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RCAM Dynamic Tool – Reliability Centered Asset Management Solution

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SUMMARY

Owners and operators of electrical power systems face numerous challenges regarding the effective asset management. The following key questions reflect the need for strategic decision support:

- What is the current condition of assets?
- How will their condition develop in the future?
- How to extend the lifetime of assets?
- When should I replace assets?
- Am I doing the right maintenance at the right time?
- Which resources are needed for the replacement of assets?

"RCAM Dynamic" is a tool which has been developed by SIEMENS AG for many years and successfully installed on some customer sites (e.g. Asian and European DSO's) to answer such questions. RCAM Dynamic includes the following key functionalities:

- Consolidation of all information in one comprehensive Health Index (HI).
- Enhanced asset transparency including current conditions and
- Forecast for health index by estimation of individual condition parameter degradation
- Monetary risk indication of assets present and future
- Definition of the appropriate maintenance strategy for assets.
- Investment optimization based on best time for refurbishment and/or replacement.

The tool can be adjusted according to available data and the requirements of online monitoring as well as manual indicators of asset conditions and is capable to aggregate dozens of online and offline data points from main subcomponents of electrical power equipment (e.g. circuit breaker).
The tool functionalities are based on patented RCAM methodology applied by Siemens since many years for asset performance management.

KEYWORDS

Transmission and distribution system operation, asset management, reliability centered maintenance, asset health index, reliability centered asset management, condition monitoring, ISO 55000, asset management strategy.

(1) INTRODUCTION

With the liberalization of energy market, the regulation agency and energy providers are equally interested to find out suitable level of risk, which can be accepted by customers in case of interruptions and by network operators in terms of maintenance costs. Therefore, the reliability assessment has become a challenge and an essential commitment in the power utility industry today [1]. In this context the reliability management process is a very important task in the field of asset management, due to the huge amounts and conditions of system assets, particularly in distribution systems, which have a crucial impact on the system performance. An improved reliability level can be obtained e.g. by increasing of investments in maintenance. Despite, the risk cannot be reduced to zero. In general, the risk level depends on the probability and severity. The task of asset management is to balance the risk level and the supply quality by influencing on probability and reduction of adverse risk effects. Such methods are described, for example in [2]. In order to take an objective decision due to the investment strategy in the next view period, the instruments and the methods for risk vs. quality optimization are necessary. These methods must take into account such factors as system topology, asset reliability, economical and sociological aspects of outages in power systems.
The methodology starts with the consideration of parameters, influencing the condition of the asset and the aggregation of these parameters to one comprehensive Health Index of assets “Asset HI”. Through separate examination of the condition parameters on the physical level it is furthermore possible to forecast these conditions for the future.
Consideration of the future HI makes it possible to derive the best maintenance strategy for the next 10 or 20 years, such is the main aim of the asset maintenance methodology.
The proof of concept is done in frame of the work for medium voltage circuit breaker type 8DB10 from Siemens, such is very common for medium and small distribution grids as well as for big industrial facilities.
The comparison of two different maintenance strategies for this type of equipment namely time based maintenance and reliability centered maintenance enables us to compare the economic aspects of both and, if necessary, to refine the requirements for them due to more information or mathematical tool sets.
The paper goes into detailed methodology relating to conditions and health calculation for one special asset type, observed here namely the medium voltage circuit breaker of Siemens 8DB10 type. The paper describes the condition parameters as well as the ranges to qualify these condition parameters.
As an indicator for the appropriated maintenance strategy, the risk indicator is used. This indicator is calculated as the combination of factors condition and importance.

(2) DESCRIPTION OF RCAM METHODOLOGY

In the following the RCAM methodology is deeply explained. The offered Asset Management System is based on RCAM Dynamic and facilitates the unified data acquisition, data processing, visualization, and integration into an Asset Management process as requested e.g. by ISO 55000. The connection of optional monitoring packages may be considered at a later stage.
The objective of implementing RCAM Dynamic is to monitor, gather and process condition data of power distribution assets in a central system for diagnostics to provide valuable information for daily use on maintenance planning and risk mitigation – in short Asset Management.
The principal of calculation flow in RCAM Dyn is shown in the picture below.

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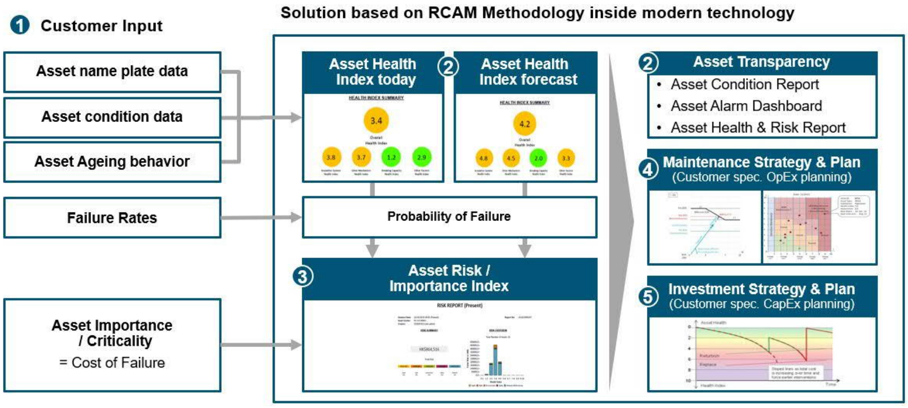

Picture 1: RCAM Dyn calculation principals

The calculation work flow includes 5 main procedures, which are explained in the next chapters.

2.1 Customized input parameters for Asset Health Calculation.

In addition to static equipment data (type plate data), the following information on the equipment is used as input:

- Asset status data as physical measured values of the individual subsystems such as current, voltage, time, pressure, etc.
- Asset Age as absolute value in years since commissioning of the equipment
- Assumptions about the degradation of the individual condition parameters with the equipment age, which can be derived from the field observations and adjusted accordingly.
- Constant failure rate over time, which can be taken from the equipment statistics.
- Asset importance, which is composed of four dimensions: OpEx, CapEx, network performance and HSE influences that could emanate from individual resources.

2.2 Main functions of RCAM Dyn

The RCAM calculation methodology contains four main functions, some of which are built on top of each other:

1. Calculation of the Health Index (HI) for the current point in time by normalizing and weighting the individual physical equipment parameters, as well as predicting HI (Forecast HI) by using the aging individual parameters.
2. Estimation of the risk by using the importance parameters and the error rates of the equipment.
3. Calculation of the optimal maintenance times (Next due Date Maintenance Plan) by comparing the risks and predicted conditions of the individual resources.
4. Derive an optimal investment plan by simulating a replacement and/or refurbishment program and comparing the resulting life cycle costs.

A more detailed description of the function is given in chapter (3) in the following.

2.3 Selection of asset maintenance strategy.

This chapter gives a short overview about the maintenance strategies, supported by RCAM Dyn.

Since the manufacturer design the same product for a large range of users having a broad spectrum of operating environments, the OEM must select the worst-cases or the most-challenging situations. This means that for most users the maintenance timing is conservatively based (TBM).
To make Maintenance more cost-effective, equipment needs to be serviced according to its special needs. In this way unnecessary wasting of maintenance resources, both material and human, can be avoided (CBM).
But not all assets may be treated equally. Reliability Centered Maintenance links TBM and CBM methods and uses an importance value and the estimated condition value to apply different maintenance strategies for assets according to their location in a Condition Importance Matrix. Reliability however is only one Risk dimension (RCM).

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Risk Based Maintenance develops the system reliability and network impact within RCM to a further stage. In doing so, it draws upon RCM, CBM, TBM and CM and uses aspects from each, where appropriate. Its goal is to minimize costs of maintenance to achieve an acceptable performance, to increase the mid- and long-term profitability under acceptable risk. Thereby a balance is sought between performance, cost and risk (RBM). An addition to static equipment data (type plate data), the following information on the equipment is used as input.

(3) CALCULATION OF CURRENT HEALTH INDICES OF 8DB10 CIRCUIT BREAKERS TYPES

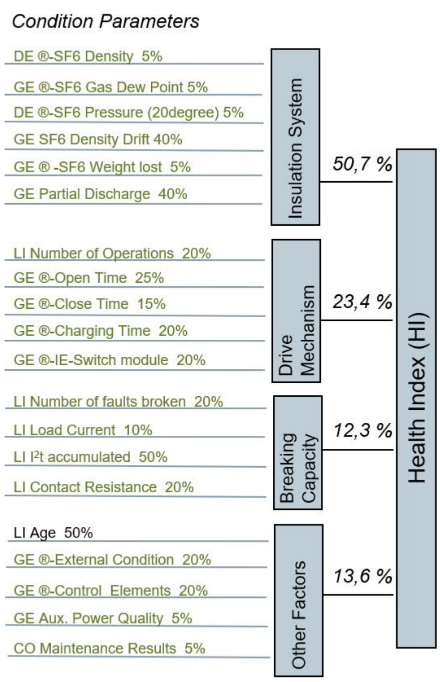
The proposed methodology uses physical condition parameters in order to calculate an asset health index (Asset HI). To manage the different input data, a hierarchical system has been applied. The basis for the calculation builds the provision of the asset model for the HI calculation. The asset model is the entry point of the condition estimation of specific assets. Every asset in the RCAM Dynamic data base is classified in three levels. The uppermost level is composed of the Asset Group which assigns the asset to a specific data model. New groups cannot be created by the user himself and will demand consultation by Siemens. Asset Types form the second level which defines the interval of the parameter values and their respective ageing factor. Finally, the Asset ID identifies every single asset and enables the system to assign measured values to them. These affiliations are called the “Group set”

<table>
<tr><td>Asset Group:</td><td colspan="4">Meduim Voltage Gas Insulated Switchgear</td><td colspan="3">Asset Group G2</td></tr>
<tr><td>Asset Type:</td><td colspan="2">MV GIS|8DB10</td><td>G1|Asset Type Y</td><td>G1|Asset Type Z</td><td>G2|Asset Type X</td><td>G1|Asset Type Y</td><td>G1|Asset Type Z</td></tr>
<tr><td>Asset ID</td><td>MV GIS|8DB10|Busbar 1</td><td>G1|TpX|Asset ID2</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Picture 2: Asset classification

Exemplarily classification of a 8DB10 circuit breaker looks like in the picture 2.

For the calculation of asset condition, the asset condition parameter should be nominated. During the nomination process the methodology of Failure Mode Effect Criticality Analysis (FMECA) acc. to [3] can be applied. The result of this process is asset HI calculation model, presented in Picture 3.



Picture 3: 8DB10 Asset condition calculation model

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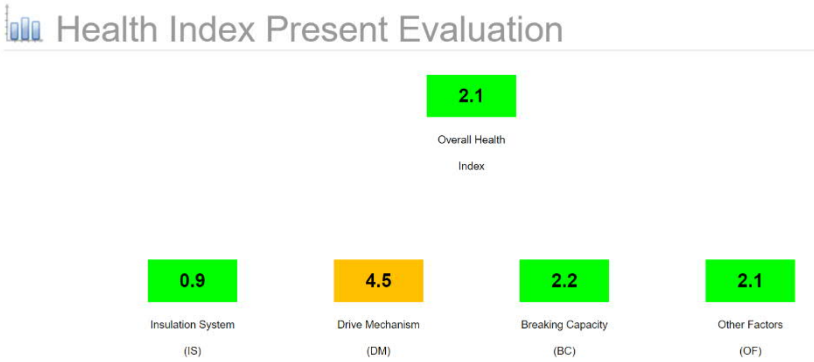
The model consists of 20 condition parameters grouped in four sub parameter groups: **Insulation system (IS), Drive mechanism (DM), Breaking capacity (BC) and Others (OT).** The results calculated from each sub parameter group are weighted acc. to failure distribution of the whole system and aggregated to common health index of the overall asset.
In the following picture presents the current HI calculation results from a group of 57 8DB10 circuit breakers.



Picture 4: Calculation results of current HI over the group 57 circuit breaker of type 8DB10

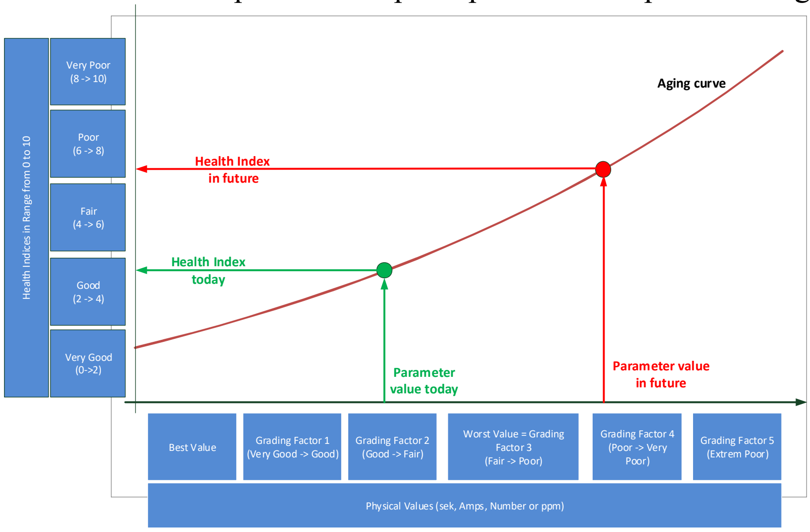
A small excerpt from the list of results is presented in the table 1:

Eq ID	Equipment Type	HI	IS	DM	BC	OT	Age
1	8DB10	1.6	0.6	3.9	1.7	1.5	21,5
2	8DB10	1.6	0.6	3.9	1.7	1.5	13,5
3	8DB10	2.2	0.9	5.1	2.3	2.2	18,5
4	8DB10	2.5	1.1	5.4	2.7	2.6	21,5

Table 1: List view of result of current HI calculation

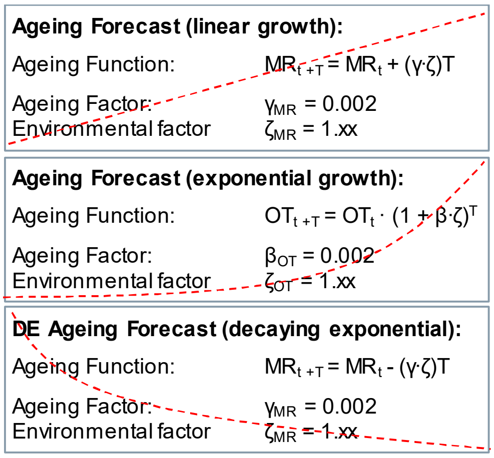
(4) ESTIMATION OF FUTURE HEALTH INDICES OF 8DB10 CIRCUIT BREAKERS TYPES

According to the parameter ageing putted into the system, RCAM Dyn estimates the future HI of the assets under consideration. The Picture 5 below presents the principle under the parameter ageing.



Picture 5: Principles of the parameter ageing in RCAM Dyn

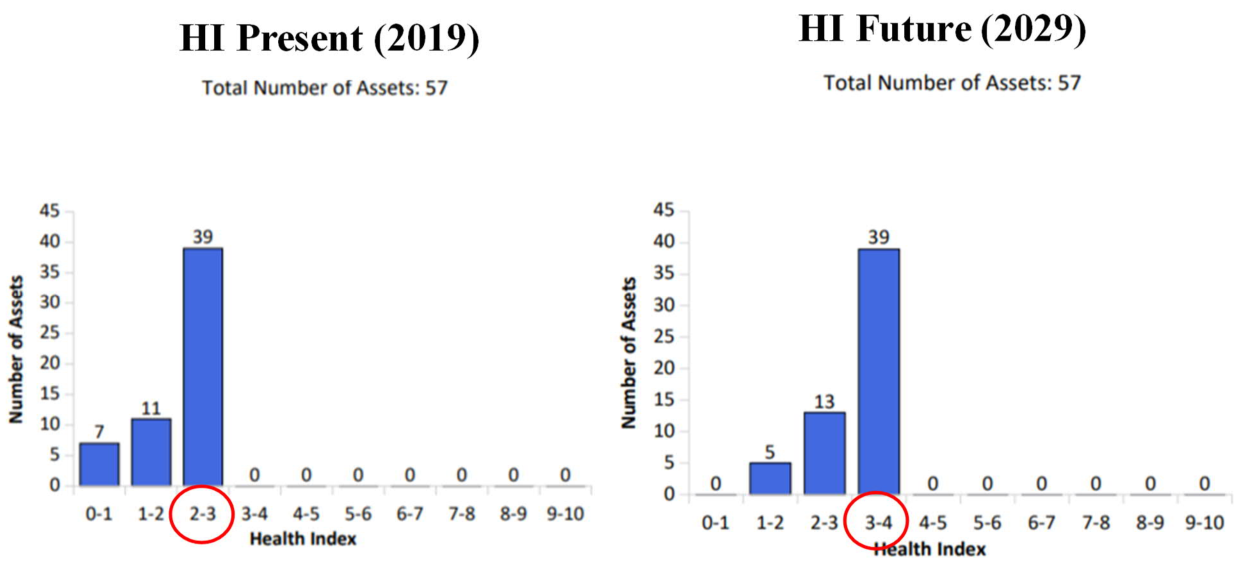
An ageing function is assigned to each condition parameter of the asset type, so that together with the ageing factor a future development of the parameters can be predicted. The list of applied ageing functions is depicted in the Picture 6.



Picture 6: Available ageing functions

The selection and nomination of the ageing functions depends on available asset information from the past such as failure statistic over age, service reports or protocols from the inspections and maintenances. This is strongly recommended to prove the assumption and to adjust the parameter ageing in a periodical way.

The picture below presents the comparison of distribution of the present HI's of 8DB10 circuit breaker and the corresponding results 10 years later (in 2029)



Picture 7: Comparison of present and future assets HI

In the picture 8 can be clearly recognized the shift of the overall HI from 2-3 to 3-4. The degradation of the asset health index is the fundamental element for the development of an appropriated maintenance schedule and the replacement strategy. Together with the consideration of component importance, this can lead to a sustainable maintenance strategy both for the next observation period and for the longer-term perspective. The procedure to include the importance in the decision-making process is described in the next chapters.

(5) CONSIDERATION OF PROBABILITY OF FAILURE AND RISK

The risk assessment in electrical power systems presuppose the specification of risk types arising in the considered level. For this reason, the separation of risk events by their impacts and by the reasons that caused these events must be performed, depending on different types of equipment. Risk is defined in IEC 60300-3-9 as "combination of the frequency, or probability of occurrence and the consequence of a specified event…" [4].

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The probability of occurrence as a synonym for the more common used term Probability of Failure (PoF) depends on the asset condition and therefore direct correlates with health index of the asset. Based on the often-used bathtub curve for consideration of the life cycles of equipment the constant failure rates are used for the description of the bottom part of the curve. This is the start point of the derivation the dependency between Probability of Failure and Health index of the asset in the RCAM Dyn methodology too. The same methodology is well described and applied in [5]. The result of the dependency consideration is in Picture 8 presented as PoF over HI function. This function is used for risk calculation.

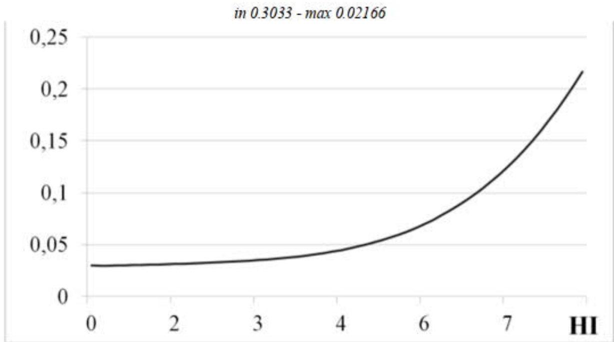
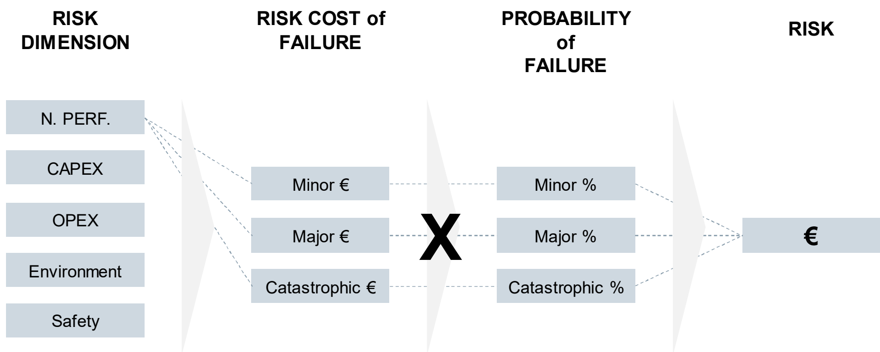


Figure 12: PoF vs. HI (OFGEM)

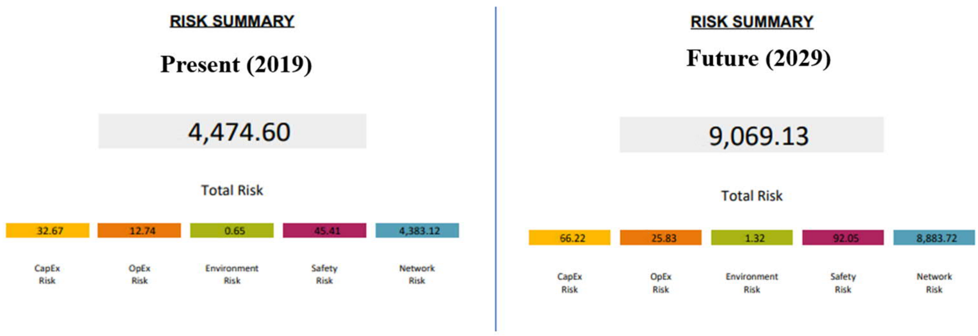
Picture 8: PoF over HI

The formula for the total risk calculation is depicted in Picture 9:



Picture 9: Total Risk calculation procedure

The calculation includes five dimensions of risk: Network Performance as Non-delivered Energy, CapEx, OpEx, as well as Environmental and Safety impacts. Furthermore, the failures are separated in Minor, Major and Catastrophic Costs of failures in terms of financial impacts. The results of present and future risk calculation are depicted in picture 11:



Picture 10: Present and Future Risk calculation for 8DB10 asset type

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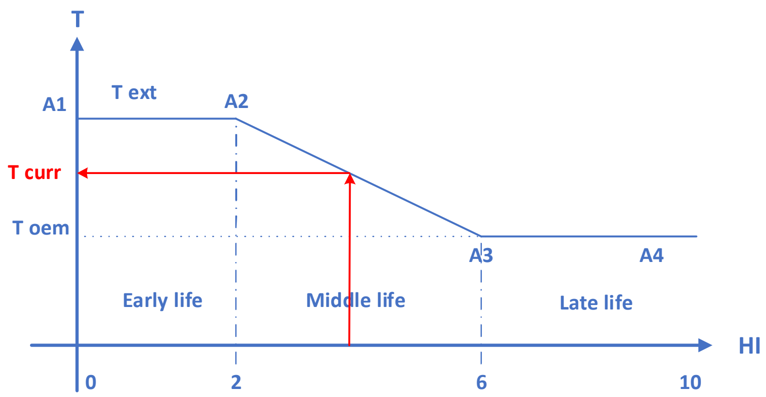
(6) DERIVATION OF NEXT MAINTENANCE DUE DATE FOR THE ASSETS

Up to now all ingredients are available to start preparing the decision support for the most effective way to maintain assets in the short and middle term of view. Next maintenance due date (NDD) is a proposition of the date for the next maintenance action in such a way that the over all risk of failure from the considered asset stays in the same level.

Before starting the methodology presentation one important term should be introduced. Maintenance period T is the manufacturer's recommended time-based ordinary maintenance interval. This maintenance interval of T is specified by manufacturers considering the worst-case scenarios of operation, in such the equipment is in most possible stresses and consequently in most possible degradation mode. Even in this situation, ageing increases exponentially with age, so the recommended maintenance interval T at the beginning of operation seem too conservative and should be even shortened at the end of operation.

NDD principle is to take the health index in the consideration and to set up the maintenance interval acc. to condition and importance of the asset. For this reason, the Dynamic Maintenance Interval was defined acc. to the following picture.



Picture 11: Dynamic Maintenance Interval

The main idea is to extend the Maintenance Interval by some appropriated factors in the early life of an asset to **T_ext**, to shorten the interval in the middle life and to go back to **T_oem** maintenance interval. To find out which current HI interval **T_curr** applicable for specific HI the connection between HI axis and dynamic maintenance interval line should be considered. The dynamic maintenance interval is therefore dependent on four anchor points:

- A1 = (0, T_ext)
- A2 = (HI = 2, T_ext)
- A3 = (HI = 6, T_oem)
- A4 = (HI = 10, T_oem)

These anchor points should be determined according to the current situation in the grid operation. They should also be adjusted during in the future. The table below shows an extract of the results report for the NDD analysis of the 8DB10 circuit-breakers.

Equipment ID	First Commissioning Date	Health Index	Last Inspection	Last Maintenance	Next time based Maintenance (TBM)	Condition based Maintenance Interval (CBM, Years)	Next condition based Maintenance (CBM)	Difference in years
1	03/01/2006	1.6	03/01/2006	03/01/2006	03/01/2014	16.0	30/12/2021	7,99452055
2	03/01/2006	1.6	03/01/2006	03/01/2006	03/01/2014	16.0	30/12/2021	7,99452055
3	03/01/2001	2.2	03/01/2001	03/01/2001	03/01/2009	16.0	30/12/2016	7,99452055
4	03/01/1998	2.5	03/01/1998	03/01/1998	03/01/2006	16.0	30/12/2013	7,99452055

Table 2: Results of NDD calculation for maintenance interval of 8BD10 asset group.

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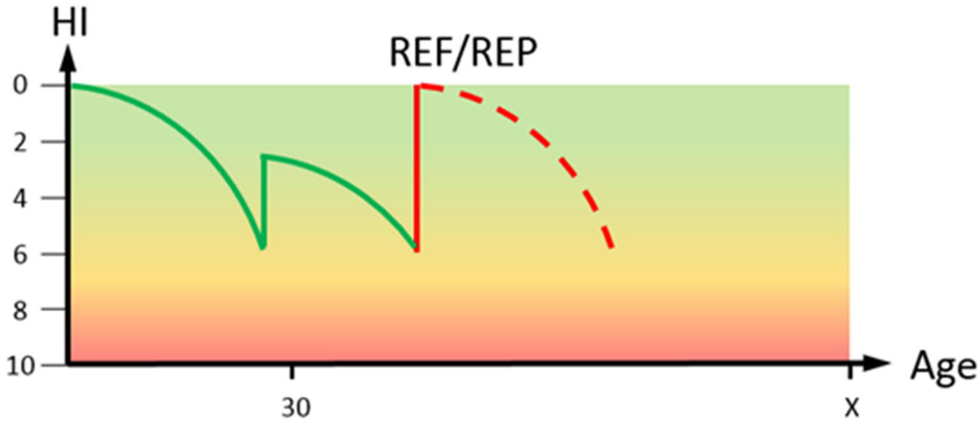
(7) CONSIDERATION OF THE REINVESTEMENTS IN ASSETS

The Replacement / Refurbishment function provides an overview about the optimal time for taking strategic interventions being mid-life refurbishment and end-life replacement. It is a purely economic consideration based on risk scenarios which are derived from the PoF over HI correlation.



Picture 12: Ref / Rep scheme over given timespan

In the condition model, there are the following assumptions taken to define the HI improvement after 'mid-life' refurbishment as follows:
Several Condition Parameters are reset to 'very good' after major maintenance with the purpose to document the effectiveness of this measure. The list can be seen in the model Asset condition calculation model acc. to Picture 3 – the ones marked with an ®.
As a result of the Replacement and/or Refurbishment Simulation (R/R) RCAM Dyn provides a strategic intervention report over the selected asset group or some specific assets. In this report I1 corresponds to Intervention 1 and means the 'mid-life Refurbishment' of an asset. I2 here is the Intervention 2, being 'end-life Replacement of an asset.
An extract of strategic intervention report is shown in the table 14.

Equipment ID	HI today	I1 Date	Age be-fore I1	HI be-fore I1	I1 Type	HI after I1	I2 Date	Age be-fore I2	HI be-fore I2	I2 Type	HI after I2
1	2.5	28/06/2028	31	3.2	Refurbishment	0.9	28/06/2045	48	3.0	Replacement	1.5
2	2.5	28/06/2028	31	3.2	Refurbishment	0.9	28/06/2045	48	3.0	Replacement	1.5
3	2.5	28/06/2028	31	3.2	Refurbishment	0.9	28/06/2045	48	3.0	Replacement	1.5
4	2.5	28/06/2028	31	3.2	Refurbishment	0.9	28/06/2045	48	3.0	Replacement	1.5
5	2.2	28/06/2031	31	3.2	Refurbishment	0.9	28/06/2048	48	3.0	Replacement	1.5
6	1.6	28/06/2036	31	3.2	Refurbishment	0.9	28/06/2053	48	3.0	Replacement	1.5
7	1.6	28/06/2036	31	3.2	Refurbishment	0.9	28/06/2053	48	3.0	Replacement	1.5
8	2.5	28/06/2028	31	3.2	Refurbishment	0.9	28/06/2045	48	3.0	Replacement	1.5

Table 3: Strategic intervention report for 8DB10 assets

(8) CONCLUSION

The target of the method presented in this report is to find some simple and comprehensive decision support for the asset management in the power system. The importance of such methods is getting increased interest in course of searching for a trade of between quality of support and cost reduction. The presented method applies the Reliability Centered Maintenance and uses the condition and importance of the assets to find the optimal time for maintenance, refurbishment and replacement.
The derivation of such models requires knowledge about the technical functioning as well as about the economic impacts on the operation of the power equipment. In this way, a complete model of the equipment can be created. This provides then sustainable information for the asset manager. Nevertheless, the procedure described above requires the models being critically scrutinized and updated from time to time.

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