Fundamental Aspects of Data Quality for HV Asset Condition Assessment

WG D1.17, HV Asset Condition Assessment Tools, Data Quality - Expert Systems

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Abstract:

High voltage components like cables, transformers and switchgear play an important role in the transmission and distribution of the electric energy to the utility's customers. Nowadays, asset management heavily relies on the use of information and data to facilitate the asset management decision process. As a result, the decisions should be based on information from various sources, from within the organization of the utility as well as from its environment, and involve a large amount of different information aspects.

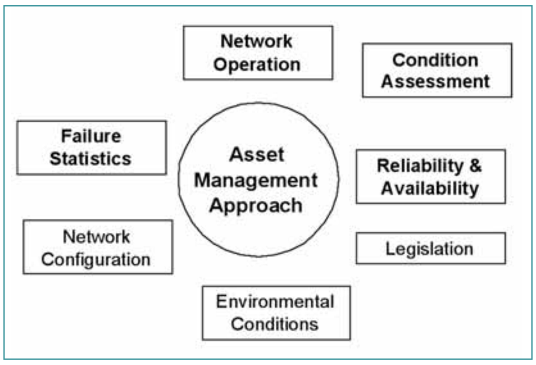

Fig. 1: Different aspects concerning considered life time decision support for HV infrastructures.

The major aspect for a considered maintenance program is based on the type of the used components and their present insulation status. To monitor the aging or condition of an asset or its particular components, suitable diagnostics are necessary. Based on the activities of the Cigré WG D1.17 *HV Asset Condition Assessment Tools, Data Quality - Expert Systems* this paper contributes to the discussion on utility maintenance processes and necessary data structure to describe the condition records of HV assets.

Index Terms:

Network components, condition assessment, decision support, data formats, data structures, decision support, asset management

Introduction

Transmission and distribution components in the power network are capital-intensive assets, which force the owners of these assets to utilise them in the most efficient way. Efficient utilisation demands a thorough analysis of the relation between the assets performance and the stakeholders' expectations.

Electrical power utilities can choose various methods to obtain information about technical condition of their assets, e.g. inspections, diagnostic measurements.

In order to contribute to this subject in 2003 the Cigré WG D1.17 has been established and distribute the activities in two Task Forces:

TF 01: *Condition Assessment for Maintenance Decision Support,*

TF 02: *Data Structure for Asset Condition Information.*

This contribution describes what factors and data are of importance in assessing the performance level of an asset [1-3]. In particular, various aspects will be discussed in the following:

1) fundamental aspects of the asset management decision process, and the information sources necessary for this decision process. Moreover, the application of structured approaches is shown in implementing the diagnostic information in the assessment of the technical condition of the assets.

2) data organisation aspects of formatting relevant information to enable comparative decision making between asset groups are discussed.

Condition assessment for maintenance decision support

For a successful AM decision process it is necessary to translate the necessary information aspects from usable data sources. Different data types influence the identification/separation, type and complexity of data sources and the decision systems they support. Figure 1 shows a diagram-based overview, concerning the different aspects of a life time decision support for HV infrastructures and the most important will be discussed below.

Due to the numerous types of different components as installed in the network it is impossible to implement condition assessments for the whole population at once. In order to select those components which benefits from condition assessments, it is necessary to apply different selection criteria. The criteria as described in this chapter support the selection from a system point of view.

Failure statistics: As no high voltage component has an endless lifetime, every component will show certain failure behaviour (figure 2-4). Dependent on the type of components, the failure behaviour can be different. The main goal of applying maintenance is to prevent these failures. However, if certain components show an increasing number of failures, the maintenance program should be adjusted and be more pinpointed on these failing components. Hence, it is frequently necessary to combine a large amount of practice and failure data, and deliberate over the results in the maintenance program. In particular, the failure information of a particular network has to be verified on a large population as available e.g. in database of decision support systems, see figure 3.

Failure rates in the network are an important indication for selection of an asset for condition assessment. These failure rates can be analysed on different levels:

Network system level: Failure patterns on the network system level gives information about failures which are typical for specific areas or groups of components (figure 2). For example an increased amount of failures of cables in a certain area with a high level of ground water can be the reason to focus on condition assessments in this specific area. Failure patterns on system level can also give information about the relation between failures and component groups that are responsible for these failures like transformers, switchgear or cables.

Asset system level: If a specific asset system e.g. a cable network shows an increasing number of failures in a specific time span, this is a criterion to perform assessments to this specific cable system (figure 3). This increasing number of failures can be related to the overall ageing of the cable system or as a result of specific deterioration in one of its sub-components.

Component level: Failure patterns on component level are more related to component types like joints, terminations, cable parts etc. Dependent on the type of components or even manufacturer or year of construction, the deterioration behaviour can be different (figure 4). If certain component types show an increasing number of failures, the condition assessments can be focused on these frequently failed components.

A combination of the above described selection levels will result in the best selection of the asset systems which are apposite for condition assessment. ● ● ●

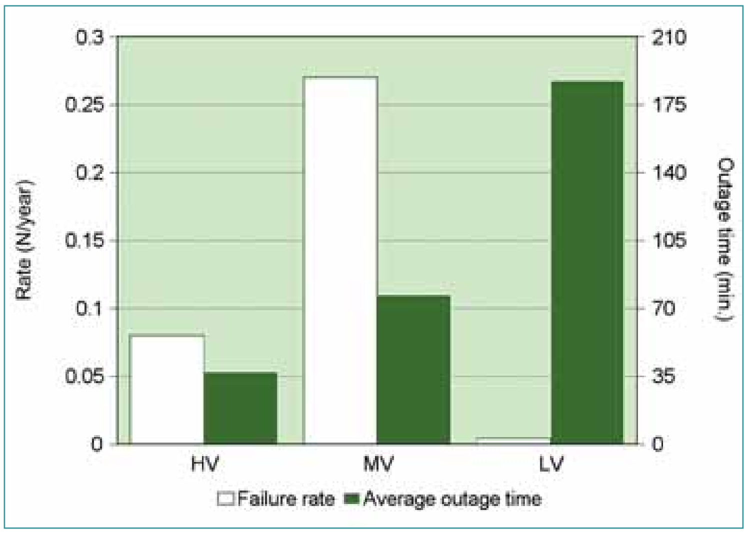

Fig. 2: Example of the failure rate and the average outage time per interruption electricity as result of failures in the network. The reflected numbers are averages for the ten years [4].

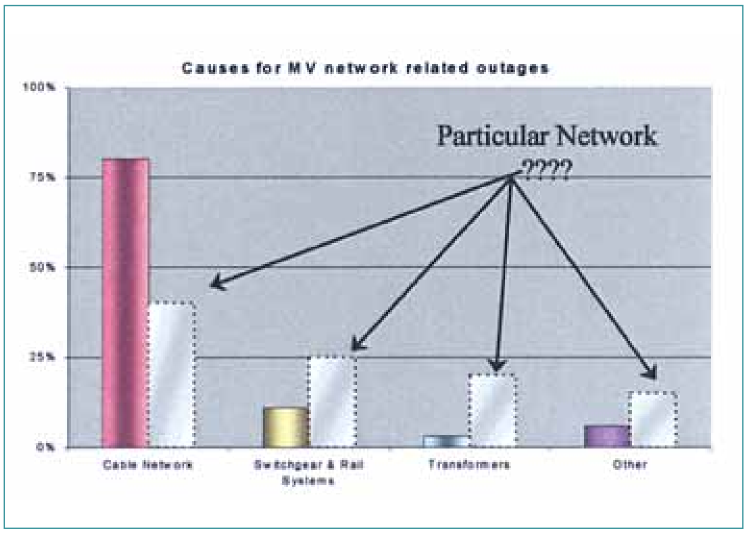

Fig. 3: Outages related to the MV network, divided into four categories. Failure analyze of a particular network can be analyzed with respect to a larger population as available through knowledge sharing.

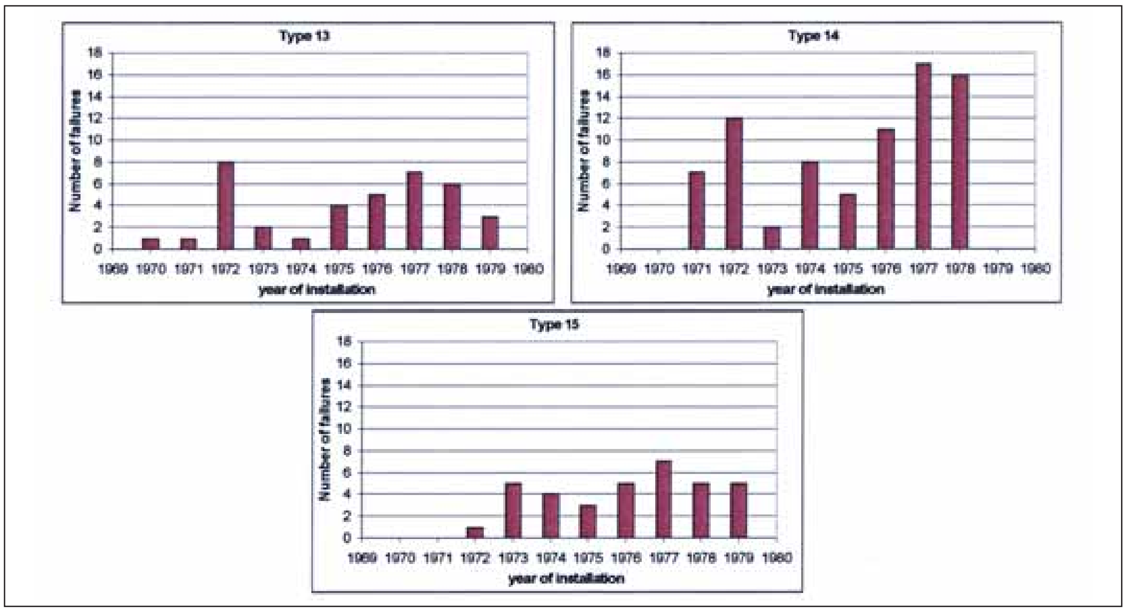

Fig. 4: Example of failure analysis for three different types of the same asset (epoxy filled cable joint) as observed in a certain period of time in function of the installation year.

Network Operation: During the service life of HV components the network operation will result in changing profiles of electrical, thermal and mechanical stresses. It follows from figures 5 that load changes as present in the network during day/night, working day/weekend may influence the diagnostic parameters as observed using on-line monitoring techniques. In particular, a number of information elements are of importance to evaluate the service life reduction:

(a) the history and the future of annual load,
(b) the maintenance aspect, such as poor workmanship and digging activities,
(c) temporary or transient over-stresses, such as short-circuit history and over-voltage distribution function.

Due to the fact that there is direct relationship between the insulation degradation and the thermal load, the availability of this knowledge may influence the estimation of the service life reduction of HV components. In particular, in case of power cables changes in thermal load may influence the axial and radial expansion and may result finally in additional degradation effects, e.g. local field enhancements, gas formation or treeing.

Condition assessments of HV components are nowadays fully integrated in maintenance programs and asset management decision processes. The crucial role of the outcomes of condition assessments within utilities responsibilities caused an increasing interest for the quality of the diagnostic tools and the results (Table 1). For example power cable systems can be seen as compositions of different types of components like joints, cable parts and terminations. Considering the failure patterns of cable systems this means that each component can have its individual failure pattern. E.g. power cable systems are distributed components with an unpredictable change of configuration during lifetime.

This means that in case of a failure at any location along the length of the cable, the resulting breakdown will only cause local damages in the cable insulation or in one of the accessories. Condition assessments of e.g. power cable systems do not only deal with the failure patterns but also with these changing configurations as well.

Relevant information needed for AM decision support is dependent on several asset-related parameters, such as the insulation ageing of a component and the probability of an over-voltage across a component, e.g. as a result of switching activities.

Switchgear Diagnostics	Transformer Diagnostics	Cable Diagnostics
PD diagnosis	Tap-changer	PD diagnosis
Contact velocity	Dielectric loss	Dielectric loss
Resistance	Dielectric response	Outer screen test
Motor current and coil	Partial Discharges	DC leakage current
Dielectric losses (oil)	DGA	Dielectric response

Table 1: Example of major HV assets and possible advanced diagnostics to be applied for insulation condition assessment.

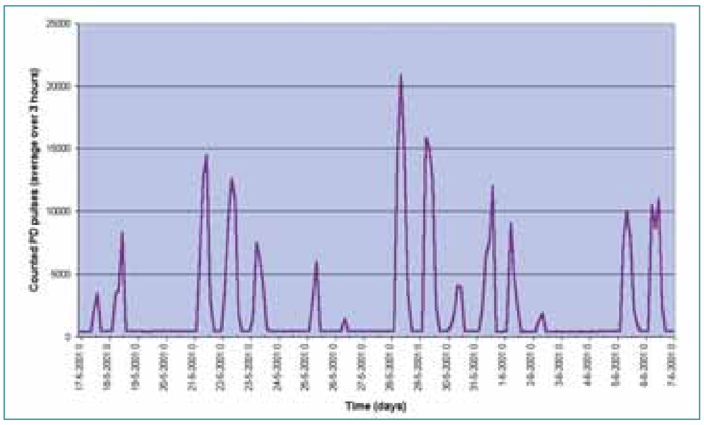

Fig. 5: Load cycles effects on diagnostic electrical parameter (partial discharge) in power cable system as measured on-line during 1 month time.

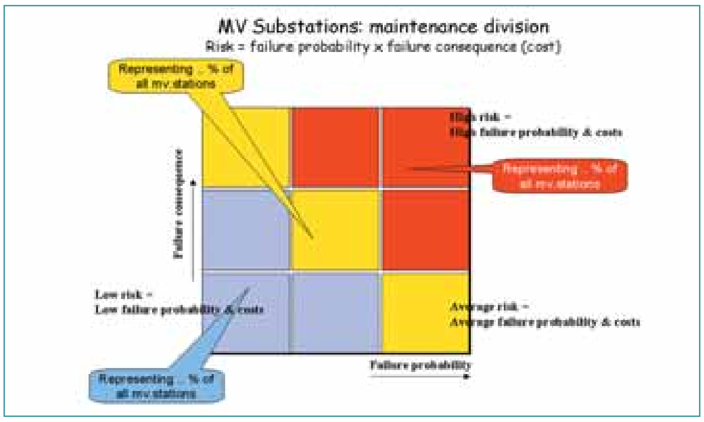

Fig. 6: Practical example of prioritizing the maintenance

The component ageing is related to the absolute age, the type, the history and the operating conditions of a network (sub) component. In order to decrease the probability to a failure, condition assessment can be used. A combination of diagnostic tools for condition assessment has to be chosen and applied, depending on the different types and locations of insulation defects.

The technical aspects cover amongst others condition assessment, aging models, and failure probability, but also information on the equipment inventory, the network topology, the available spare parts, the current maintenance procedures, the history of maintenance actions and the history of failures.

The amount of condition information that is being produced nowadays by various kind of diagnostic techniques gives more detailed insight in the real condition of an asset. Finally, the information as obtained from diagnostic inspections has to be translated into knowledge rules which can support the Asset manager in his maintenance decisions. Therefore, specific guidelines for condition assessments and for making necessary knowledge rules and determining different criteria are needed to interpret the measurement results. To achieve the above mentioned classification it is necessary to index the outcome from the condition inspections (Table 2).

Reliability & Availability; Nowadays, the possibilities of scheduling the maintenance activities become difficult as a result of the increasing 24/7 request of power and the optimized utilization of the power assets. The availability of power assets to maintain becomes more difficult. Large industry plants with continuous processes can often only maintain assets when there is a planned production stop. As a result of the low availability of these assets, the reliability of those assets can deteriorate, with the possibility of outages leading to unexpected production stops. Again, the consideration should be made between the technical aspects and the economical effects of applying maintenance.

E.g. in the case of power cable network the expected reliability and availability is strongly dependent on the acceptable risks, see figure 6 [5]. Finding a com- • • •

Table 2: Relation between technical conditions, condition based maintenance index and required actions.

Condition status	Condition index	Service life status	Age index	Required action
No defects or aging symptoms observed	9	New or aged	1 or 2	No extra attention required e.g. next inspection in 5..10 years
Certain degree of insulation degradation observed; not harmful defects present	6	Strongly aged	3	Extra attention is needed e.g. inspection within 1 year
Significant insulation degradation observed and serious defects are present	1	Nearby end of lifetime	4	Maintenance is necessary; e.g. repair or replacement

ponent with a low performance in vital situations will necessitate an action that will improve the performance dramatically. At the other hand, finding a component with a very high performance in a non-critical situation from the risk consequence point of view will give possibilities to decrease maintenance activities of redundancy strongly.

Practice based on a method to estimate the financial consequences of a failure given by:

- number of connections involved, e.g. < 200, 200-800 or > 800,
- customer type, e.g. small industry, large industry, household,
- expected power supply interruption, e.g. 2hrs, 2hr-4hrs, > 4hrs, and
- the failure probability given by asset construction, e.g. number of accessories, diameter, length, number of short-circuits, e.g., 0, 1, 2 or more,
- insulation condition, e.g., good, moderate or bad, operational load, e.g. < 70%, 70%-100% or > 100%.

The financial consequences includes regulator penalties, loss of energy supplied and possible replacement costs, the failure probability is estimated on risk elements like age, environmental conditions and different weight factors of specific type of components. The utility even takes one interesting step further: the total asset group has been divided into three categories: critical, medium and non-critical, each with their own amount of percentage of the total population (see figure 6). The high-risk group is then submitted to the normal maintenance program, which can consist of inspections or preventive maintenance, while for the other two groups a representative sample is maintained.

Data structure for asset condition information

It is essential for decision-making processes to structure relevant information into a classification and coding system. So the main purposes of the classification and data handling is the provision of a common format to characterize and identify failure types with the help of their features, in order to enable different users to employ the same approach to the storage and retrieval of failure information.

The second purpose is to group the failures into families in order to facilitate the use of failure information for different maintenance applications. Therefore a common data format is needed for: provision of a common data format to characterize, identify and exchange component behaviour through their features, analyzing e.g. grouping, filtering and the data in order to facilitate the use of information for different asset management purposes.

The complete data streaming from the data sourcing to asset management decision is structured in figure 7. It contains Data Sourcing, Data Handling- and Analysis and Data Exchange tools to obtain finally a qualified AM Decision Making system. To enable comparative decision making an information basis and data structure, which allows the assignment of attributes to measurement data, condition data, and operational conditions, is needed.

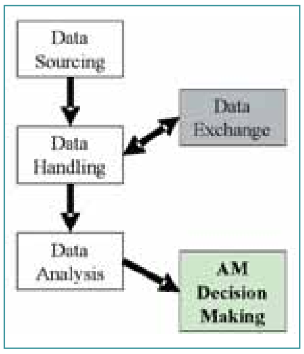

Fig. 7: Necessary data components for a decision making process.

The outcome of a measurement or inspection can be a numerical value, a comment (in the form of a written text) or one of a predefined set of outcomes (such as high, low, medium). Based on this analysis several types of data can be distinguished, which will be discussed in the following.

One dimensional (1D) numerical data are the single number outcomes of a measurement (Table 3).

In the condition assessment of insulating material of all high voltage components two of health indicators that are usually measured are the dielectric losses and capacitance. An example of these two measured parameters in switchgear insulation is given in Table 2. As can be seen from the table *tan delta* and capacitance measured values are single numerical values. To assess the insulation condition by these single values they are compared to a predefined control limit value. These two quantities are one dimensional numerical data (1D) in this specific case.

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1D Norm generation: the aim of sorting the data in groups according to their type is to be able to use appropriate statistical tools (or other tools) for defining norms or control limits.

Inspection data	Switchgear phase	Tan. Delta [10^{-4}]	Cap.] [nF
04-09-00	Red phase	14,5	0,245

Table 3: Diagnostic parameters: Tan δ and capacitance measurement in switchgear insulation

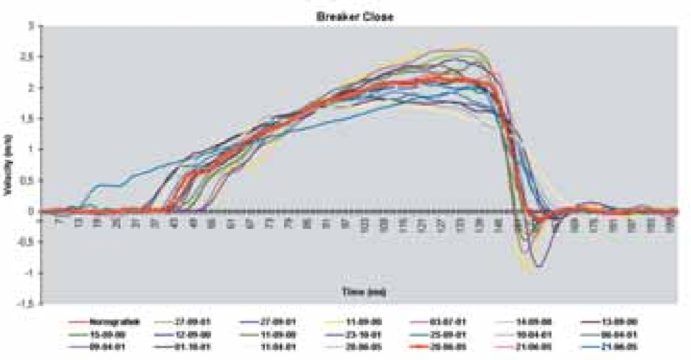

Fig. 8: Example of establishing norm curve on 2D numerical data of velocity measurements of switchgear.

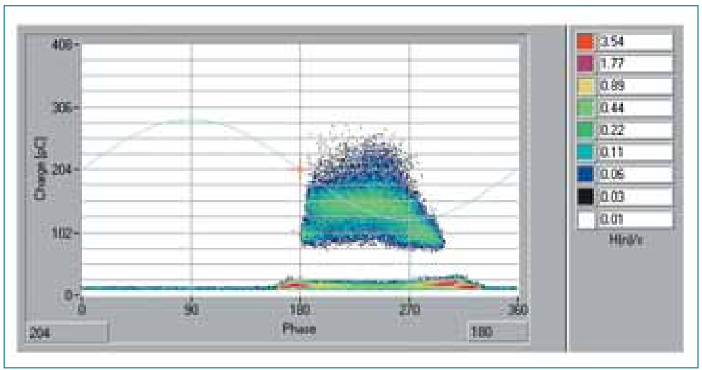

Fig. 9: Example for the 3D presentation of PD events PD pulse magnitude vs. phase-angle, the coloured points are a measure for the pulse number and represent hence the third dimension.

Two dimensional (2D) numerical data are 1D quantities which are measured, plotted or analyzed as function of only one other quantity such as time, voltage, temperature or any other parameter, see figure 8.

2D Norm generation: in the case of 2D numerical data the approaches used for making norms usually converge in two: based on experience as for the one dimensional parameters, limits of acceptance/ rejection can be set, and dependent on the measurement device data appear also in graphical form. In this case a "Norm" curve is determined as average of several ones measured in the same type of component over the time.

Three or four dimensional (3D) numerical data are measured, plotted or analyzed as function of each-other in order to make a condition assessment, see figure 9.

3D Norm generation: In the case of 3D numerical data there are practically no defined approaches for making norms. Based on experience certain defect or pattern can be recognized a by simply studying the graphical shapes, then the decision can be made for further action. One possible approach for making norms in this case is by defining limiting surfaces or it can be based on cluster analysis of PD 3D pattern (figure 10).

Multiple-choice data are verbal quantification of a predefined set of outcomes of a measurement or inspection, e,g, good, bad, dry or wet.

Multiple-choice norm generation: in the case of multiple choice data the same strategies as for 1D numerical can be followed for norm generation.

Text data can be every individual comment made for a specific parameter of the component. It could be for example: "After visual inspection was carried out on the transformer X, oil leakage was detected".

Text data norm generation: To enable statistical analysis standardisation of text items is desirable. This will transform this kind of data into multiple-choice data. Text searches might provide a basis but no examples are known at this moment.

Requirements to data sourcing and handling

To develop valuable and consistent information handling system e.g. data base the industrial data requirements will consider the following concepts and principles:

- objective, so that independent users reach similar results,
- comprehensive, it should contain as much usable and significant information,
- precise and unambiguous, there must be only one place for each item, and that position must be the same for every user of the data and classification system,

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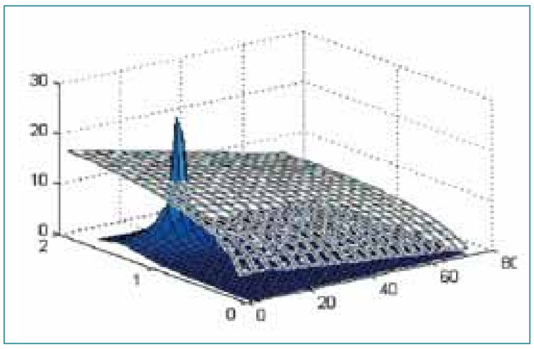

Fig. 10: Example of the limiting surface in the case of three dimensional data. It is a three dimensional plot of PD versus depth and stator slot number in the generator.

– expandable, so that it is applicable to the widest possible range of items, stable, so that the format should be little affected by new data.

Also, reassignment of the items should not be possible unless attributes change within an item, proper sizing, large enough to assure fewer classes than components. The coding should have regular length in order to obtain ease of handling either manually or by software means, proper notation that is simple and no ambiguous to apply, recognize and communicate. Classes and terms used should be familiar to users, homogeneous. Items within a group must be more similar to each other than they are to members of other groups, use only permanent not temporal characteristics of the information, consider the essential needs and requirements of each particular user and evaluation procedure and achieve the best compromise.

For data base analysis of the asset condition data some linkage between the following information has to be obtained, then combined and used to generate knowledge adequate for decision making (Table 4) [3].

Component domain	consisting of specific insulation characteristics of the cable structure; e.g. cable insulation, accessories;
Diagnostic domain	consisting of the type of diagnostics applied; e.g. general condition assessment, assessment of weak spots;
Measuring data domain	defining specific diagnostic quantities used during condition assessment.

Table 4: Database domains of an asset.

Conclusions

The structuring of the data will enable the accumulation of global exchange to assign a condition index according to a proper classification system. This will allow the retrieval of maintenance actions for similar failures, which will aid diagnosis. If different users address their failures, they will all be able to contribute to the creation and growth of a global exchange, which could be used to provide access to component records.

The purpose of further work on this topic is to suggest an information basis and data structure which will allow the assignment of attributes to measurement data, condition data, operational conditions etc. to enable comparative decision making.

Therefore a standardized data structure and condition index to share condition and maintenance records is necessary. This facilitates procedures to analyze technical, economical, social data e.g. input data: condition data, operational data, network data to support the maintenance policy and risk management for AM decisions.

References

[1] D. Kopejtkova, H.P. Ott, H. Rössler, F. Salamanca, J.J. Smit, A. Strnad, Ph. Wester, *Strategy for condition-based maintenance and updating of substations*, 36th Cigré, Paris 1996, paper 23-105.

[2] J. McGrail, , E. Gulski, E. R. S. Groot, D. Allan, D. Birtwhistle, T.R. Blackburn, *Datamining techniques to assess the condition of high voltage electrical plant*, 39th Cigré Paris 2002, paper D1-102

[3] B. Quak, E. Gulski, J.J. Smit, *Datamining and information processing to support the AM decision making process*, ERA Conference on Engineering Asset Management, 5-6 Nov. 2002 London, UK

[4] F.J. Wester, Condition *Assessment of Power Cables using PD Diagnosis at Damped AC Voltages*, ISBN 90-8559-019-1, 2004

[5] E. Gulski, J. J. Smit, B. Quak F. J. Wester, E.R.S. Groot, *Decision Support for Lifetime Management of HV Infrastructures*, Proceedings CEPSI 2004, China.