Asset Management Based on Improved Online Monitoring Systems Applied to a 110/380 kV Substation

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***Abstract*—In the context of cost saving pressure at electric utilities the requirements on information's quality about physical asset are increasing. This paper presents an online monitoring system and the paradigm of their integration in a comprehensive Asset Management System. It will be described a system of presently installed monitoring units, which provide input data for the hierarchic diagnostic system in order to work out demand oriented informations for different kind of business processes. The main emphasis has been put on the communication of the necessity of integration. Keeping in mind the immense saving potential regarding the asset management processes, the ongoing project intends to combine all available relevant data and convert them into valuable information for decision making.**

***Index Terms*— Acoustic partial discharge (PD), Asset-Management, Electric PD, Hot-spot temperature, Management decision-making, Power system online monitoring, Transfer function**

I. Introduction

In order to gain competitive advantage on the liberalized energy market, utilities are engaging in the introduction of Asset Management Systems (AMS) integrating several kind of monitoring units designed for different electrical equipments (EQ) (transformer, circuit breaker, arresters etc.). Today the mentioned units are operating autarchic and the processing of their output data is carried out mainly regardless of optimization criteria of other business processes. As a result of the practice mentioned above the expenses are high, the net income sub-optimal and the maximum return on asset cannot be realized.

In [1] has been proposed a comprehensive AMS able to provide information required for optimization of cross-functional core business processes (online, offline) and so to avoid the shortage of the presently used, not integrated information systems.

Based on the theoretical fundament described in [1], this contribution demonstrates a test set up partially has already been installed in a 110/380 kV substation in Großgartach, Germany. The monitoring units, their input-output data are visualized in Fig. 2, where also the major steps of equipment condition evaluation can be tracked down. The procedure consists of the following phases:

1. Collecting the relevant outputs of monitoring systems (MS) characterizing the related equipment component and set up its state vector
2. Fuzzification of the elements of state vectors
3. Compute the depreciation (D) of the components (C)
4. Aggregation of D of all C as proposed in [1]
5. Plotting the trend of condition development for EQs

II. Monitoring systems

A. Thermal monitoring

The lifetime of safety operation of a transformer depends on the life span of its insulation system considerably. Since the ageing of the paper insulation is determined in a great extend by the thermal stress it is very important to know the current maximal insulation temperature, i.e. the hot-spot temperature, during the transformer operation. To avoid irreversible damage as well as the premature long-term degradation of the paper insulation system, that means the hot-spot temperature must not exceed the prescribed value [2].

With this part of the monitoring system the thermal state of the whole transformer can be monitored continuously.

As input data for the thermal monitoring altogether twenty oil and air temperatures on the transformer side and on the four heat exchanger units, the tap changer position, the primary and secondary load currents, the operation conditions of the fans and the oil pumps are measured continuously. The measured date are stored every one minute. From the monitored data the implemented thermal model calculates the current hot spot temperature [2].

From the switching status of the cooling system as well as the measured air and oil temperature differences, the operating condition of each heat exchanger unit is supervised.

In addition to the above described system a "Hydran 201 R" sensor is installed to detect the dissolved gas in oil.

Both for the transformer and for the individual heat exchanger units the measured data and the computed values can be visualised. The measured data are archived into monthly files.

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B. Partial Discharge (PD) Monitoring System

The currently installed PD monitoring system consists of a 8-channel digitizing unit split up in 4-channel electric and 4-channel acoustic PD measurement systems which both provide a short response time in tracing PD activity. Parallel usage of the methods makes an easy task of plausibility tests involving DGA as well.

The above mentioned electric PD measurement system uses ferrit cores mounted on the measuring tap of the bushings and in the neutral of the transformer to decouple PD signals. As main disturbances on site narrowband noises of radio stations, impulses of power electronics and corona pulses could be named. Nonetheless the achievable sensitivity working with digital FIR filters and a two branch "digital bridge" is about 700pC [3].

Mounted on the transformer housing piezoelectric sensors are capable to receive acoustic PD impulses from inside. On site disturbances of the acoustic PD measurement are mainly of mechanical manner and do not differ much from laboratory environment where already an increased sensitivity compared to electric PD measurements appeared [4]. A PD detection ("PD yes/no") can be managed by one sensor whereas a quantitative information of the matching apparent charge needs a rather exact localization of the PD origin (hence signals recorded on more sensors). Various signatures of disturbances and PD signals can be distinguished clearly by patterns of short-time-fourier-transform [5].

C. Transfer Function (TF)

For early detection of mechanical winding displacement the TF-method is an advanced approach [6]. As a result of the current research work the online application of it enhances the practical relevance of online MSs as a whole, because in line of another online parameters the plausibility of the equipment oriented final condition diagnosis -despite of the inaccuracy of single ones- will be significantly improved.

There are three well-known experimental ways of obtaining transfer functions for comparative diagnostic usage: Time-based, construction-based and type-based. The most often used and the most accurate one is the time-based comparison which uses test finger print data from former times as a reference or compares the respective TFs of a given transformer in relation to the symmetry properties of the transformer design.

Depending on individual test set-up, the parameters for dissimilarity of TFs should be defined, where the peak value and resonance frequency of them can be considered as significant for distinction's indicator building (see Fig. 2 "TF"). The fluctuation of the mentioned index in time domain can be the subject a trend analysis. In state vector definition (see Fig. 2) according to the mechanical state assessment of the coil and core assemblies also the TF should be involved .

D. On-Load Tap-Changer Monitoring

Mentioned transformer is equipped with the OLTC monitoring system TM 100 R manufactured by Maschinenfabrik Reinhausen, Germany. This system serves controlling, monitoring, and data logging of motor drive and OLTC data.

The system records different data/events: Motor drive torque, temperatures (OLTC compartment oil, transformer oil, ambient), diverter switch current, total amount of switching operations, diverter switch changeover event and tap-changer position. Out of these data and events the systems gets the OLTC condition. With the help of the temperatures the system corrects the torque data. The diverter switch changeover event is needed to cancel the torque signal temporal shifts. The diverter switch current and the total amount of switching operations are used to calculate the diverter contact wear.

The system gives a condition report. There are three possible categories of operation: normal operation, warning, and no operation due to dangerous event has occurred.

E. Additional Monitoring Systems

Additional to the above-mentioned Monitor Systems, there are some more systems from different manufacturers.

An effective way to measure PD in gas insulated switchgear (GIS) is the ultra high frequency (UHF) method. The installed monitoring system is manufactured by SIEMENS, Germany. The result of a measurement is visualized in phase resolved partial discharge (PRPD) diagrams. Measured pulses can be compared with known PRPD-patterns.

The circuit breaker which is monitored here is performed as a SF_6 outdoor circuit breaker and a part of a 110 kV switchgear. The circuit breaker monitoring device (BCM1) is manufactured by SIEMENS / ELCON AB, Sweden. It records many different quantities like the motion of the main contact, temperatures, SF_6 density, motor operation data, etc. The monitoring system compares the listed quantities to manufacturer limits or with previous measurements.

To guarantee a save and efficient operation of wide-spread gapless MO-arresters, its current/voltage characteristic shouldn't change significantly within the whole lifetime of the arrester. Otherwise the leakage current would increase and the resulting larger power loss in the arrester could lead to its thermal destruction [7]. The SIEMENS monitoring system measures directly the temperature of the arrester, by wireless Surface Acoustic Wave (SAW) technology [8].

All systems are connected by TCP/IP or by serial standard interfaces (RS232). All data are available through a central PC regarded as Monitoring System Server (MSS)-Node [9]. Fig. 1 gives an overview about the communication architecture.

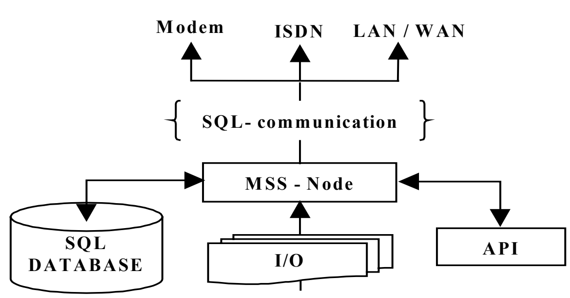

Fig. 1. Architecture of the AMS communication system

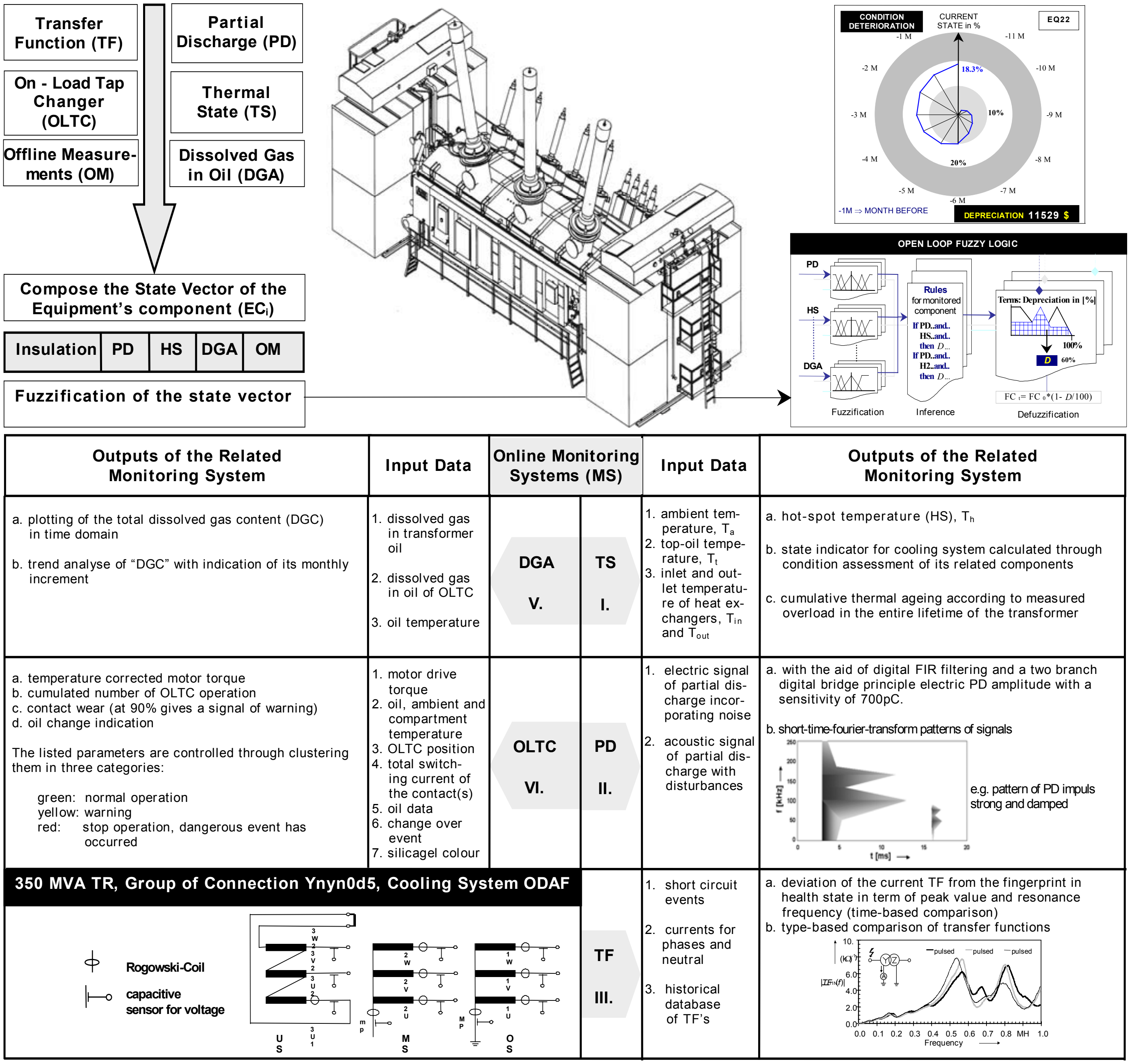

Fig. 2. Overview of online monitoring systems supporting the diagnostic function of the applied Asset Management System

III. Condition Based Risk Assessment

Advanced asset management employs predictive modeling and risk management in order to avoid system states possessing a high potential of failure escalation. The number, the current grade of deterioration, the importance and the geographical distribution of damaged units are characterizing the mentioned escalation potential which in turn influenced by functional interdependencies between those units. The first step on the way to set up scenarios of maintenance programs is to provide transparency about the above listed factors. The second one is to search for the worst case and then to assess the consequences of the current condition in monetary value. Supposed, the worst case will be a planed outage and it will not cause loss in energy supply, the consequence of equipment deterioration can be measured through its expected repair costs. This must be paid if the expectation comes truth. As a result the AMS has to posses an application module making possible to set up repair scenarios and calculate the probability of their occurrence on the base of the current equipment condition. No doubt, the exact calculation of the "next step", the expected probability *-if doing nothing-* will have a certain imprecision. Despite of that, both the enhanced online communication between core processes through AMS and the increased transparency will lead to a much better process performance in the whole concern. Especially the accuracy of the budget planing will benefit from this kind of risk assessment (for more detail on this chapter apply to [1]).

IV. Visualization in the AMS

Asset Management is an executive driven strategy. The goal of this strategy is to take decisions on the revenue producing assets (physical, financial, human) to maximize the profitability of the company. The extension of the lifetime of every single equipment cannot be regarded as an essential maximization criteria for the above cited overall objective function.

The life cycles of the physical assets have to be influenced trough appropriate maintenance program according to the decision situations emerging due to the changing requirements of various nature (network changes, load increase, regulatory etc.). It can happen that the removal of one or more equipment even before their end of life leads to long term efficient optimum. As a result the system consideration *-e.g. remaining lifetime portfolio over the entire assets or in selected equipment groups-* is a fundamental, unavoidable approach by setting up the optimal maintenance program.

The above mentioned circumstances have to be considered in the manner of information visualization in the AMS. It means that the visualization software should account for the necessary system approach. The prerequisites for that have already been considered by the hierarchy building of the AMS for the test substation [1].

A. Visualization through Visu Browser

The visualization serves as a link between remote monitoring objects and the local users. With the Visu Browser implemented as graphical user interface for the Microsoft operating systems, *-Windows 95, Windows 98, Windows ME, Windows NT and Windows 2000-* the user has the possibility to sight and to evaluate the data made available by the Monitoring System Server for further processing locally.

The system applies the separate described communication ways. However, it should be mentioned that a direct serial connection or a connection via modem or ISDN and the general access over TCP/IP respectively are possible ways to acquire data from MSS (see in Fig. 1). The requests to the distant system consist always in transparent SQL scripts, different from the internet.

All data which is necessary for local operation can be extracted from the MSS-Server. These data are stored locally and they are available for further use. This saves time particularly by repeated accesses on the same server.

The configuration data is stored in text files in the ASCII format. Local insertion of data with the usual editors is ensured thereby.

B. Online-offline representation

In principle they are two different data displaying types:

1. Online
   - Representation of the current measured data in diagrams etc.
   - Display condition and risk indicators on different level of the assets hierarchy (under construction)
   - The display feature configurable in appearance and in number of Tab-sites.
2. Offline
   - Access to arbitrary historical data
   - Evaluation -Tab-page(s)
   - Configuration-Tab-page

The Fig. 3-6 show some drafts of screen layouts designed by our cooperation partner Hesotech Ltd. They enhance the transparency and applicability of decision relevant informations by means of object -oriented structuring and evaluation of them.

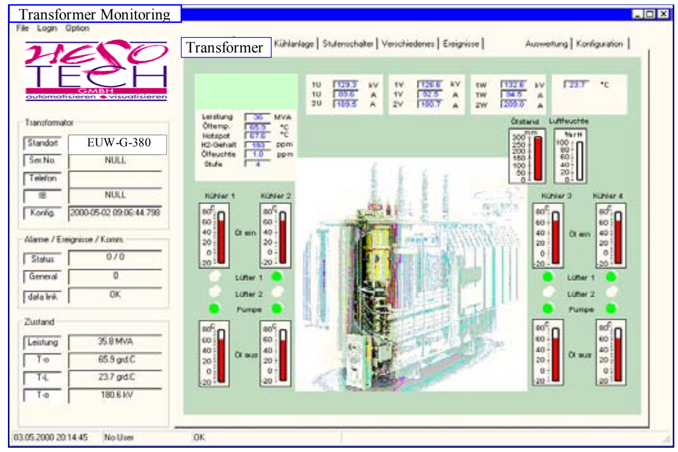

Fig. 3. Start site of transformer assessment displaying general data and status informations online

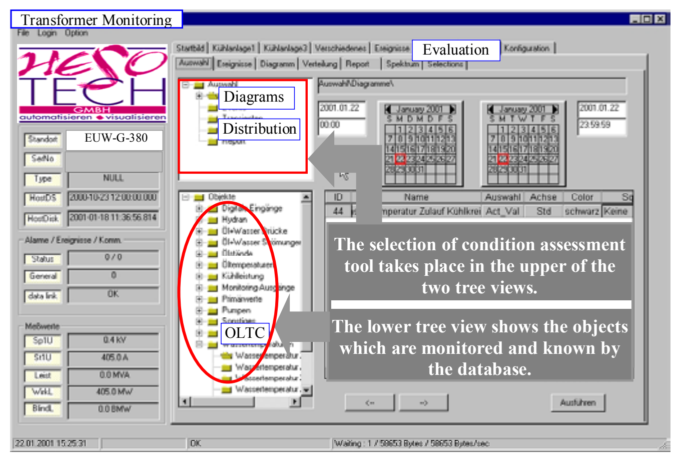

Fig. 4. The selection page for condition assessment of equipment components

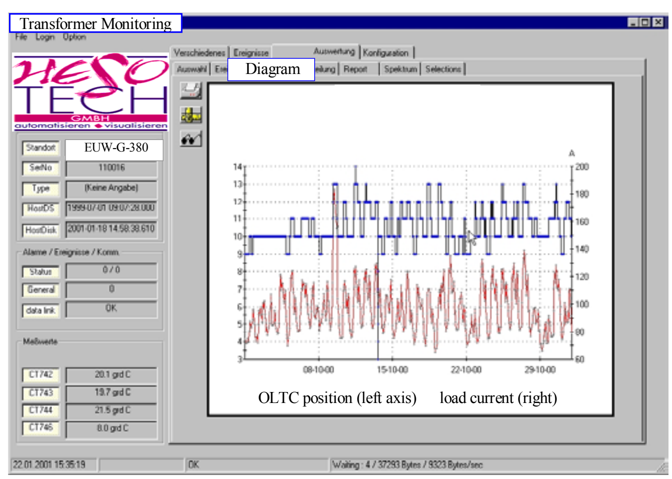

Fig. 5. Load current offline diagram synchronized with OLTC position according to evaluation option as diagram

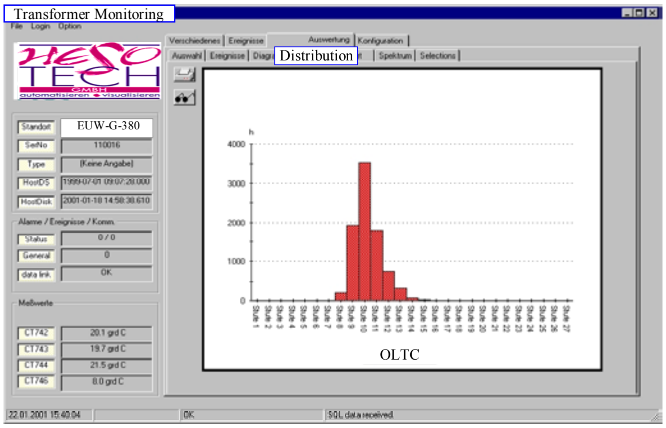

Fig. 6. Histogram of total operation time in different positions of the OLTC according to evaluation option as distribution

V. Conclusion

The described model, integrating several monitoring units, demonstrates a practical implementation of efficient Asset management in a real system. Through cause-impact based assignment of online and offline monitoring data to the related equipment's component the hierarchic evaluation of the system condition enhances the quality of assets information which makes shorter the process cycle time and consequently decreases the process costs on different organization's levels. It leads to significant cost saving along the entire supply chain, which makes the utilities more competitive in the energy market. Due to the proposed AMS the performance gap between traditional maintenance strategy and comprehensive asset management can be closed. The long term, consequent application of AMS leads to substantial gain in company profitability.

Thanks to the modular architecture of hardware and object-oriented philosophy of the application's softwares, the object-oriented knowledge representation will cause a sustainable know-how transfer in the organization, which eliminates the lost of expert knowledge caused due to staff turnover nowadays.

The biggest yield can be achieved by means of deployment of modern internet technology within the presented paradigm. The remote access of evaluated condition data through internet online is also a powerful control instrument for the top management and a useful tool for getting quality information timely on process level. The higher the management level the bigger the benefit can be achieved using the proposed AMS. The reason for that is the decreasing inaccuracy of aggregated condition data, due to the error compensating character of the aggregation operation carried out by AMS, while getting higher in the system hierarchy.

VI. Acknowledgement

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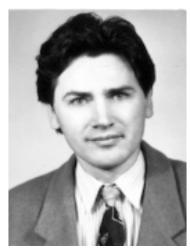
VIII. Biographies



Jozsef Osztermayer was born in Paks, Hungary, in 1962. He received a M.Sc. degree in Electrical Engineering from the Technical University of St. Petersburg, Russia, in 1987. Afterwards he joined PA. Rt., nuclear power plant in Hungary, where he worked for three years as a diagnostic engineer and after obtaining his degree in Economics he changed to controlling area. Currently, he is a research engineer at the Institute of Power Transmission and High Voltage Technology, University of Stuttgart and Ph.D. Student at the Department of Industrial Management and Business Economics, Budapest University of Technology and Economics. His areas of research interest are strategic management with special regard to asset, risk and maintenance management respectively.

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.

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