Comparison between Gas- and Air Insulated Network Concepts with the Life Cycle Cost Method

Ingo Jeromin, Gerd Balzer, *Technische Universität Darmstadt*,
Jürgen Backes, Richard Huber, *EnBW Regional AG Stuttgart*

***Abstract* — Since the liberalization of the energy markets in the late 90s of the last century, the application of gas insulated substation (GIS) becomes more important for the energy supply companies. With the use of gas insulated substations energy supply companies want to reduce their operating and maintenance costs.**

In this paper a typical German 110-kV transmission and distribution system, which is composed by rural and urban areas, is analysed. For this network the impact of the application of air insulated substations (AIS) and GIS-Substations on the whole system costs is compared.

The results depict the main cost-drivers as well as the most important elements of the system. Furthermore, it is shown how costs can be reduced by the application of different maintenance strategies.

***Index Terms*-- High voltage transmission system, life cycle costs, maintenance strategy, substation.**

I. Introduction

FOR the energy supply companies the efficiency and the operating costs of their system components become a more and more important matter of their strategic investment decisions. Hence, network operators must find a decision between air insulated and gas insulated substations. Air insulated substations stand out due to low investment costs, but on the other hand they are more susceptible to outer disturbances what has a negative effect on their operating costs. Gas insulated substations, however, have high investment costs, but have a lower susceptibility and therewith lower operating costs due to their encapsulated design.

With the help of the life cycle cost method (LCC-Method), these two concepts are compared and analysed in the following. The greatest advantage of LCC-Method is that all costs of the system are included and taken into account over the complete life time.

II. The Life-Cycle-Cost Model

The calculation of LCC in this work is performed in accordance to IEC 60300-3-3 “Dependability management Part 3-3: Application guide – Life cycle costing”. Within this standard, all cost units a component passes throughout its life are clearly defined and sub-divided into the following six cost-causing phases (Figure 1):

a) concept and definition;
b) design and development;
c) manufacturing;
d) installation;
e) operation and maintenance;
f) disposal.

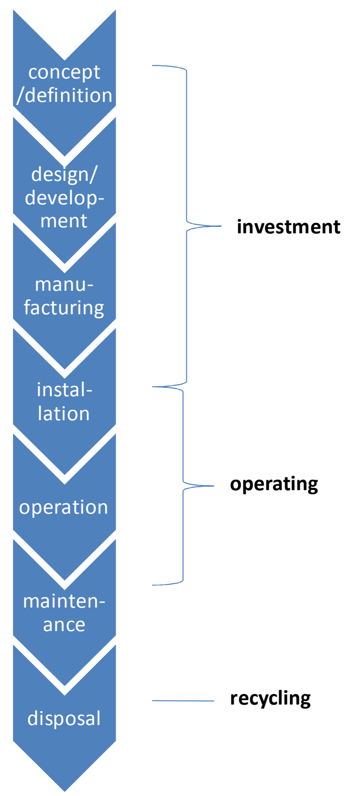

Figure 1: Life cycle phases on the basis of IEC Standard 60300-3-3[1].

When analysing these six cost-causing phases, it makes sense to combine different cost elements into following three cost brackets:

- investment
- operating
- recycling

The main difference between investment (concept/

definition, design/development, manufacturing, installation) and operating (operation, maintenance) costs is that the former cost group is already known before the investment is made. Installation costs form a special case, as they can be counted to either investment or operating costs [2].

For a more precise cost assessment, a further distinction between operational and maintenance costs is made. Such a distinction allows an easier benchmarking of different maintenance strategies, as these turn out to be the main cost drivers for the analysis.

The various cost elements are discussed in the following chapter.

III. Definitions

For a better understanding the following terms are used to explain the different expenses:

- Concept/definition: Costs incurring in connection with the concept during the specification or planning phase.
- Design/development: Costs for design, documentation and engineering.
- Manufacturing: These costs contain the expenses for production and sale of the product on the contractor side. Therefore they represent the order value of the whole distribution system. The costs for installation and commissioning of the system are not included in this part.
- Installation: Costs generated on site by installation before the system goes into operation.
- Operation: Costs arising for a sustainable operation of the whole system. Among other things these costs include expenses for power losses of overhead lines or transformers, controlling and staff training.
- Maintenance: Calculation of the complete maintenance expenditures due to different strategies e.g. time based, condition based or corrective.
- Disposal: Costs for work, material and disposal in conjunction with the decommissioning of the existing system. For example, charges for recultivation of overhead line traces are included. Possible profits in the disposal of steel, copper etc. have to be deducted as credit notes of the charges.

Further data has to be used for the calculation of the LCC, like for example:

- interest rate,
- inflation rate,
- useful lifetime of the equipment.

IV. Case Study

For the study a 110 kV network of a German network operator has been used. The network is composed by rural and urban areas; therefore, it combines transmission and distributing functions. At the moment, the network is operated exclusively with AIS-substations. In the following, it is analysed whether a rebuilding of all substations to GIS is economically advisable or not from a network operators perspective.

The components which are taken into consideration are listed in Table 1. The network is fed by a 380 kV system via 380/110 kV transformers.

TABLE 1
NUMBER OF SYSTEM COMPONENTS

Equipment	number
substations	38
circuit-breakers	162
power transformers	40
disconnectors	245
secondary equipment	126
shunt inductors	2
instrument transformers	84
transmission routes (km)	271
steel towers incl. insulators	1.086
overhead lines (km)	543

One assumption that is required for the usage of LCC-Method is the greenfield approach, which means that all components must be installed in the year zero. Table 2 shows the investment costs for AIS and GIS. The costs of the GIS alternative amount 167 per cent of the cost of the AIS alternative [2].

TABLE 2
INVESTMENT COSTS OF EQUIPMENT

Equipment	investment costs [€] AIS	investment costs [€] GIS
substations	558.000	931.860
circuit-breakers	34.000	56.780
power transformers	675.000	675.000
disconnectors	19.000	31.730
secondary equipment	26.000	26.000
shunt inductors	225.000	225.000
instrument transformers	17.000	17.000
transmission routes (km)	198.000	198.000
steel towers incl. insulators	65.000	65.000
overhead lines (km)	26.000	26.000

The hazard rates of the individual elements are taken from [3] and [4]. The hazard rate of overhead lines is partitioned with a ratio of 20 per cent on steel towers and 80 per cent on the conductors. With the help of these reliability datasets, it is possibly to calculate the availability of the individual elements as well as the complete system. From this information, the expected repair costs per year can be deduced. Furthermore, this approach distinguishes between major failures and minor failures. Major failures are defined as "Failure of a major component or element which causes the lack of one or more its fundamental functions" according to CIGRÉ 150 [5]. NOTE: A major failure will result in an immediate change in the system operating conditions, e.g. the protective equipment being required to remove the fault, or will result in the mandatory removal from service within 30 minutes for un-scheduled maintenance [5].

Minor failures on the other hand are defined as "Faults which appear and are not major faults at a constructive element or an assembly" by IEC 60946 Edition 2.2 [6]. In the following table the costs for major and minor failures are listed for different assets.

TABLE 3
REPAIR COSTS FOR MAJOR AND MINOR FAILURES

Equipment	major failure costs/a [€]	minor failure costs/a [€]
substations (AIS)	34.800	13.400
substations (GIS)	62.640	13.400
circuit-breakers (AIS)	12.400	9.400
circuit-breakers (GIS)	22.320	9.400
power transformers	77.000	29.300
disconnectors (AIS)	8.300	4.200
disconnectors (GIS)	14.940	4.200
secondary equipment	14.600	3.400
shunt inductors	61.600	86.400
instrument transformers	22.400	5.200
transmission routes (1/km)	n/a	n/a
steel towers incl. insulators	75.000	19.000
overhead lines (1/km)	0	3.000

Beside the repair costs, the expenses for overhauls and inspections are considered in tables 4 and 5. In this context, inspection means a periodic visual investigation of the principal features of the component in service without dismantling. This investigation generally comprises the examination of pressures and/or levels of fluids, tightness, position of relays, pollution of insulating parts, but actions such as lubricating, cleaning, washing, etc. which can be carried out with the component in service are also included. The overhaul is defined by IEC 60694 as work which is done with the objective of repairing or replacing parts which are out of tolerance as required by the manufacturer's maintenance manual, in order to restore the component to an acceptable condition. In tables 4 and 5 the different maintenance intervals and costs are presented [6]. In addition, table 4 and 5 inform about the average inspection intervals for the execution of an inspection or overhaul. It becomes evident that the overhaul and inspection costs are less expensive for the GIS-variant. Additionally, longer inspection intervals are required for GIS's due to the encapsulated design.

TABLE 4
OVERHAUL INTERVALS AND COSTS

Equipment	interval in [a] costs [€]	interval in [a] costs [€]
substations	1 6.800	2 4.253
circuit-breakers	5 3.400	6 2.127
power transformers	10 10.000	10 10.000
disconnectors	10 2.000	12 1.251
secondary equipment	5 500	5 500
shunt inductors	10 2.000	10 2.000
instrument transformers	10 10.000	10 10.000
transmission routes (1/km)	n/a	n/a
steel towers incl. insulators	1 500	1 500
overhead lines (1/km)	6 3.000	6 3.000

TABLE 5
INSPECTION INTERVALS AND COSTS

Equipment	interval in [a] costs [€]	interval in [a] costs [€]
substations	1 2.300	2 1.439
circuit-breakers	2 200	3 125
power transformers	2 200	2 200
disconnectors	2 100	3 63
secondary equipment	n/a	n/a
shunt inductors	2 200	2 200
instrument transformers	2 200	2 200
transmission routes (1/km)	n/a	n/a
steel towers incl. insulators	1 100	1 100
overhead lines (1/km)	2 200	2 200

V. CALCULATION OF THE PRESENT VALUE

A. Basic economic data of the calculation

The present value is a summary of all payments which arise over a fixed time period discounted e.g. to the year of the installation. It is directly dependent on the used bases of calculation. For the presented example, the following assumptions were made:

- interest rate 7 per cent
- inflation rate 2 per cent
- operating time 50 years

The failure costs for the non delivered energy are not taken into account in this study. For the 110 kV voltage level, however, it can be assumed that the interruption of the supply will be compensated by the subordinate network level.

B. Results for reference scenario

Figure 2 shows the share of the different components on the total present value of the complete system. In the AIS variant the present value amounts 360 Mio. €. In the GIS variant, on the other hand, the present value amounts 450 Mio. €.

The figures show that the steel towers have the biggest influence on the present value for both variants. In the GIS variant the huge financial impact of the GIS technology on the whole system can be clearly seen by the costs arising for the substations, circuit-breakers and disconnectors. At this point it has to be mentioned, however, that the transmission routes were considered as existing, so that no planning costs have been taken into account while calculating the present value. Furthermore, the cost driving factors inside the substation become visible when analysing figure 2. In the AIS variant the power transformers and in the GIS variant the circuit-breakers and the disconnectors can be detected as the main cost drivers. The situation that power transformers have a low influence on the present value in the case of the GIS variant is due to the fact the transformers are considered as conventional transformers and not as GIS transformers.

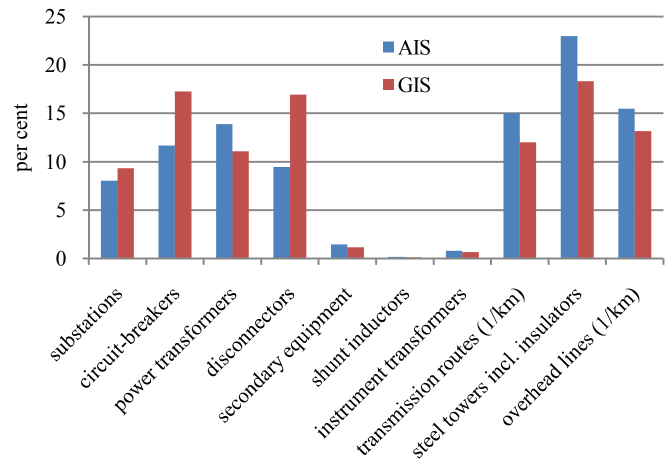

Figure 2: Present value of Life Cycle Costs

The allocation of the life cycle costs at the individual cost-causing phases can be seen in figure 3. The acquisition costs depict the largest costs in the AIS and the GIS variant. This is due to the fact that these costs incur at the time “zero” and hence are not discounted. The second largest block of the present value is composed by the repair costs. In the GIS variant this block even represents 60 per cent of the acquisition costs. The operation costs, the third-largest cost block, is attributable to the losses in the power transformer and the overhead lines.

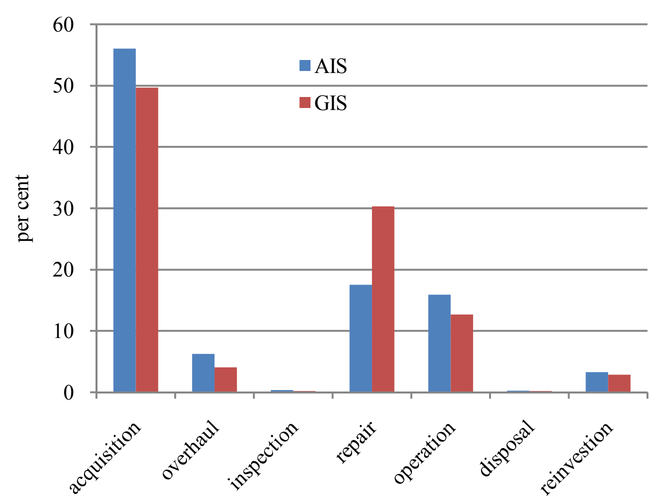

Figure 3: Allocation of the life cycle costs at the individual cost-causing phases

The next figure presents exemplarily the present value for the circuit breakers. It can clearly be seen that the repair cost have the greatest influence on the present value. They dominate the costs with a share of 78 per cent (AIS) and 85 per cent (GIS), respectively. The high value in the GIS scenario results from the fact that the circuit breaker is not directly accessible in case of a fault. Hence, a fast and simple evaluation of the failure from outside, as in the case of AIS's, is not possible.

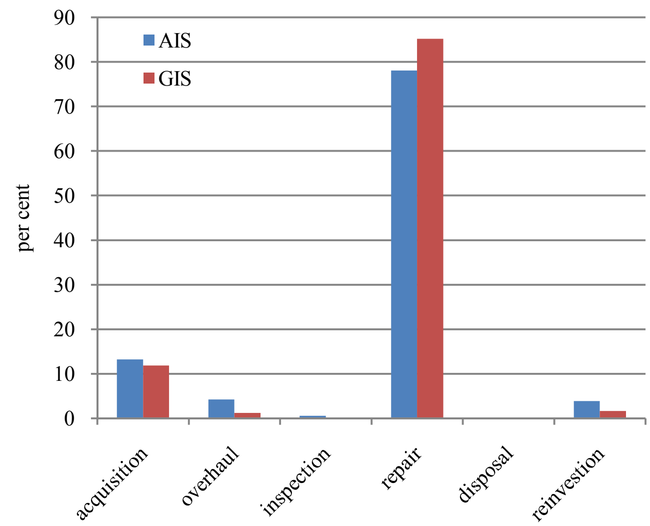

Figure 4: Present value of circuit breakers for AIS and GIS

VI. Conclusions

Summarising it can be stated that the LCC-method is a useful technique to compare different technologies such as GIS and AIS.

The analyses have shown that that the GIS variant is not the best solution from cost point of view when compared to AIS. The costs savings which are generated by a greater reliability of the GIS technology are exceeded by the outage costs.

Furthermore, future investigations in this area have to consider the financial benefits which arise from the lower space requirement of GIS substations in contrast to AIS substations which was not considered in the present study.

In addition, Life-Cycle-Cost Analysis is a meaningful instrument to illustrate changes in the finance. On this way, it is possible to customise the maintenance strategies to new conditions.

VII. References

[1] IEC 60300-3-3 "Dependability management Part 3-3: Application guide – Life cycle costing"

[2] Laskowski, K.: Life Cycle Cost-Betrachtungen von Hochspannungsschaltanlagen (2006).

[3] VDN-Störungs- und Verfügbarkeitsstatistik – Berichtsjahr 2006.

[4] Balzer, G.: Störungsanalyse der Betriebsmittel einer Schaltanlage (1997). Elektrizitätswirtschaft. Jg. 96, Heft4.

[5] Cigré 150 WG 23.02: Report on the second international survey on high voltage gas insulated substations (GIS) service experience (2000).

[6] IEC 60694 "Common specifications for high-voltage switchgear and controlgear standards".

VIII. Biographies

Ingo Jeromin received his Dipl.-Wirtsch.-Ing. degree in Business Administration and Electrical Engineering in 2007 from Darmstadt Univ. of Technology, Germany. He is currently doing his PhD thesis at Darmstadt Univ. of Technology, Institute of Electrical Power & Energy in the area of maintenance strategies for high voltage systems. His research interests are in the area of Life-Cycle-Cost Analysis, maintenance strategies and regulation management.

Gerd Balzer received the Dr.-Ing. degree in 1977 from Darmstadt Univ. of Technology, Germany. He was the Employee of BBC/ABB and the Head of the Department of Electrical Consultancy for 17 years. He joined the Darmstadt Univ. of Technology in 1994 and got a full professorship in the Department of Electrical Engineering and Information Technology. His main research interests include asset management and network planning. He is the Head of the Institute of Electric Power Systems, a senior consultant of ABB and the Chairman of the IEC Working Group "Short circuit calculations". He is member of the VDE and CIGRE.

Jürgen Backes, EnBW Regional AG, Stuttgart, received his Dr.-Ing. degree in 1998 from the University of Saarland, Germany. He is member of the Technical Asset Management, High-voltage grid, of EnBW Regional AG, Germany.

Richard Huber; EnBW Regional AG Stuttgart, is the head of the Technical Asset Management, High-voltage & high-pressure grid, of EnBW Regional AG, Germany.