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Grid reliability analysis as a tool for effective asset management

Abstract

The paper deals with current trends of asset management within utilities. On the one side distribution utilities are motivated to make profit, on the other side there are requirements from the customers respectively regulatory to ensure reliable and safe electricity supplying. To be more closely to these two issues it is necessary to realize comprehensive and sophisticated analyses and consequential optimizations for responsible decision making. One of the ways to get answers for e.g. future financial development influenced by improvement of reliability is to know condition of grid.

INTRODUCTION

Distribution grid is a system where a very high level of reliability is expected nowadays. This issue shows higher relevance in free market with electricity and controlled business by regulators. Distribution grid operators are motivated to research the ways how effectively to achieve qualitative and reliable supplying of electricity to customers.

Grid operators have clearly to know the structure and volume of grid and try to find out the answer on question, why reliability shows certain level. The sophisticated failure statistics model is important here, where detailed information of each event concerning reliability in network are recorded. Based on these information it is possible to undertake decisions for investments assignation where to invest e.g. which voltage level is important from which point of view or e.g. to invest into primary devices to obtain less frequency of failures, or into secondary devices to improve duration of failures and so on.

Distribution utilities are recognizing that aging of distribution infrastructure is very important parameter with significant influence for the planning and grid development strategies as well. The reliability point is also not negligible. In these questions the sophisticated asset simulation tools can be useful where various scenarios can be simulated connected to required budget and reliability in global and from relevant device point of view.

Proper maintenance policy seems to be another way how to meet acceptable reliability level. This issue has mid- respectively long-term impacts. Maintenance has very close relation with reliability – it is only point of analyzes and investigations to evaluate it and to find out the assumed levels and influences.

I. ASSET MANAGEMENT

Asset management is used as a synonym for operating a group of assets over the whole technical lifecycle guaranteeing a suitable return and ensuring defined service and security standards [6,7]. This means to focus on sustainability. A major challenge for distribution grid operators is the increasing amount of assets which have to be replaced in the next years due to their age. Therefore, besides a business environment which undertakes long-dated decisions, optimized and integrated strategies for replacement and maintenance of the assets are needed. In this context it is very important to have or to develop the ability to analyze the comprehensive dependencies between maintenance and replacement as well as the expenditures and the supply quality to refer the right decisions. The ability to assess different scenarios for the bulk grid or parts of the grid having the same structure or technology is a major competence in asset management. These assessments develop extensive knowledge about the effects of alternative strategies on the asset base. With this knowledge asset managers can actively develop the grid and spend the money in a way that the long term goals are reached as well as the short term budgets.

II. RELIABILITY IN DISTRIBUTION GRID

There are numbers of indices for the reliability evaluation in networks. International working groups (IEEE or CENELEC) recommend general definitions for distribution systems indices which are used in general. Here is important to say of whom point of view the reliability is evaluated. It means that individual subjects in electricity supplying process like regulatory, distribution grid operator or customer could be interested in various reliability indices or levels.

In general, the regulator uses global indices for supervising and evaluating reliability in distribution systems. These are SAIFI, SAIDI, CAIDI and others. If equal methods for calculations are used, then these indices are usable for comparison several DSO's. The interruptions longer than 3 minutes are considered into following formulas.

SAIFI (System Average Interruption Frequency Index) is a measure of how many sustained interruptions an average customer will experience over the course of a year.

$$SAIFI = \Sigma\, n_j / \Sigma\, N_S \qquad (1)$$

SAIDI (System Average Interruption Duration Index) is a measure of how many interruption hours an average customer will experience over the course of a year.

$$SAIDI = \Sigma\, (n_j * t_j) / \Sigma\, N_S \qquad (2)$$

Where: n_j – number of customers interrupted by particular failure
t_j – mean duration of particular failure
N_S – number of customers in distribution system

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These indices consider distribution network like bulk system and they don't focus in each individual customer or some device like part of network. That's the reason they are called global indices.

III. RELIABILITY MODELS AND ASSET CONDITION

It is one of base question in reliability modeling, which element of distribution grid is to choose for analyzing. In general for various studies grid is divided to elements such overhead lines, cable lines, transformers, circuit breakers and so on. Each of these elements should be researched in technical as well financial views.

If we consider the underground cables like nonrepairable asset class we can apply ideal bath tube curve. There is shown number of failures of certain asset segment (partition of MV cable) dependent on age in Figure 1. It can be seen that as the cables are becoming older as the number of failures is rising. It is necessary to underline that these data are still in collection progress. These discrete values can be approximated by suitable function coming from mathematical model.

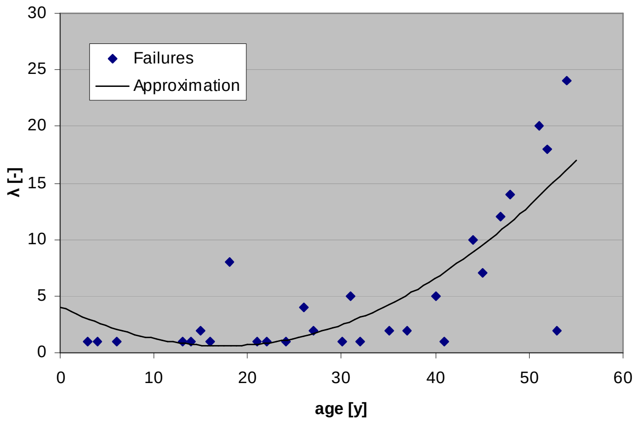

Figure 1. Approximated reliability bath tube curve based on event statistical evidence.

It is generally believed that the key to achieving this lies in controlling the condition of the assets. This is becoming increasingly possible as technological improvements have led to the development of information systems for the collection of condition information and improved noninvasive tests for condition.

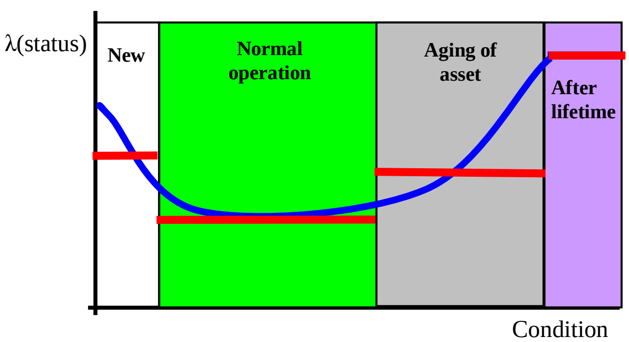

Figure 2. Approximated reliability bath tube curve based on asset condition.

Hence databases of condition information are starting to become available and these will soon become more comprehensive and widespread. This trend is in turn driving the development of methods for asset management based on condition measures and these are the subject of this paper. For asset strategy planning modeling the asset ageing chain correctly is the key to the success of the model. As different asset types have different ageing characteristics a chain for each asset type is logical.In Figure 2. there is shown example of asset condition reliability model with 4 different states of asset during its life cycle. With the red color are shown discrete values of probability of failure, blue line is approximated behavior. When distribution grid operator settles the tool for collection and evaluation of asset condition data, these can be used for prognoses tools.

IV. MATHEMATICAL MODELS

In the mathematical sense, reliability is measured by the probability that a system or a component will work without failure during a specified time interval (0, t) under given operating conditions and environment. The probability P(T>t) that the time to failure T will be greater than a specified time t is given by the reliability function R(t) = P(T>t), also referred to as the survival function. The reliability function is a monotonic non-increasing function, always unity at the start of life (R(0) = 1,R(∞) = 0). It is linked with the cumulative distribution function F(t) of the time to failure by R(t) =1 – F(t): Reliability = 1 – Probability of failure. If T is the time to failure, F(t) gives the probability $P(T \leq t)$ that the time to failure T will be smaller than the specified time t, or in other words, the probability that the system will fail before time t [2]. The cumulative distribution function of the time to failure is related to the failure density function by

$$f(t) = dF(t)/dt \qquad (3)$$

Often used reliability function is the failure intensity and it is defined as laying density function of failure probability to reliability function [2]. This parameter could be also calculated like portion of failed devices to all operated devices during certain time period, e.g. number of failures per 100 km of lines and so on.

$$\lambda(t) = f(t) / R(t) \qquad (4)$$

There are various distribution mathematical models that can be used for reliability description (normal, lognormal, Gama, exponential, Weibull, etc.). Because of reliability is a stochastic phenomenon it is necessary to take care of proper evidence of each event which was done in grid. Based on such data it is possible to apply some of mentioned mathematical models to depict grid or its part for asset management purposes.

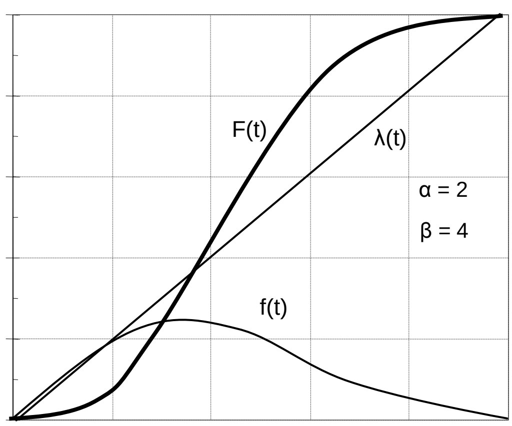

Figure 3. Weibull distribution model often used in reliability modeling

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V. MAINTENANCE IN DISTRIBUTION GRID

It is task for research to find out if the ideal „bathtube curve" mentioned in „Fig. 1" deals with maintenance strategies in relevant devices. However there is tendency to use devices in grid without maintenance almost all types of distribution devices require inspection, testing and/or maintenance to ensure proper operation and minimize the probability of failures. The maintenance strategy can be broadly categorized as:

- Run-to-failure (RTFM),
- Periodic (TBM),
- Condition based (CBM),
- Reliability centered maintenance (RCM).

After installation, equipment is not inspected or maintained until a failure occurs. This is cost effective for non-critical components with minimal maintenance requirements.

Each of mentioned maintenance form has various influences on asset condition, related failure probability and at last costs. Run-to-failure is the simplest maintenance strategy. Using periodic maintenance at specific time intervals, certain maintenance procedures are performed on equipment regardless of equipment condition or equipment criticality. Condition-based maintenance monitors equipment and only requires maintenance when signs of deterioration become evident. Reliability-centered maintenance is a process used to determine maintenance requirements based on equipment condition, equipment criticality and cost.

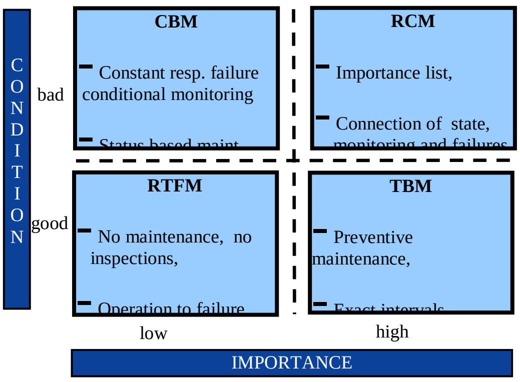

Figure 4. Maintenance strategies description.

An assumption is that the condition of device after maintenance is improved. In the real world, maintenance is rarely perfect. After each maintenance effort, device reliability will usually be a bit worse than the last time maintenance was performed. A further complication is that the failure rates after maintenance can often increase temporarily. This phenomenon is due to the possibility of maintenance crews causing damage, making errors during re-assembly, leaving tools inside equipment and so on. If the maintained device survives for a short period of time, the maintenance was probably performed properly and failure rates are decreased accordingly. Bathtub curves are commonly taught in theory, and typically have been applied to equipment with moving parts. For network operators, it is welcome to ask whether this type of failure curve accurately reflects electrical device aging. There are some assets, like cables, where no maintenance is assumed. But for the most part maintained devices are in distribution grid in reality.

In next Figure 5 there is shown one of expectable impact on reliability of realized or not realized maintenance:

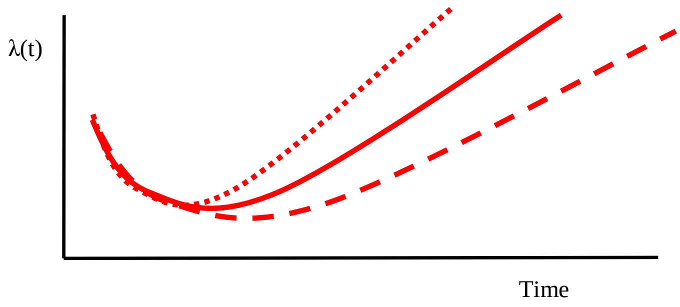

Figure 5. Expected impact of realized and not realized maintenance.

CONCLUSION

The approach described in this paper is suitable to analyze the mid-term and long-term impacts of comprehensive asset management strategies and scenarios for practical use. The targets from which the strategy is deduced can be assessed by criteria points mostly like budget, number of assets maintained, replaced, decommissioned, or supply quality. Uncertainties in the asset models have an impact on the results, but qualitative and quantitative results can be achieved if sufficient data are available. Such models and approaches may not to give accurate numbers but they can show the trends of key points in future by applying the certain strategy. It will describe the grid and its development in global view.

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