Enhanced Competitiveness with a Modern Asset Management System

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***Abstract*--The increasing competition in the liberalized energy market requires from the utilities, power generation and transmission companies possessing substantial physical assets to optimize their business processes in enhanced manner. Cost, time, quality, risk and flexibility are parameters subject to optimization. This implies, that all processes especially those belonging direct to the core activities should be surveyed with regard to reduction or improvement of the above-mentioned strategic parameters. Based on physical measured data the described approach focuses on the early detection of failure escalation and recognizing trends in equipment condition before the fault consequences occur in the financial statements. Using this feature in a process oriented controlling environment, the Asset Management System (AMS) turns out as a powerful support by setting up the maintenance strategy and by taking decisions on different levels of organization. It supports to optimize cross functional business processes and consequently helps the company to exploit to the full the unrestricted competition on the energy market which has arisen with the liberalization.**

***Index Terms*—Management decision-making, Power distribution reliability, Power system monitoring, Risk analysis, Power transmission maintenance, Strategic planing**

I. Introduction

THE Asset Management is becoming a vital business discipline in electric utilities because its capital in physical assets constitutes the substantial part of total assets. With highly developed information technologies the efficient exploitation of asset data processing can provide additional competitive advantages on the energy market. In the mentioned companies the asset pool mainly consists of electromechanical equipments being continually exposed to value reduction due to condition deterioration. The immense amount of value depreciation, the stochastic manner of various aging phenomena and the shortage on information quality about the actual equipment's condition in traditional plant book keeping explain the strategic importance assigned to this paradigm. The paper will show a conceptual architecture of an AMS integrating standalone Online Monitoring Units (OMU) of primary electrical equipments and a central Diagnostic Unit (DU). The system architecture and one of the decision supporting methods depicted in Fig. 5 give a quick insight into this reliability centered approach focused on practical use. The paper gives also a short review about the Target Costing Methodology that has been used as theoretical fundamental for continuous risk assessment of eventual breakdown events. The authors are dealing with the following questions: How to form a single indicator which gives a reliable estimation and a good visualization of changing risk? What structure of system hierarchy should be chosen to be in conformance with organizational and process requirements? How to give priority to maintenance works in the case of limited budget?

II. Roll Concept of The AMS

Depending on the asset nature *(financial, physical, human etc.)* there are a lot of definition of this management approach, but the main concept is the same. For physical assets the most appropriate definition could be the following: "Systematically employment of decision situation oriented methods *(software applications)* incorporating the relevant set of related processes, performance measures and calculation procedures in order to optimize conflicting process objectives for the whole business life" (see also in [1, 2, 3]). An overview of the competing strategic goals and the main features of AMS are illustrated in Fig. 1.

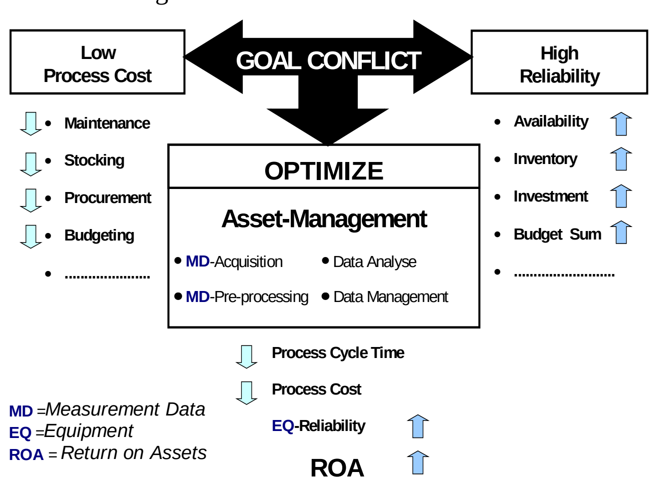

Fig. 1. Optimization of conflicting business objectives through dynamic Asset Management

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To achieve the best compromise, called optimum, the consideration of the interplay between existing business processes and their multidiscipline perception *(technical, economical, environmental etc.)* is of grate importance. Proper interpretation and time varying weighting of conflicting key factors stemming from different kind of relevant processes is a basic requirement to asset managers. They should be able to set up scenarios of anticipated decision situations in advance, to select the most important related process data for them and through an appropriate algorithm to calculate a few key indicators facilitating the decision making. Placing those indices at executive's disposal timely is crucial important in order to avoid risk escalation with high gradient (see Fig. 2) and to reduce the complexity of breakdown scenarios.

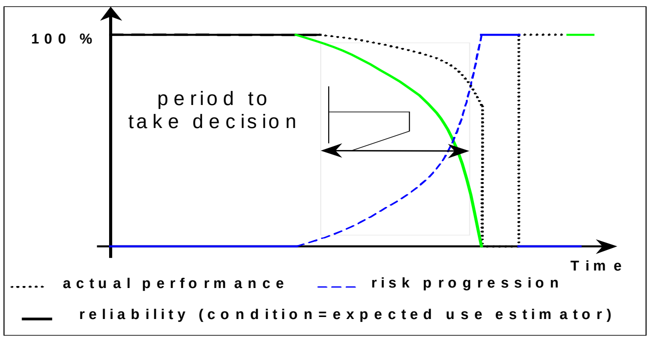

Fig. 2. Progression of breakdown risk against system reliability

While setting down the complexity, the transparency in the underlying procedures should be kept on high level what offers the decision makers a solid communication fundament. A particular emphasis has to be put on providing of data like

1. component oriented cost allocation
2. historical operating circumstances in time sequence
3. process -and system component layout
4. procurement and repair time of components

Equipment oriented knowledge representation and improved visualization throughout the process hierarchy are highly recommended elements of AMS and are to be considered in software design.

Static techniques like book keeping are tracking down the condition deterioration of plants in the form of predefined discount rate. This usually results in significant discrepancy with regard to the actual plant state having considerable impact on the quality of financial decisions. It is also the aim of the AMS to provide an integrated system for more precise depreciation assessment based on current condition data.

In order to emphasize the information managing role of AMS acting as an information interface to functional and cross functional processes, (*like budgeting, maintenance, procurement, stock keeping etc.*) the organizational and process aspect [2, 3] of this comprehensive paradigm are illustrated on the bottom of Fig. 5 (see also Fig. 1).

To benefit economically from data gathered with an increasingly number of online monitoring systems and offline tests, the developed algorithm (*besides the traditionally alarm function*) supports an early warning function as well. This is able to detect, quantify and track down the risk at the very incipient stage of fault escalation. In case of small condition deviation from failure free state on many equipments at the same time, just their appropriate aggregation on the highest hierarchy level can make it possible to highlight the often locally wide distributed, latent rising risk jeopardizing the system function as a whole. The real time risk assessment feature of the AMS assists to carry out a "What If Analysis" continually on the selected process level which can spread over the whole supply chain [3]. The asset hierarchy used in AMS has to serve as a failure map as well as, what enables users to ask for: 1. geographical and functional fault location 2. current and expected risk distribution among the monitored system components. This kind of visualization provides decision makers with timely access to all required information in a demand oriented structure.

III. The Theoretical Background of Model Building

Target Costing Methodology (TCM) is a technique of determining the Allowable Product Cost (APC) and then designing and producing the product to meet this cost. This allowable cost is the one that provides the expected profitability, given the predicted volume, selling price and functionality of the product. The procedure of the target cost definition involves the following main phases:

1. Calculation of target cost of the product (see APC)
2. Selection of the for customer relevant product's functions and weighting them (F_j)
3. Definition of function contribution's share of i^{th} components supporting the related product function F_j (FC_{ji}).
4. Allocation of APC among components on the basis of their Total Function's Contribution to all related F_j (FC_{iT})

The APC calculated from expected market price will be allocated among product components through their FC_{iT} as shown in Fig. 3. The Allowable Component Cost for i^{th} component (ACC_i) can be defined according to (1).

$$ACC_i = FC_{iT} \cdot APC \quad \text{where} \Rightarrow \; FC_{iT} = \sum_{j=1}^{n} (F_{ij} \cdot F_j) \qquad (1)$$

The practical reasoning to this design technique might be summarized as the following sequence of thoughts: how much the total function contribution share of the i^{th} component so much its relative use, the more its use the more the ACC_i for it. For more details refer to Fig. 3, Fig. 4 and [4].

As a result of an iterative design procedure of TCM, the direct proportionality between the cost of a product component and its total function contribution to product functionality (*correlating direct with customer satisfaction*) can be taken as given. Supposed that the selected function's preference distribution (F_1,.F_j,.F_n) is time invariant and the causal relationship between a set of measurement data about component's condition versus its monetary depreciation with Fuzzy Logic (FL) is describable, the current performance capacity of the product (*regarded now as an overall condition indicator*) can be calculated on uniform monetary value basis.

In case of condition evaluation of operating physical assets in an electrical substation, the algorithm of thinking should be reverse to the above cited one in design phase, namely, the more the depreciation of components the less their function's contribution. As a result the overall condition of the equipment and its expected use for the substation functionality declines due to its anticipated breakdown.

Beyond doubt the product reliability as relative index can be estimated through the ratio of function's contribution (FC_t) to the respective contribution magnitude in health case (FC_0), hence the current reliability can be assessed with the same indicator as the condition state. Furthermore it should be noted

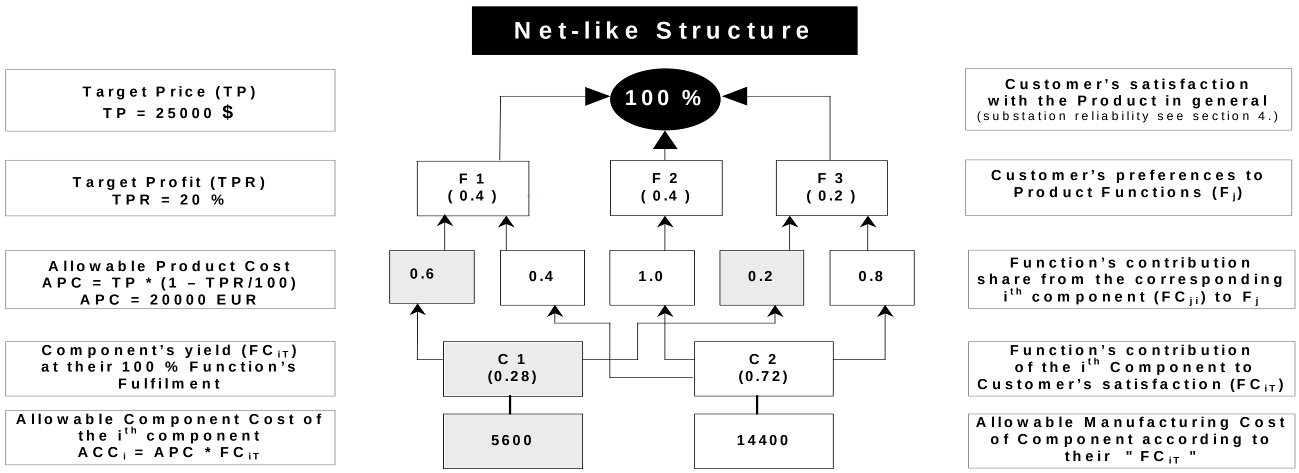

Fig. 3. Manufacturing cost calculation model for product components using their function's contribution share in the supported function as a target cost distribution factor

here that there is mostly a remarkable time difference between the start point of FC fall (*reliability*) and the subsequent function breakdown (actual use = 0). This time period of failure impact's delay is at executive's disposal to make the right decision in order to prevent a catastrophic failure escalation and adjust the relevant business processes (*load transfers between feeders, maintenance or replacement etc.*) to the new optimization criteria (see Fig. 2).

IV. Building The Asset Hierarchy And Outlining of Equipment's Components

Regarding a substation as a "product" (*designed with TCM*) then its hierarchic decomposition can be implemented by the analogy with the procedure used in the Target Costing Methodology (see the right side of Fig. 3). Different system functions contributing to substation reliability are represented through Groups of Equipment's (GE) consisting of electrical equipment's (e.g. *transformers etc.*) with identical function. Furthermore, GE-s are subdivided into single Equipment's (EQ) and the latter into their parts corresponding to the tree structure (see Fig. 4 and Fig. 5). Theoretically it is possible that one component would contribute to two or more components placed in Higher Hierarchy Level (HHL). This would lead to netlike structure depicted in Fig. 3. In order to keep the FC aggregation's algorithm as simple as possible, (*secured through tree structure*), the theoretical case above is not taken into consideration in the structure building. If the

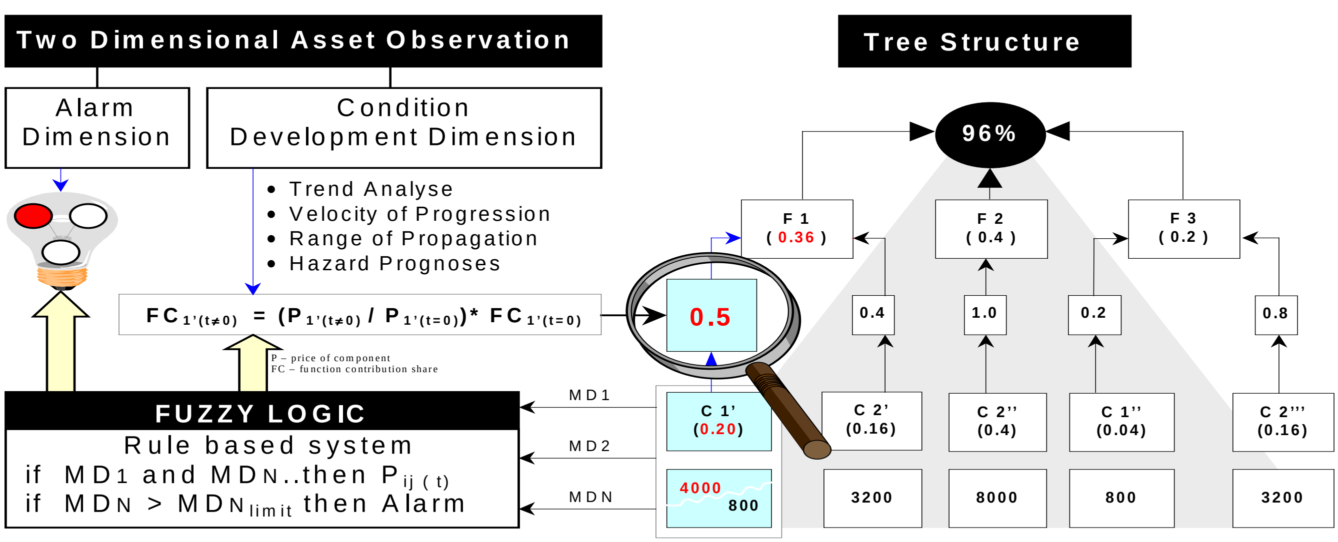

Fig. 4. Condition assessment on monetary value basis using Open Loop Fuzzy Logic for expert knowledge integration and component's depreciation evaluation

simplification is not acceptable the necessary correction should be carried out by adding supplementary rules in the Open Loop Fuzzy Control (OLFC).

OLFC is acting upon the model as FC distributor and it secures the proper transformation of monitored "health" data deviation into depreciation expressed through defuzzification of acting fuzzy rules as shown in Fig. 4. More about the processing of expert knowledge using fuzzy logic in [5].

The depth of decomposition and the accuracy of component definition have a significant influence on the information's quality provided by the AMS. This means, that those components should be selected for condition monitoring, which tend to fail mostly and whose FC reveals a considerable role in the fulfillment of respective component's function(s) in HHL. The approximately relationship between measurement data chosen for condition monitoring and the corresponding component's depreciation (*in turn FC reduction*) can be set up through using membership functions reflecting former experience, failure statistic, recommendations in standards, expert and supplier knowledge [5].

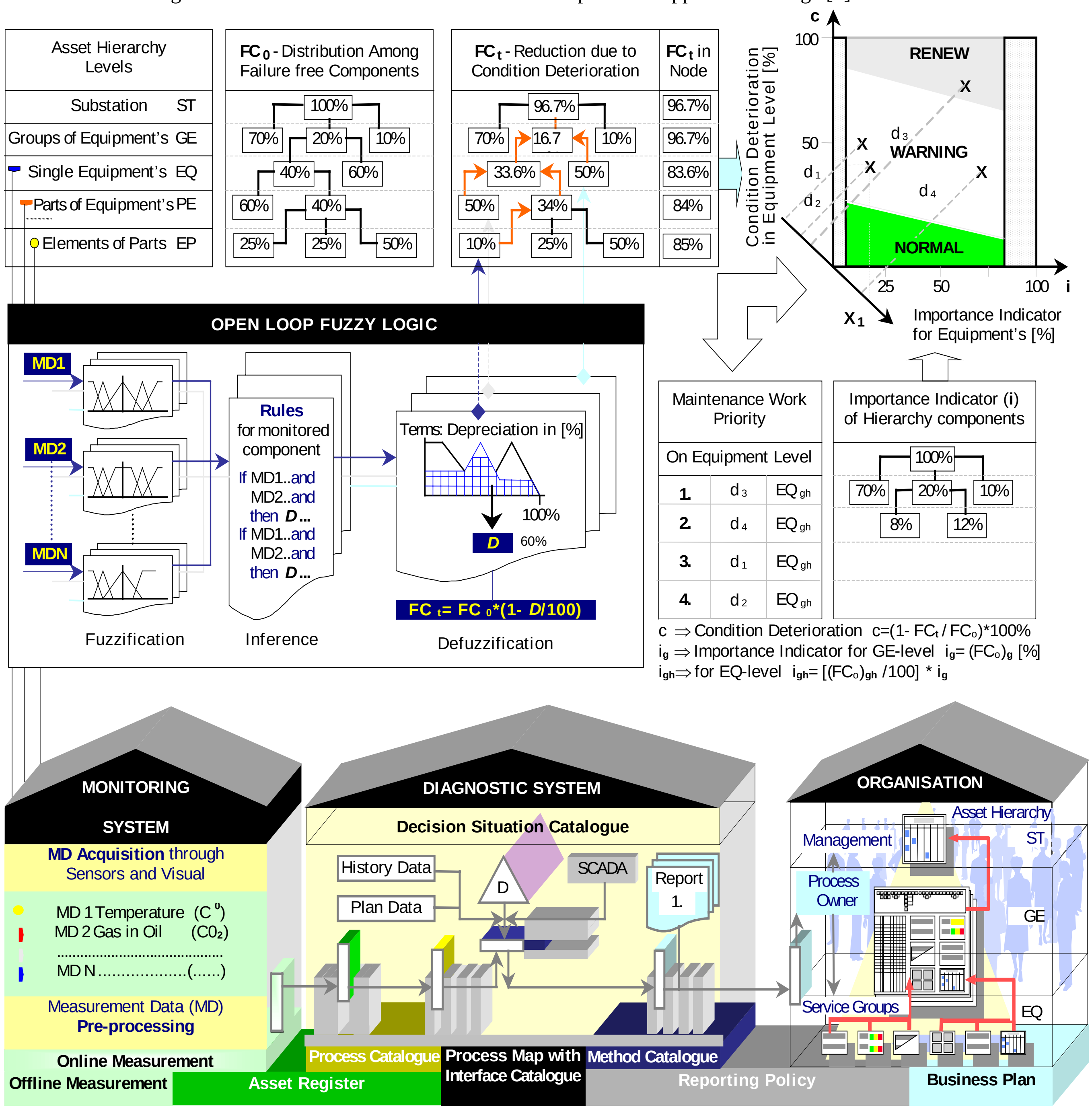

Fig. 5. Comprehensive Asset Management Model in process-oriented business environment supported by multilevel diagnostic system and one of its application for online equipment's condition and risk assessment

V. Setting Maintenance Priorities by Limited Budget

The equipment's condition and the importance of its function from system's reliability viewpoint are regarded as the major parameters for setting the maintenance priorities. In addition to the condition deterioration "c", serving as condition estimator, also the importance indicator "i" will be calculated on monetary value basis. The linear combination of both "c" and "i" results in the risk estimator quantified through the respective vector distance for EQ_{gh} (d_1, d_2....d_n) as shown in Fig. 5. The higher the actual risk the higher priority should be assigned to the respective equipment in maintenance schedule, in order to eliminate the most dangerous risk potential at first. Whether the prevailing risk should be reduced or not is up to the decision maker setting the threshold for it.

Quantifying the importance indicator is a significant task of model customization. In general this indicator has a time varying character. Its value can change from one plan period to another and depends on a lot of variables like the net topology [6], load dispatch [7], disposal of reserve, weather conditions etc. Since the extend of this paper doesn't allow to consider all variables having impact on the equipment's importance, the most frequent case will be demonstrated below. That means that the EQ's load, assumed to be continuous, corresponding with the nominal design parameters and the energy supply won't be interrupted in case of repair but will be provided through switch over to another source. It is the most realistic situation according to the well known n-1 principle.

In the described example the importance ranking among EQ-s has been carried out on the basis of the relevant FC_0's (*computed on purchase's price basis*) for EQ's level (see Fig. 5, importance "i"). The applied logic "the more use the higher importance" underlying the importance's indicator calculation follows the principle in TCM described in section 3. The approach above provides a satisfying but not exact result by setting priorities for maintenance scheduling in general situation. The reason for the inaccuracy is the unchanged calculation basis for FC_0's, (*had been used as initial state's parameters for condition assessment as well as, see section 4.*) while the assessment's objective has been changed from functionality (*the capacity to work*) to availability. But on what basis can the more precise FC_0 for "i" be computed and in which situations do we have to consider it necessary? In order to answer the question above one should apply the TCM again. The cost of the function represented through the respective EQ consists of the procurement's and Installation's Cost (IC) making up together the Investment for the EQ (IEQ). The most significant cost driver for IC is the time having crucial impact on availability and therefore on loss in revenue due to possible power supply break down. The more IC (*it is proportional to the restoration time*) the less the availability and this increases the importance of the respective EQ. Consequently, for FC_0 definition of EQ's from availability point of view, (*versus functionality by condition assessment*) not just the purchase price, (*characterizing the contribution to the functionality*) but the entire investment's cost should be regarded as relevant. Its share in total investment of the corresponding group of equipments will show the relative importance of it in comparison to another EQ-s. Taking into consideration the mentioned correction is especially important if equivalent EQ-s on different places with profound dissimilar circumstances (*geographical, climate, tariffs etc.*) are subject to the prioritizing. Through proper mathematical manipulation of the basis for "i" all significant constraints (*derived from the current decision situation*) can be embedded in this indicator that enhances the applicability of the basic structure presented in Fig 5 and chapter 6.

VI. Algorithm of Condition Evaluation

According to substation's hierarchy pointed out in section 4 the asset is decomposed and classified on 5 levels as follows: substation (ST), group of equipment (GE), equipment (EQ), parts of equipment (PE) and elements of part (EP). The interconnection between them has been described in matrix form, which indicates the aggregation's network of function's contributions in the selected asset portfolio:

$$ST \; =[GE_1, GE_2,..., GE_g,..., GE_k] \quad (2)$$
$$GE_g \; =[EQ_{g1}, EQ_{g2},..., EQ_{gh},..., EQ_{gl}] \quad (3)$$
$$EQ_{gh} =[PE_{gh1}, PE_{gh2},..., PE_{ghi},..., PE_{ghm}] \quad (4)$$
$$PE_{ghi} =[EP_{ghi1}, EP_{ghi2},..., EP_{ghij},..., EP_{ghmn}] \quad (5)$$

where: k, l, m and n are the maximum number of system components belonging to one node of higher hierarchic level in the tree structure.

The prices of components on the lowest hierarchy level are the initial input parameters (s. Fig. 6). Their aggregation can be carried out using the algorithm on Fig. 7. The FC_0's (*which are equal to the respective price share*) are depicted in Fig. 8.

The fact that the sum of FC's of selected components in every node of the "network" is taken for 100% in failure free state results in a simple procedure calculating the matrices for FC_0, FC_t and "c" respectively. They are shown in Fig. 8 to Fig. 10. For the equations underlying the computation of related matrix's elements see Fig 5.

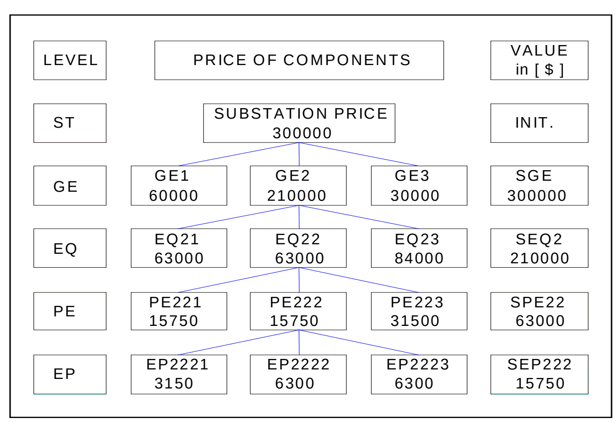

Fig. 6. Price of components in the hierarchy calculated from manufacturing cost

On Fig. 9 and Fig. 10 those components are marked with grey which have been degraded due to failure detected by monitoring system.

The visualization of the indicators is the final and very important stage of the evaluation because the interpretation depends on it to a large degree. To use the polar coordinate system for this reason is advisable. Fig. 11 shows the trend of condition deterioration of EQ22 where the current state reveals the warning status. The current depreciation of the equipment makes up about 11 529 $ in December.

The analysis of possible interplay effects between EQ-s charged with failure is beyond the scope of this paper, but it has to be mentioned to keep the phenomena in perspective and remind the asset manager of including it as a third dimension for risk estimation calculation (see Fig. 5 and section 5). It means to assess the expected depreciation increment of EQ_{gh} due to impact of malfunction of other EQ-s.

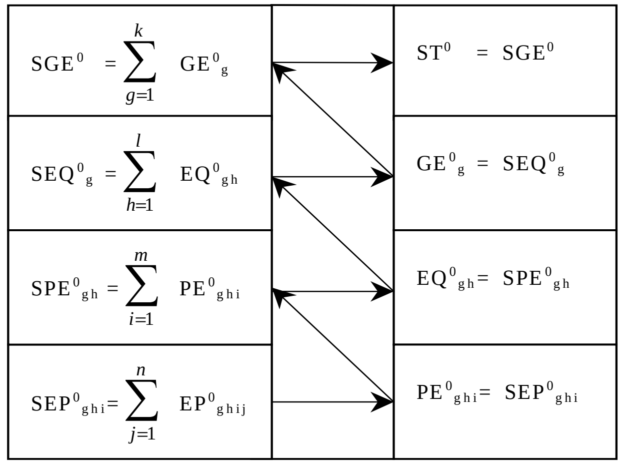

Fig. 7. Basic algorithm underlying to price data aggregation throughout the hierarchy

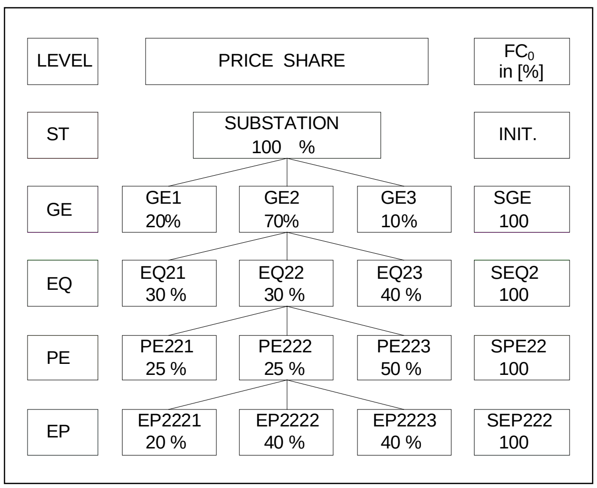

Fig. 8. Price share of components in relevant superior one representing their function's contribution

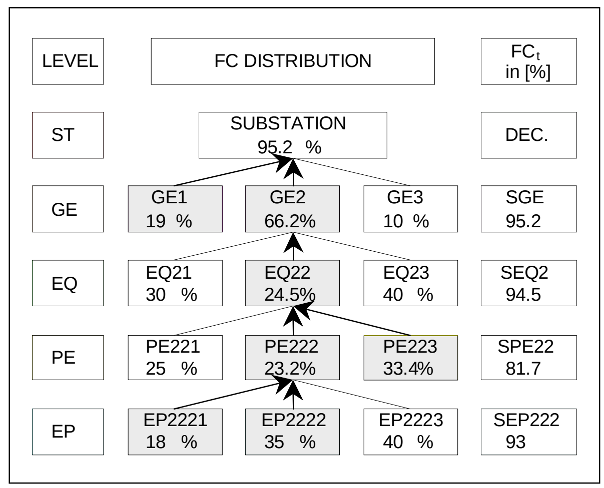

Fig. 9. Function's contribution change due to component deterioration got from OLFC

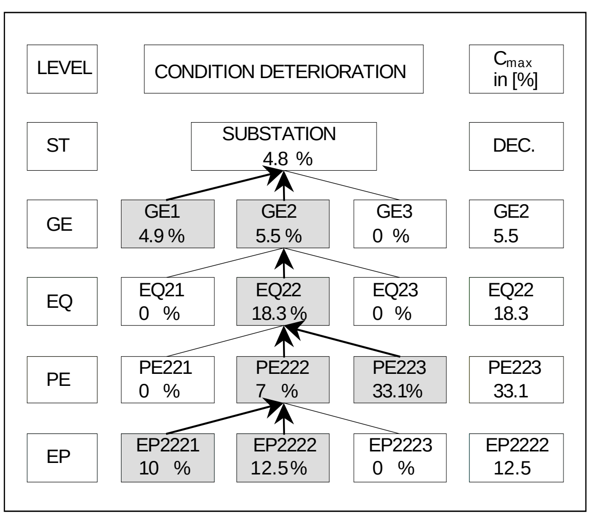

Fig. 10. Condition drop down on station's level and it's top down Root & Cause Analysis

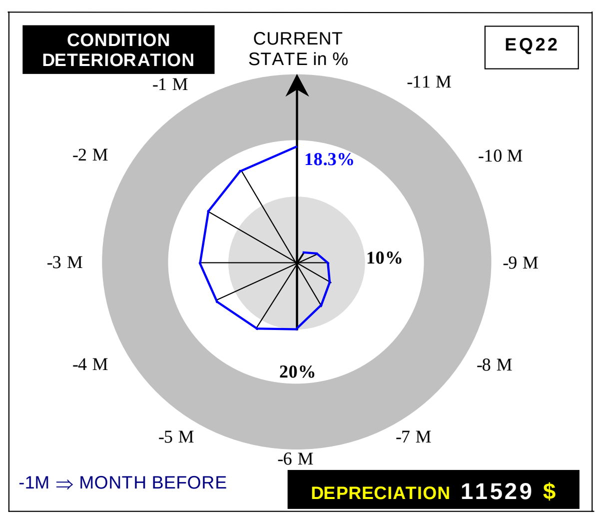

Fig. 11. Visualization of historical condition data for critical plant EQ22 in monthly resolution

VII. Developing Fuzzy Rules

The example in Fig. 12 demonstrates the OLFC for transformation of insulation's oil test data into value Depreciation (D). The expected Maintenance Budget (MB_{iE}) on PE- level can be calculated through Probability (P_{ghij}) of related component's breakdown and its Total Repair or replacement Cost (RC_{jT}) according to (6). The exact functional relation between D and P_{ghij} is not known. However, it might be assumed that the direct positive correlation ($D=P_{ghij}$) describes the mentioned relationship with acceptable accuracy in warning status. The hypothesis above, which is always subject to individual component-oriented fine tuning has been applied in (6) below.

$$MB_{iE} = \sum_{j=1}^{n} RC_{jE} \quad \text{where} \Rightarrow \quad RC_{jE} = P_{ghij} \cdot RC_{jT} \qquad (6)$$

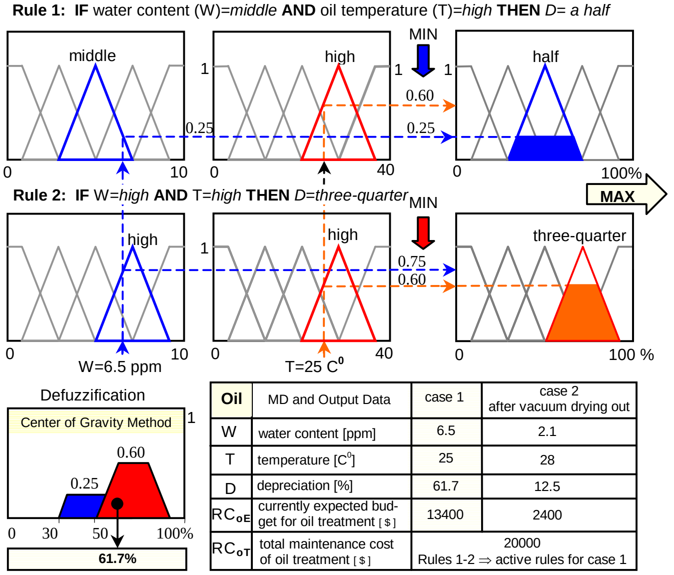

Fig. 12. Fuzzy Logic based interpretation of condition data demonstrating the "bridge" function of AMS between physical and financial asset

VIII. Conclusion

The proposed asset management model incorporates all relevant aspects of dynamic management with special regard to continuous risk assessment. It takes into account the prevailing expert knowledge in a systematic way. Despite the inaccuracy of single assessments, the results obtained with this approach renders reliable information about the current asset's condition. Using the suggested asset hierarchy the acceptable information credibility can be attained due to cause-impact based aggregation of numerous online and offline parameters having impact on the equipment's condition.

The strong points of the concept are that the overall substation condition can be characterized with a single indicator and that through using an importance index for all equipments the current hazard risk from system point of view is always in focus by decision making. Further advantage of this comprehensive approach is that the functional and logical dependencies manifested in the hierarchy and fuzzy rules provide a high transparency all over the asset data and so a solid communication fundament within the entire organization.

IX. Acknowledgement

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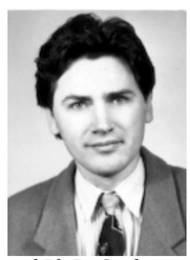
XI. Biographies



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Kurt Feser was born in Garmisch-Partenkirchen, Germany, in 1938. He studied Electrical Engineering at the Technical University of Munich and received his Dip.-Ing. and Dr.-Ing. degree from the University of Munich in 1963 and 1970 respectively. In 1971 he joined Haefely & Cie AG, Basel, Switzerland as a chief development engineer. From 1980 he was as director and member of the executive board of Haefely responsible for capacitors and high voltage test equipment. In April 1982 he joined the University of Stuttgart as head of the Power Transmission and High Voltage Institute.

Prof. Feser is a fellow of IEEE, member of VDE and CIGRE, chairman of IEC TC 42 "High voltage test technique" and author of more than 200 papers.