IMPROVEMENT IN DISTRIBUTION RELIABILITY BY INTEGRATING ASSET MANAGEMENT AND OUTAGE MANAGEMENT TASKS

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ABSTRACT

This paper is proposing a solution for improving distribution reliability by integrating asset and outage management tasks. How handling the asset and outage management in the same framework offers opportunities for improving the overall performance of distribution system operation is discussed.

INTRODUCTION

Faults and failures of components in distribution system may cause interruption of power supply to customers. Since distribution systems in general encounter high frequency of outages caused by weather, component wear and tear and other reasons, the need to reduce outage time is evident for two reasons: a) the growing customer requirement for high quality of service. Sensitive loads in some industries such as VLSI chip manufacturing or ore smelter processing are very sensitive to interruptions in power supply. Potential consequence of failure is more severe nowadays than a decade before; b) the growing demand from utility shareholders for higher profits. The most direct impact of faults on the profit is the loss in customer billing due to undelivered kWh, as well as maintenance expense. The concern is how to reduce the outage and repair time so that the service can be restored as soon as possible.

The Energy Independence and Security Act of 2007 defines the Smart Grid solutions as the modernization approach for the electricity delivery system [1]. When it comes to the distribution system, the modernization refers to the advanced distribution management system, integration of distributed generation and information exchange between utilities and customers [2]. Above all, a future distribution system should have improved reliability and reduced outage time. Reliability indices defined in an IEEE standard are used to evaluate the distribution system performance [3]. The System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) are two most widely used indices. The lower the value of SAIDI and SAIFI, the better the performance in terms of reliability.

Currently the improvement in distribution reliability is hampered by four major issues: a) lack of data: besides voltage and current measurement at substations, very few such measurements are available from other locations in the system, b) aging of equipment: most of the primary equipment installed in the USA distribution system is pretty old, in some instances over 30-40 years, c) ineffective fault processing and maintenance practices: precise location of faults caused by the lack of data creates longer restoration times since the fault location is hard to pinpoint due to current practice to use trouble calls and manual switching [4] while maintenance is performed either with a run-to-failure strategy or with a fixed ahead-of the-time planned schedule [5]; d) limited data management and communication facilities: additional data that may improve outage and asset management solutions depend on data exchange and communication facilities for this purpose are rather poor.

Recent research in outage management is focused on how to better process the trouble calls [6], supplement information from trouble calls with AMR system and other sources [7], and investigate various improved methods to locate faults [8]-[10]. Recent research in asset management focuses on, condition-based maintenance to predict component failure and reduce maintenance cost by monitoring the condition of equipment on-line [11, 12]. The new approaches in both the outage and asset management is in use non-operational data, which is recorded in the field by intelligent electronic devices (IEDs). This paper considers the overlapping of IED database used by outage and condition-based asset management and proposes the concept of integration of asset management and outage management tasks. The expected benefits from integration include: leveraging in IED installation cost, reduction in restoration time, and better management of maintenance resources.

CONCEPT OF INTEGRATION

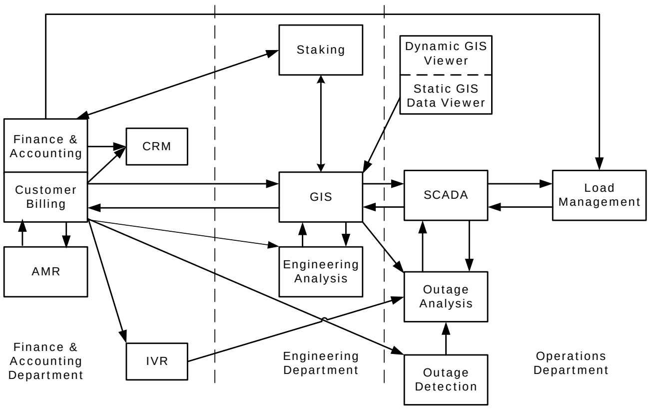

Fig.1: Traditional distribution utility business process

A traditional distribution utility business process approach is illustrated in Figure 1. In this approach, outage analysis is primarily based on inputs from customer report, telling which customers are not connected, and incident verification report (IVR), confirming which customers have lost power. Asset management is primarily based on off-line data without extensive use of operational and/or condition based non-operational data.

One of the constraints to implement the new technologies is the availability of data. Condition-based maintenance, for instance, requires real-time field-recorded data, e.g.

voltage, load current, etc., to perform condition assessment. On the other hand, to implement a voltage-measurement-based fault location algorithm, voltages from several nodes along the feeder are required [10]. Integrating the outage and asset management tasks through the use of data and models of common interest should enhance the efficiency and effectiveness of the overall business process. The strategy of using extensive field data provides two benefits:

- due to improved maintenance, primary equipment will fail less frequently, reducing the number of forced outages;
- due to more precise location of faults and better prediction of the equipment "health", outage restoration practices will be far more efficient and effective.

The improved business process using the integration should explore the correlation between outage management and risk-based management of equipment assets leading to optimized equipment maintenance practices. This will reduce the risk of outages, as measured by reliability indices, energy not served, cost of failure, or other measures. The optimization may be implemented using an asset management concept that selects and schedules maintenance tasks to minimize outage risk.

The integrated asset management and outage management tasks are shown in Fig.2. Fault location and condition assessment retrieve field-recorded operational and non-operational data, as well as system models and configuration data from a common database. Based on this data, the reduction in failure cost is evaluated in an integrated risk-based assessment program.

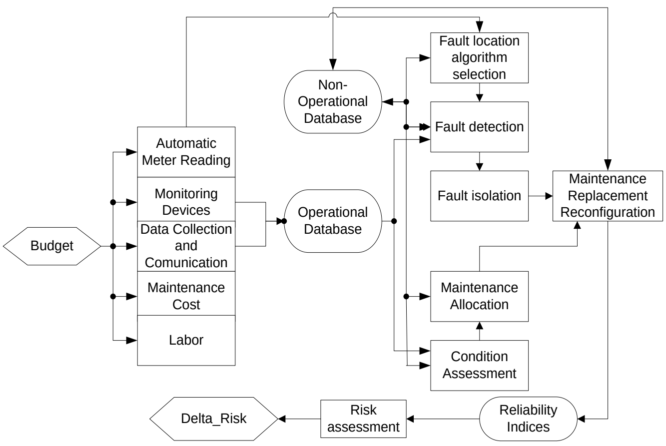

Fig.2: Integrated outage and asset management tasks

IMPROVEMENT CAUSED BY DATA INTEGRATION

Using the integrated database, new algorithms can be implemented for both outage management and asset management applications. For example, accurate fault location can be achieved using fault location algorithm in [13] and [14]. This algorithm uses sparsely-measured voltage magnitudes, and has error detection & management section, so it can pinpoint fault to the nearest node. Fig.3 is a flow chart of this algorithm.

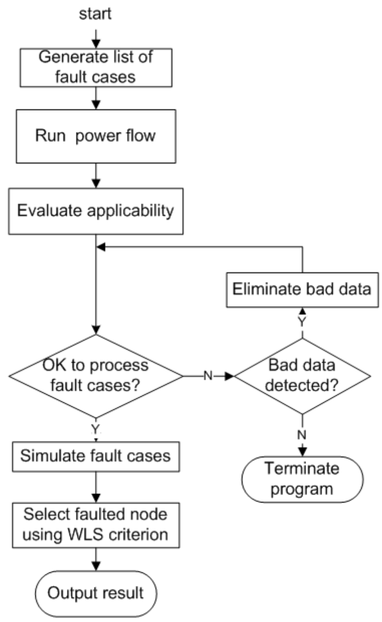

Fig.3: Fault location algorithm based on sparse voltage measurements [15]

Compared to traditional fault location method, the implementation of this algorithm is able to save time and labor for the field inspection. On the other hand, condition-based maintenance is available based on the field data, so the times and duration of forced outages can be largely reduced [12],[15].
A detailed description of the benefit of integration for the outage and asset management can be found in [16].

ASSESSMENT OF BENEFITS

The benefits of integration reflect in two ways: improvement in system reliability and increase in revenue for utilities. Both aspects can be correlated with the reduction in the outage cost. To evaluate the benefit quantitatively and comprehensively, a risk-based analysis of outage cost is introduced. The risk is formed using selective reliability indices reflecting interests of both customers and utilities.

Risk reduction is comprised of two parts: reduction from maintenance, $\Delta Risk_{AM}$ and reduction from refining fault location affecting the outage management tasks, $\Delta Risk_{OM}$.

The consequence of equipment failure can be expressed as the weighted sum of SAIFI, SAIDI, ENS (energy not served) and DevRisk (cost of maintenance) [16].

a) Effect on customer satisfaction:

$$SAIFI(k) = \lambda(k)\frac{n_k}{N} \quad (1)$$

$$SAIDI(k) = \lambda(k)\frac{\sum_{j=1}^{n_k} d_j}{N} \quad (2)$$

b) Revenue loss of utility:

$$ENS(k) = \lambda(k) P_j d_j \quad (3)$$

c) Cost of equipment failure:

$$DecRisk(k) = Cost(k)\{\lambda(k) + (1+r)^{-MTTF}\} \quad (4)$$

where:

$\lambda(k)$ is the failure rate of component k;

n_k P_j is the number of interrupted customers for each sustained interruption;

N is the total number of customers served for the area;

P_j is the load connected at load point "j";

d_j is the duration of interruption experienced by the jth customer;

Cost(k) is the cost of repairing component k;

r is the rate of return acquired from deferring replacement of a component;

MTTF is the mean-time-to-failure of component k.

Since maintenance changes the factors of failure rate (λ) and mean-time-to-failure (MTTF), reduction in risk obtained from maintaining a component k can be expressed as follows:

$$\Delta Risk_{AM}(k) = \alpha_1 \cdot \frac{\partial SAIFI(k)}{\partial \lambda(k)} \cdot \Delta\lambda(k) + \alpha_2 \cdot \frac{\partial SAIDI(k)}{\partial \lambda(k)} \cdot \Delta\lambda(k) + \alpha_3 \cdot \frac{\partial ENS(k)}{\partial \lambda(k)} \cdot \Delta\lambda(k) + \alpha_4 \cdot \left[\frac{\partial DevRisk(k)}{\partial \lambda(k)} \cdot \Delta\lambda(k) + \frac{\partial DevRisk(k)}{\partial MTTF(k)} \cdot \Delta MTTF(k)\right] \quad (5)$$

where α1~α4are the weight factors.

Similar to expression of *ΔRiskAM*, the consequence of interruption from the outage management can be comprised of weighted sum of SAIDI, ASIDI (average service availability index), MAIFI (momentary average interruption event frequency index) and MED (major event day).

(1) Effect on customer satisfaction:

$$SAIDI(i) = \frac{r_i N_i}{N} \quad (6)$$

(2) Revenue loss of utility:

$$ASIDI(i) = \frac{r_i L_i}{N} \quad (7)$$

(3) Penalty for important customers sensitive to momentary interruptions:

$$MAIFI(i) = \frac{IM_i Nm_i}{N} \quad (8)$$

(4) Cost of reconfiguration:

$$MED(i) = \{SAIDI(i) \mid SAIDI(i) \ge T_{MED}\} \quad (9)$$

where

r_i is the restoration time for each interruption event;

N_i is the number of interrupted customers for each sustained interruption;

N is the total number of customers;

L_i is the connected kVA load interrupted for each interruption event;

IM_i is the number of momentary interruptions;

Nm_i is the number of interrupted customers for each momentary interruption event;

TMED is the major event day identification threshold value.

Since fault location practices change the duration of fault (r), number of interruptions (IM) and the range of affected area (Nm), risk reduction in one interruption event i is expressed as follows:

$$\Delta Risk_{OM}(i) = \beta_1 \cdot \frac{\partial SAIDI(i)}{\partial r_i} \cdot \Delta r_i + \beta_2 \cdot \frac{\partial ASIDI(k)}{\partial r_i} \cdot \Delta r_i + \beta_3 \cdot \left[\frac{\partial MAIFI(i)}{\partial IM_i} \cdot \Delta IM_i + \frac{\partial MAIFI(i)}{\partial N_{mi}} \cdot \Delta N_{mi}\right] + \beta_4 \cdot \frac{\partial MED(i)}{\partial r_i} \cdot \Delta r_i \quad (10)$$

where β1~β4 are the weight factors.

The overall reduction of risk obtained in a reporting period is expressed as a linear combination of *ΔRiskAM* and *ΔRiskOM*.

$$\Delta Risk = \sum \Delta Risk_{AM}(k) + \sum \Delta Risk_{OM}(i) \quad (11)$$

OPTIMIZED ALLOCATION OF BUDGET AND RESOURCES

Once the risk model of outage cost is formed, it can be used in the optimization of budget allocation. The formulation of the optimization problem for budget allocation is:

$$\begin{aligned} \text{Objectives: } & \max.\ |\Delta Risk(B_{Met}, B_{Lab}, B_{Com}, B_{Dev})| \\ & \&\ \max.\ \Delta Revenue(B_{Met}, B_{Lab}, B_{Com}, B_{Dev}, T) \\ \text{s.t. } & B_{Met} + B_{Lab} + B_{Com} + B_{Dev} = B \\ & \&\ |\Delta Risk| \ge \Delta Risk_{\min} \\ & \&\ \Delta Revenue \ge B \end{aligned} \quad (12)$$

where

$B_{Met}, B_{Lab}, B_{Com}, B_{Dev}$ are budgets allocated to installation of new meters and other measure devices, labour expenses, construction and maintenance of communication media and device repair/replacement respectively;

T is the period during which the return in revenue is supposed to cover the investment;

$\Delta Risk_{\min}$ is the lower limit of the expected reduction in outage risk;

$\Delta Revenue$ is the revenue increase;

B is the total budget.

The budget allocation and changes in risk and revenue are linked via reliability indices. Once a plan is made, the reduction in the duration and frequency of outages can be predicted, and thus the values of reliability indices. The plan that can most effectively improve system reliability and creates profit to utilities should be selected.

CONCLUSIONS

The integration of asset and outage management tasks is proposed in this paper. The main focus of this paper is on:

- Integration of field data for outage and asset management ;
- Evaluation of benefits from the integration using risk-based analysis;
- Formulation of an optimization problem for budget allocation.

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