CONDITION ASSESSMENT OF MV TRANSFORMER SUBSTATIONS TO OPTIMIZE THE INVESTMENT STRATEGY

Carsten Lagemann
RWE Rhein-Ruhr Netservice – Germany
carsten.lagemann@rwe.com

Markus Zdrallek
RWE Rhein-Ruhr Netservice – Germany
markus.zdrallek@rwe.com

ABSTRACT

Most electricity distribution grids in the west of Germany – especially the 110-kV- and Medium-Voltage (MV) grids- have been extended largely between 1960 and 1975. Looking especially at the MV (transformer) substations installed today in the grid operated by RWE Rhein-Ruhr[1] it can be recognized that about 35% of these substations have been installed in this period of time. So taking only the age of the MV substations into account, a lot of investment in replacement of components is required during the next years. Since the replacement budgets are limited, more sophisticated investment strategies have to be adopted, regarding the actual individual condition of each substation rather than only its age. Against this background the paper presents a method to determine the condition of MV substation basically objective and with a minimal effort. A unified check-list has been established and is used in the area of RWE Rhein-Ruhr for two years. In this period of time about 24.000 MV substations have been examined and benchmarked from the conditions point of view. The order of the objective condition determination appoints the budget that is spent in an individual grid area and thus leads to a fair distribution of the limited budget and so to an optimized investment strategy.

INTRODUCTION

The ongoing deregulation of the electricity market has created a new regulatory framework for network operators. While the stated objective is still to safeguard energy supplies, as the regulations continue to make markets increasingly transparent there is a growing need for active measures to be taken and further optimisation to be achieved. A decisive factor in this respect is to make the right investment at the right time. However, competent decisions as to the priority measures and their timing can only be taken on the basis of sound empirical values. The cost-benefit ratio can only be synchronised and optimised if there is a sufficient quantity of comparable information to hand and provided that this is reliable. One of the problems facing operators today is that many of the expert assessments that have to be taken "on the spot" are becoming asset-relevant decisions. Most of these decisions are heuristic in nature and depend on the individual experience that has been acquired by the employee in question. In the case of large network areas requiring a large body of operating staff these decisions are often based on different lines of approach and different sets of assessment parameters.

[1] RWE Rhein-Ruhr is Germanys largest distribution network operating company, which operates about 95.000 km of cable und overhead line grid from Low-voltage to 110-kV in the west of Germany

MAIN PROJECT OBJECTIVES

When the infrastructure of the medium and low-voltage system comprises some 35,000 MV substations, 5,500 medium voltage (MV) switchgear bays, 50,000 km of medium voltage /low voltage (LW) cable and 30,000 km of MV/LV overhead transmission line, which is exactly the set-up currently managed by RWE Rhein-Ruhr Netservice, replacement demand (a result of the network extension programme of the 1960s) makes it absolutely essential to switch from an age-dependent to a condition-oriented investment strategy. It is also important to ensure that all the well-known problems associated with the multitude of plant and equipment of all types and dates of manufacture that have been added to the network over the years are included in the condition assessment. In order to consolidate the existing know-how on individual items of equipment and to move on from a subjective to an objective condition assessment of the demands of tomorrow RWE Rhein-Ruhr Netservice has decided to launch a multi-year project. The first comprehensive set of results for the MV substations are presented below.

The main aim of the project initiated by RWE Rhein-Ruhr Netservice in January 2005 was to identify the procedure used for the systematic condition assessment of MV substations in particular and for medium-voltage networks in general. The goal was to develop a method that standardised the procedure used for carrying out inspection surveys throughout the entire RWE Rhein-Ruhr Netservice area. Such a system would also allow the inspection work to be undertaken more efficiently and –most important- more objective. By excluding subjective factors by a standardized procedure, for example, it becomes possible to draw a comparison between network districts and achieve a uniform quality standard. By applying a systematic procedure it is also possible to establish an integrated inspection routine. This means that the surveys are not affected by historically acquired factors and are not focussed on a certain area.

The survey findings acquired in this way are to be run through a rating schedule consisting of selected weighting coefficients so that a useful set of ratios can be calculated. In this way it should be possible not only to use a small set of figures to compare areas within the Rhein-Ruhr network region but also to monitor and assess different types of station and switchgear units, transformers and other operating equipment associated with the MV substations.

After several inspection cycles have been performed, and sufficient operational experience acquired, the results are to be used as an indicator for an objective maintenance and replacement strategy and will also serve as reference data for the medium-term planning of network investment and servicing costs. Consideration is also being given to using condition assessment as a kind of certification as proof of performance for the distribution system operator and if necessary for the regulator too, so that this certification could then be offered as a service to third parties (municipal utilities, industry, etc.).

DATA ACQUISITION

For the first phase of the project "Systematic condition assessment of MV substations" it was necessary to organise the entire body of operational know-how into a uniform checklist.

This checklist contains 67 operationally relevant points that have to be assessed by the field service engineers when carrying out their inspections. The assessment options presented in table 1 are available for each assessment point.

Table 1: Assessment options

Assessment option	Grading
No deficiency present	1
Deficiency to be remedied within 2 years	2
Deficiency to be remedied within half a year	3
Deficiency to be remedied immediately	4
No equipment for inspection	0
Inspection not possible on the equipment	0

During a series of field trials various evaluation options were tested for the individual inspection points on the checklist. The assessment method used in practice (see above) was that which displayed the smallest spread of results when the selected equipment was inspected by several users. The rating schedule not only assesses the condition of the equipment but also the degree of urgency associated with any remedial measures required; this means that allocation of work to the relevant departments can be planned more efficiently.

The individual inspection points on the checklist are also combines to form main inspection components, a process that has no direct influence on the inspection work itself.

The main inspection components are:

- MV substation building - outside
- MV substation building - inside
- Medium-voltage-switchgear
- Low-voltage equipment
- Transformers
- MV substation accessories

The inspection data are recorded on a mobile laptop computer; from time to time –when the field service engineer reaches his office- they are transferred and stored in the backend technical information system.

COMPUTATION PROCESS

The following diagram shows in simplified form the interface between the inspection process (checklist results), the assessment of each inspection point, the weighting allocated to each inspection point, the importance of the main inspection components and the condition index that is derived.

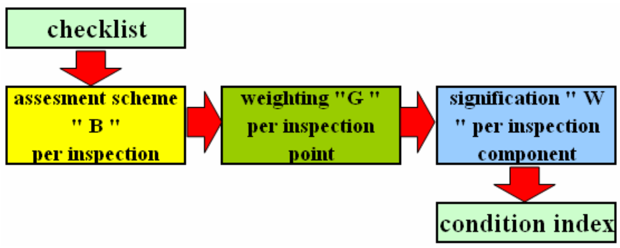

Figure 1: Principal condition assessment procedure

In the computation process (compare figure 1) each inspection point is represented by the index B_i. The index B_{max} describes the maximum possible rating that is entered into the calculation for estimating the condition index.

Each inspection point is also given a weighting (G_i.). Because of the need for detailed information here (including for example grid and maintenance planning) field data based on expert know-how were incorporated for project definition purposes. The following classification system was essentially used for the weighting system:

- The equipment plays a key role in the main inspection component. Breakdown must be avoided.
- The equipment plays an important role in the system and any malfunction can have serious consequences.
- Equipment breakdown will produce a system failure but will not have a serious impact on electricity supply.

Figure 2 shows as an example the weighting system used for the individual items that make up the main inspection component "MV substation building - outside".

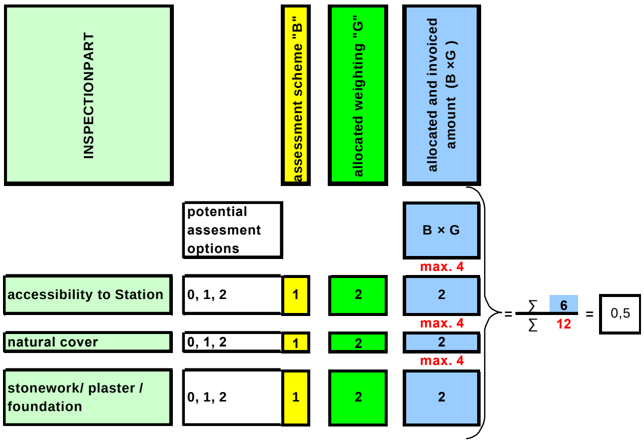

Figure 2: Example for the weighting calculation

In order to be able to calculate the condition index at any main inspection component it is necessary to work out the maximum weighted rating for each individual inspection point being assessed and then to make a sum total of the findings. This also serves to reduce the likelihood of subjective appraisals being made during the station survey. Other assessments of the condition index are based on the “importance” factor associated with each main inspection component.

The sum total of the actions required at the main inspection components represents the condition index C_i to be taken at the MV substation. This is also represented in summary form by means of equation 1.

$$C_i = \left(\frac{\sum_{a=1}^{6} \left(W_a \cdot \frac{\sum_{i=1}^{n} (G_i \cdot B_i)}{\sum_{i=1}^{n} (G_i \cdot B_{\max})} \right)}{\sum_{a=1}^{6} (W_a \neq 0)} - 0.25 \right) \cdot 1.33 \qquad (1)$$

This means as higher the condition index is, as worse is the condition of the MV substation.

ANALYSIS OF RESULTS

Data volume

The data records for further analysis consist of complete survey reports from the MV substations. These reports were compiled during 2005 by the various regional technicians using the software inspection tool and then filed in the technical backend system at the relevant technical site. A total of 24,500 data records were available by the end of the first analysis phase. In most cases additional specifications were allocated to these files via the technical site, such as type of station, activation date and manufacturer.

The condition index at regional level

In order to establish an initial “area-wide condition index” in the individual regional centres the average value was taken from all the MV substations in each regional centre. All the survey reports were included in the analysis, irrespective of the type of station, the switchgear specification and the transformer manufacturer. These results were used to produce the following grading system (table 2)

Table 2: Grading system for grid districts

Green	MV substations in the regional grid concerned have on average a need for action of 0 % to 4 %
Yellow	MV substations in the regional grid concerned have on average a need for action of 4 % to 8 %
Red	MV substations in the regional grid concerned have on average a need for action of over 8 %

Applying the defined grading system to all of the 24,500 inspection results leads to the regional distribution shown in figure 3. Figure 3 states that the condition of the regional grids is quite different. While some areas like region 1 or 8 consist of MV substations with a rather good condition, there are others (region 4 or 5) with many MV substations of bad condition (red columns). This overview is a first indication for the distribution of grid investment.

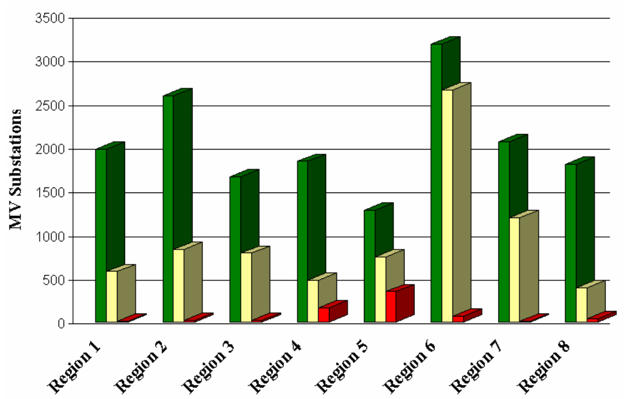

Figure 3: MV substation grading for different regions

Here the previous representation only establishes an initial comparison between the locations where some form of action or investment is required. For a detailed analysis it is necessary to draw a more precise distinction between the MV substations on the basis of design. In this respect it is possible to differentiate between MV compact substations, MV pole substations and MV building substations.
Even with this form of differentiation it can be assumed that the quantity of information held is sufficient, since between 3,000 and 5,000 survey reports are available for each substation type.

MV compact substations

From the data records it was possible to identify some 5,000 files directly as referring to MV compact substations. Here it has to be recognised that MV compact substations were not built in any great numbers until the early 1970s and that this construction programme was mainly associated with network extension work. The 1990s also saw an increase in new construction by way of investment in replacement equipment, mainly MV building substations.
It was expected that the condition index here would follow the same trend as that found for MV pole substations and MV building substations. In the case of MV compact substations, however, and unlike the other substation types, the expectation is for an operating life of some 40 years, assuming that maintenance and repair work is undertaken after a period of no more than 20 years.

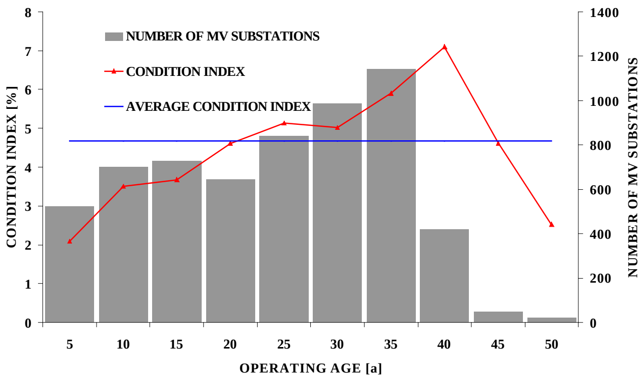

Figure 4: Condition index of MV compact substations

As Figure 4 shows, the condition index trend rises quite sharply in the first few years of service.
However, this rise is not constant but is interrupted by a declining trend at two periods in the equipment's life, namely between 11 and 15 years and between 26 and 30 years. This can largely be attributed to repair and maintenance work undertaken. However, in the case of MV compact substations the increased potential for absorbing wear and tear does not appear to be of sustained duration. After a service life of between 36 and 40 years there is a further sharp rise in the condition index and replacement is required in most cases, as the curve for the number of MV compact substations shows.

The curves shown in Figure 5 depict the condition index recorded for main inspection components at MV compact substations. The sharp rise in the general condition index is mainly associated with transformers and low-voltage equipment. After a certain period, as far as the transformer trend is concerned, there is no further increase and in fact the curve suddenly begins to fall. The remaining main inspection components are affected by wear and ageing to much the same degree and usually reach a definite maximum operating life after about 40 years in service.

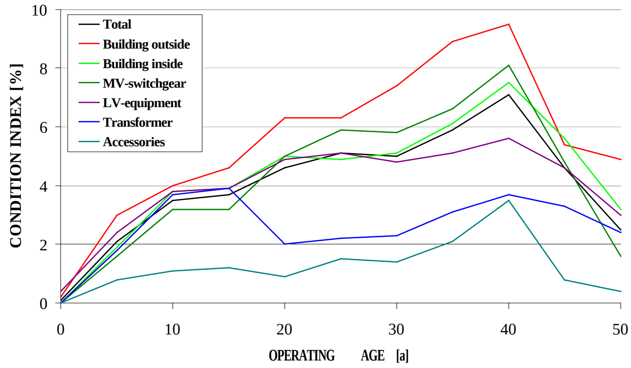

Figure 5: Condition index for main inspection components

Figure 6 shows the rising trend for condition index which results when MV substations more than 40 years old are disregarded. This appears to be a meaningful exercise, given that substations with a high condition index are replaced when they come to the end of their economically assessed service life.
The result is a steeply rising exponential curve. However, it is not possible to say how far this would continue if the MV compact substations in question were to be used beyond their planned operating life without more intensive maintenance measures.

In years gone by it was normal practice simply to replace the equipment concerned, with the result that no reference data are available for MV substations exhibiting signs of extreme ageing.

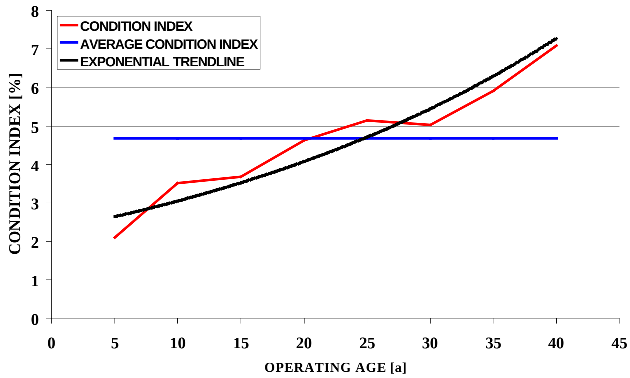

Figure 6: Condition index with exponential trendline

FUTURE PROSPECTS

As the first inspection phase was carried out by a large body of field service engineers the results of the survey are still liable to subjective influence. However, because of the huge number of reports produced this subjectivity is reduced to a large degree. What is more, factors such as grid structure, physical structure and age continue to have a decisive influence on the condition index.

On the basis of the available inspection reports compiled according to substation type it was possible to identify meaningful "condition index" trends for MV pole substations and MV building substations. These curves rise significantly until repair and maintenance work begins to have an effect. The trend line for MV compact substations, as discussed above, can also be explained in this way, though here the curve rises much more steeply.

When analysing the survey results particular attention was paid not only to the individual inspection points but also to the main inspection components "medium-voltage equipment" and "transformers". This operation showed that signs of ageing, in the form of an increasing condition index, were present in the case of certain items of equipment and that in the majority of cases this could be attributed to wear and tear and specific equipment characteristics. Various criteria can be used to distinguish between and analyse medium-voltage items of equipment (insulating medium, manufacturer and model).

Further improvements in the condition assessment process for MV substations will include the introduction of a reference catalogue for standardising the assessment criteria used for logging the survey results. This will assist the field service engineers in making a more objective assessment of any deficiency encountered and in allocating the assessment points.
Finally it is important to establish that the extensive survey data available have been referred to during the investment planning process at RWE Rhein-Ruhr and that this information has been incorporated into the final decision. The mentioned method has already been successfully employed for several external customers, who are able to benefit from the provision of detailed information based on the survey results, namely:

- Identification of MV substations with deficiencies and failure-prone individual inspection points
- Grouping of local area MV substations into sectors
- Depiction of trends / calculation of mean values
- Condition index per MV substation
- Condition index at main inspection components per MV substation
- Average assessment of individual inspection points
- Conclusions about repair and maintenance conduct
- Conclusions about ageing effects (reversibility)
- Assessment of network as regards deficiency arising

The database built up using this approach, which contains more than 24,000 survey results obtained from a large collective body of substation types, individual items of equipment and dates of manufacture, also acts as a basis for drawing up ageing models and determining failure frequency rates. Unlike many other research projects [2,3,4], where the fault and damage statistics used as reference material are usually fairly restricted, this system offers real promise of producing a reliable condition assessment of MV substations, especially when it comes to producing ageing models.
Because of these positive results the method is now also being used in connection with overhead line survey work. The first survey data are now available and will be processed in the course of the coming months. An attempt will also be made to use the same approach for the local low-voltage network so that all forthcoming investment decisions at RWE Rhein-Ruhr can in future benefit from an additional source of well-founded information on the condition of the operating equipment.

CONCLUSIONS

The paper presented a successful method to determine the condition of MV substations basically objective and with a minimal effort.
The unified inspection data of 24.000 MV substations collected over the last two years is not only used to spread the limited budget fair over the individual grid areas. A powerful data base has been generated which allows to analyse several different questions like how the condition of different types of substations, of different manufactures, of different transformer types and so on changes during the years. The paper will present some of these quite interesting analyses. The long-term objective of the extensive data collection is to make a contribution to the still unsolved problem of how components of electric power grids age. The theory of component ageing has been described quite often (well known bathtub curve), but to fill the curve with real data has not been managed yet.

REFERENCES

[1] Kajsler, Andrej "Systematic condition assessment of medium-voltage grids"
Thesis, University of Siegen, 2005

[2] Stürmer, Johannes "Maintenance and replacement strategies for power distribution networks"
Thesis, University of Dortmund, 2001
Shaker Verlag, Aachen 2002

[3] Zickler, U.; Machkine, A.; Schwan, M.; Schnettler, A.; Zhang, X.; Gockenbach, E. "Asset management in distribution systems considering new knowledge on component reliability and damage costs" 15th PSCC, Liege / Belgium, 2005

[4] Zdrallek, Markus "Reliability analysis of electricity supply systems"
Thesis, University of Siegen, 2000
Shaker Verlag, Aachen 2000