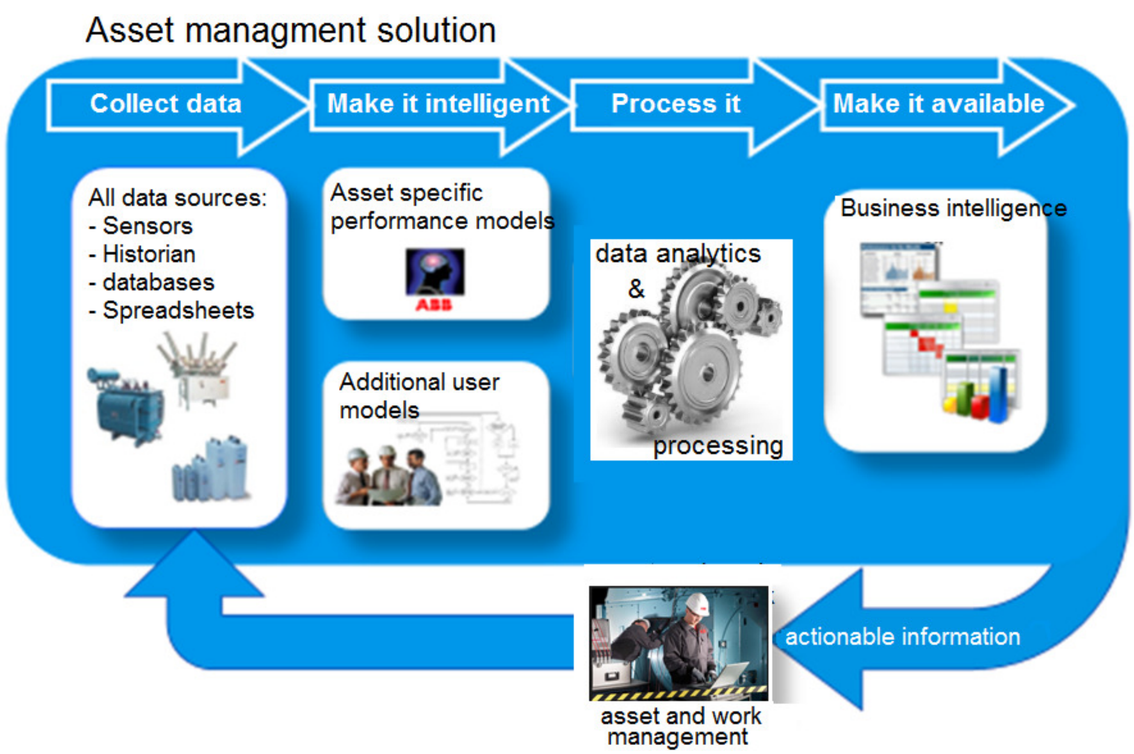

Figure 2 – Data processing strategy in the asset health solution

3. Transformer Algorithms

The asset health solution contains a set of comprehensive algorithms that are parameter-specific (such as to detect atypical levels and trends of gas in oil, oil quality parameters, etc.) and supported by statistical tools to follow trends, identify abnormal behaviour, and flag statistical outliers, and look for statistical correlations (for example: is combustible formation statistically correlated to load increase?).

The list of parameter-specific and online sensors (when available) algorithms include:

- Bushings, cooling, and oil preservation system
- LTC (offline, DGA, type, etc.)
- DGA (offline) including laboratory accuracy for trend calculation
- DGA online (multiple types of sensors supported)
- Standard oil tests (moisture, dielectric strength, power factor, interfacial tension, acidity)

- Online bushing monitoring (sum current)
- Online PD (electrical and UHF)
- Furans
- Thermal profile (dynamic hot-spot calculation)
- Particles count
- GIC (geomagnetically induced current)

Comprehensive algorithms:
- Transformer Analytics to calculate transformer probability of failure given condition and importance – hereafter called Transformer Analytics
- Expert System to correlate variables, probability of failure, and make recommendations

Statistical tools:
- Historical distribution of individual parameters
- Boxplot calculations to all parameters
- Stepwise trend analysis
- Comparative statistical tool (unit vs. family)

The algorithms also support offline and online data of the same kind (for example DGA). They also support simultaneous readings of both offline and online (for example: a given transformer has online DGA sensors, but eventually gets readings from manual oil samples with laboratory DGA). All the above operate as support tools to the most fundamental algorithm (Transformer Analytics), better described in [5,6]. It maps all transformer component failure modes, as illustrated in Figures 3-7 below, to produce an estimated probability of failure (PoF) ~~to~~ for each individual unit of a large fleet. Finally, an Expert System oversees the whole set of algorithms and their outputs – to produce a set of automated flags and recommendations for maintenance actions, in order to mitigate operational risk. The Expert System contains a huge set of rules and recommendations that may be applied to a specific situation that is developing. In the asset health solution, the user may also include a set of specific rules to their typical maintenance procedures that may not be set up by default in the solution. The system is flexible enough to incorporate new rules and new maintenance recommendations that may be necessary after the system has been utilized for some time, and has learned from experience.

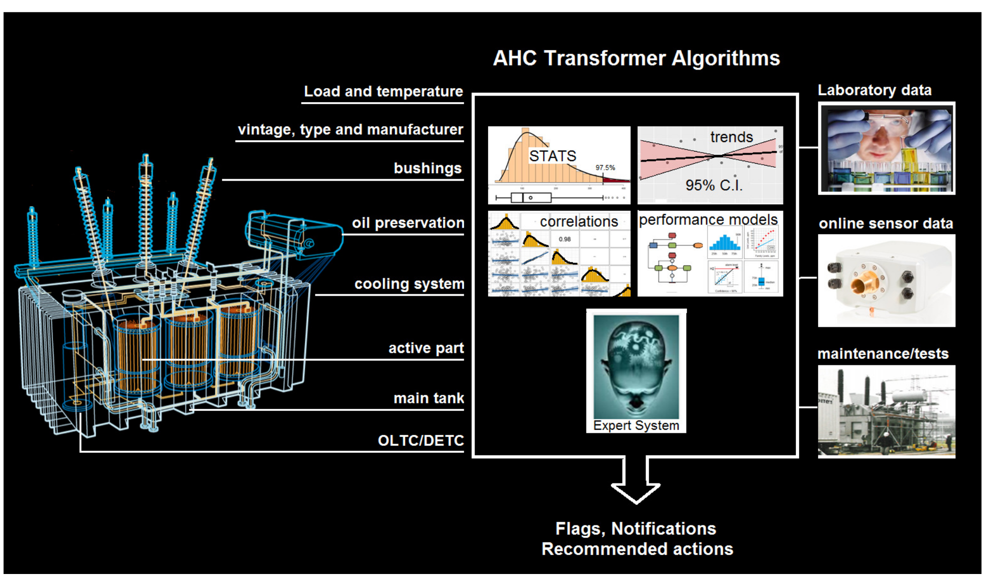

Figure 3 – General structure of the transformer algorithms in the solution. The structure shown in the middle of the illustration ~~is~~ handles major component data (nameplate, vintage, ratings, etc.), eventual offline laboratory results, maintenance information and electrical tests, as well as online sensors data.

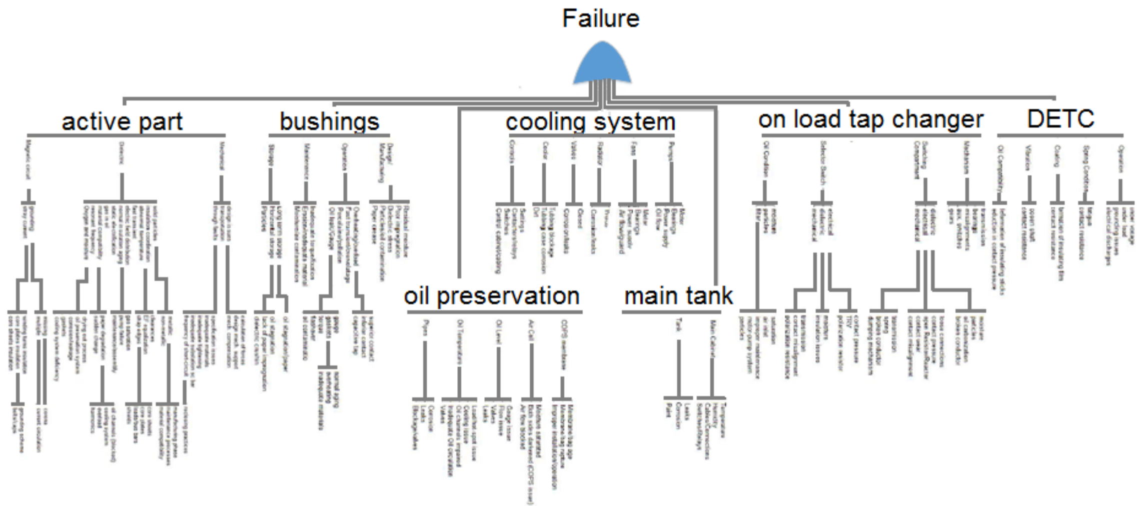

Figure 4 – Foundation of the Transformer Analytics using the general structure of a RCM (Reliability Centered Maintenance) failure mode investigation. The Failure Mode Effect and Analysis in Transformer Analytics takes into account mechanical, thermal, and dielectric withstand conditions of individual transformers and accessories.

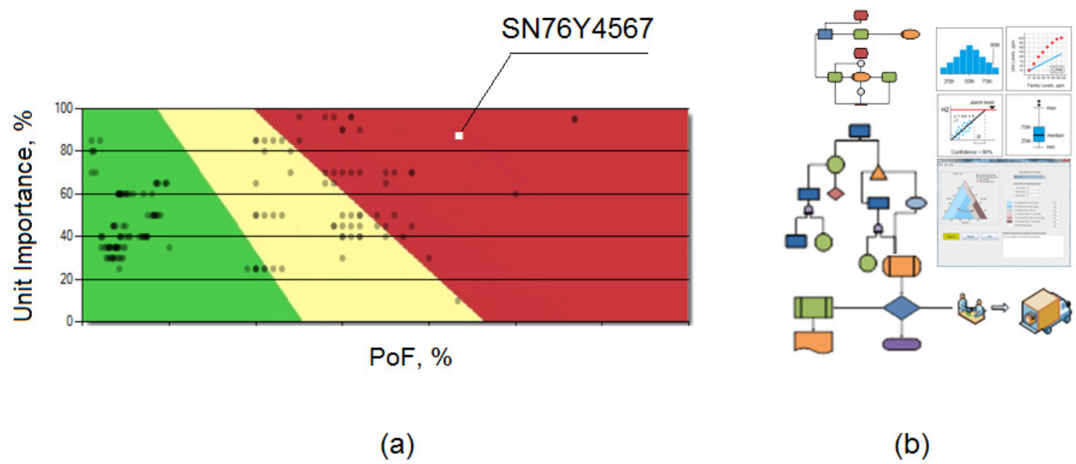

Figure 5 – Output of the Transformer Analytics providing (a) criticality map with location of each transformer according to the estimated probability of failure (PoF) vs. importance of individual unit and (b) illustration of the Expert System when converting algorithms and calculations into actionable information.

Figure 6 – The asset health solution top level screen of the solution showing classification of transformers and other assets in the red (requiring immediate attention), yellow (requiring some attention but not urgent) and green zones (may require attention, but does not impact operational risk as is).

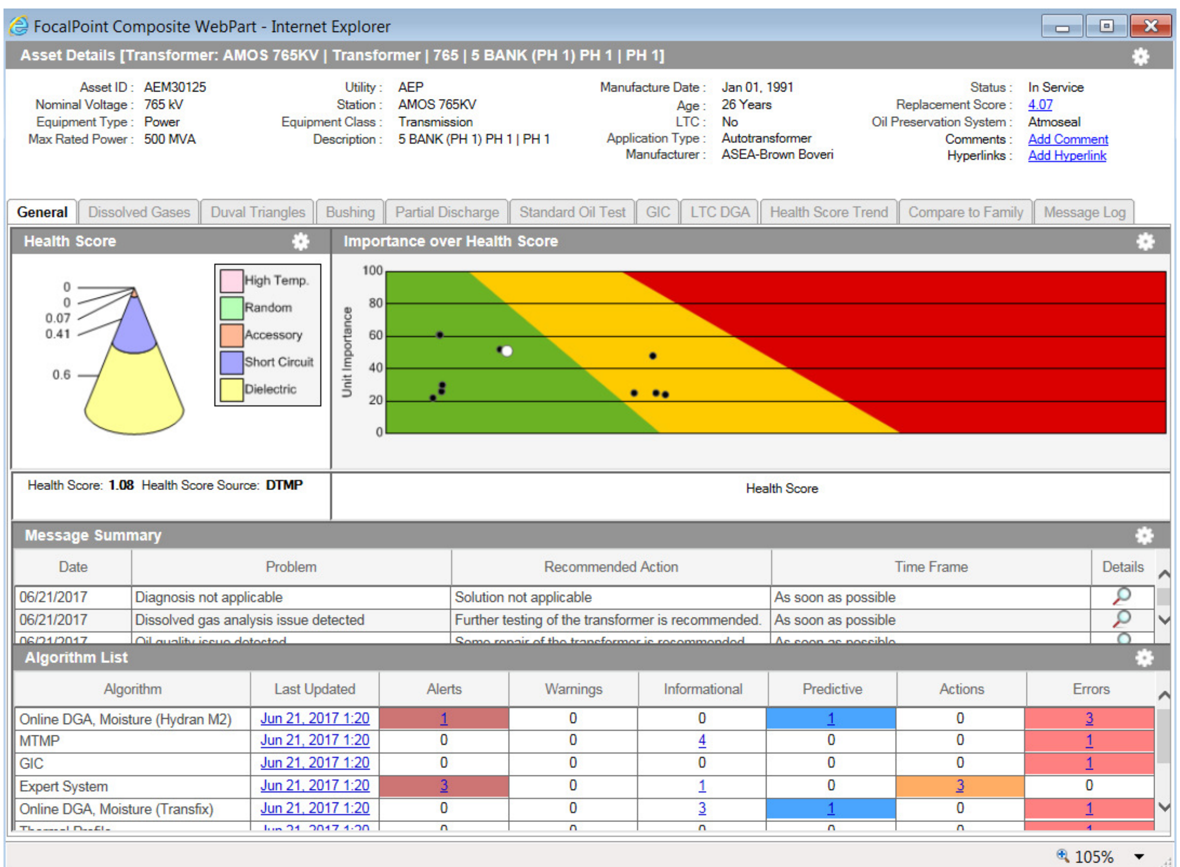

Figure 7 – Asset health solution transformer technical detail screen showing the many tabs with operational data of all transformers included in the program (8,318 units).

4. Success Stories

The business case for the Asset Health Center was based on three main areas: Failure Prevention & Safety, Maintenance Optimization, and Prioritizing Asset Renewal. The benefits achieved at this point have exceeded the original business case model in the last 3 years.

4.1 Failure Prevention & Safety

Three EHV transformer failures prevented (50%): $15-20M
EHV Transformer prediction at 5 of 6 monitored so far: 83% prevention rate.

4.2 Maintenance Optimization

Working with transformer analytics to prioritize transformer maintenance as a standard process:
Circuit breaker monitoring caught SF6 gas leaks at large circuit breaker station
Transformer monitoring caught gassing issues at site (numerous)
Cooling and wiring issues at site (numerous)
Found bad pressure device in Transformer (numerous)
Found bad relay at site (numerous)

4.3 Prioritize Asset Renewal

The asset health solution data & algorithms are being used in planning decisions (standard process)

5. Challenges to Implement and Next Steps

The implementation of the asset health solution project had several challenges to overcome. The first challenge to our project was that the data needed for the transformer algorithm was located in several systems. The asset nameplate information, inspection data, and testing data was located in our "Utility home-grown" asset management system. The transformer work order data was located in a vendor software product. The SCADA data (real time loading, e.g.) was located in one PI Historian, and the sensor data was located at a physical station. Working with our software vendor and our internal IT department, we met this challenge by creating an internal IT infrastructure, to allow all the data to be accessible to our asset health solution central database – by merging the data into two scalable databases under a two-step process. The first step was to complete the data mapping. This was the most difficult part of the project. Our project team had to analyze all the offline and online data that was (or will be) available, review all the data needed in the transformer algorithm, and ensure that all the data was mapped correctly based on usage, naming, units, and timing. The project team also had to deal with duplicate data, missing data, incorrect data, and different data processes. Data discipline has been instituted by creating a transformer working group that outlined better inspection and testing data templates, and a data process to reduce input errors into the asset management system.

The offline data (work order, nameplate, inspection, testing) was brought into an oracle data warehouse. Database views were created that allowed the asset health solution ETLs to bring the data into the solution centralized database. The oracle data warehouse was scalable and flexible. If more data is needed ~~more data~~ from our current or similar sources, it is an easy adjustment in the oracle data warehouse to add that data as new database views. The online data (SCADA and sensor) was brought into a single PI historian. The SCADA data was implemented with a PI to PI connection, and the sensor data was brought in via the 61850 protocol.

Another challenge was creating support for the asset health solution project across the organizations. The software product was new to the Utility and our engineering teams. The engineering organizations were not convinced of the benefit possibilities. Also, monitoring devices had been tried at various times in the past with little success. Field resources were very apprehensive that the new initiative had merit, so were slow to support the monitoring initiative. To combat this challenge, the utility created a dedicated project team to support the asset health solution project. The dedicated team worked across organizations on communication, benefit confirmation, funding approvals, change management, process integration, organizational training, and technical assistance. The project would not have been successful without a team of dedicated change agents.

The final challenge has been process integration and cultural acceptance. Process integration has been achieved by realizing the benefits and communicating the benefits through training, webinars, Utility newsletter articles, and management meetings.

Many field team members have seen the safety and failure prevention benefits first-hand, so they were easy converts. For safety and failure prevention reasons, the Utility Transmission has made it a requirement for the EHV transformer monitoring equipment to be fully functional before energization. Partial discharge alarms are sent to operations for evaluation, and possible addition to standard safety procedures.

As the software and data have been integrated into processes, benefits continue to be realized. For example, the asset renewal team is using the asset health solution software replacement and health scores in a standard process to determine replacement needs and justification. Prior to this standard process, the most important factor was age of the asset in determining replacement need and justification. The current transformer algorithm in the solution creates a replacement score and health score based on asset nameplate data, offline inspection and testing data, and condition-based monitoring. The replacement needs and justification have been greatly improved with the new asset health solution software, by adding monitoring equipment to the assets, and by implementing the new asset renewal prioritization and justification process across the Utility Transmission.

6. Discussion/ Concluding Remarks

The safety issues mitigated by avoiding failures, on top of the substantial savings attained by its application, demonstrate the impact that an Asset Health Solution strategy may bring to any utility. The Utility has found the Asset Health Solution to be so successful in attaining its goals, detecting and minimizing transformer failures, optimizing maintenance resources, prioritizing asset renewal, and enhancing safety that it wishes to expand the solution into other assets not yet being monitored by the program.

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