# OPTIMIZATION OF LONG-TERM CASH FLOW CALCULATIONS FOR HIGH VOLTAGE EQUIPMENT

Leyla ASGARIEH
Technische Universität Darmstadt – Germany
leyla.asgarieh@eev.tu-darmstadt.de

Gerd BALZER
Technische Universität Darmstadt – Germany
gerd.balzer@eev.tu-darmstadt.de

Armin PRECHT
EnBW Regional AG – Germany
a.precht@enbw.com

Christian SCHORN
EnBW Regional AG – Germany
c.schorn@enbw.com

## *ABSTRACT*

*Due to the incentive regulation one of the main asset manager challenges are long-term cost analyses in order to optimize the yearly expenditures. Therefore, an ageing model has been established and will be explained in this paper which enables to calculate the yearly costs and thus to obtain long-term information, for example about balance values and cash flow values, for high voltage equipment.*

## INTRODUCTION

In times of deregulated markets and particularly since the beginning of the incentive regulation in Germany in January 2009, long-term cost assessments play a decisive role in the asset management process. Therefore the goal of this paper is to accomplish a cost analysis in order to optimize the yearly cash flow of the utility concerning high voltage equipment. For this purpose, in a first step a condition assessment is accomplished and introduced to a simulation model. Therewith, an asset simulation can be performed in order to receive the ageing behaviour of a fleet of equipment (in this case $SF_6$, air blast and minimum oil circuit-breakers). The established ageing model considers the individual behaviours over the circuit-breaker life time, for example the failure rates, the inspection and overhaul cycles as well as the maintenance and repair costs.

In a second step, after the estimation concerning the condition assessment and ageing behaviour another main aspect that has to be taken into consideration is the financial assessment. Therefore, the cash flow calculations as well as the determination of the interest on equity are significant.

The value of cash flow points out to what extent, during a certain time horizon, current operating activities will lead to a surplus of income. Therefore, it is an indicator of success which shows the ability of a utility to generate funds on its own.

In this paper, a long-term cash flow calculation, with a time horizon of 40 years, will be determined for the above mentioned circuit-breaker types.

Furthermore, the items to prepare a balance sheet for the trade balance as well as the items to be able to calculate the system charges required for the Federal Network Agency in consideration of the incentive regulation requirements are of interest and can be determined by the asset simulation.

The following chapters will describe briefly the developed ageing model and the requirements of the incentive regulation. Furthermore, the importance of the cash flow calculation will be described and accomplished and finally compared for two different scenarios. In a final step the ageing model will be modified in order to optimize the yearly expenditures and therefore the cash flow values.

## AGEING MODEL

The developed ageing model mirrors the behaviour of assets, in this case circuit-breakers, over their life time under consideration of external events. Apart from describing the behaviour of one asset type it is also possible to combine different equipment types in order to be able to simulate the ageing behaviour of a whole grid.

Fig. 1 shows exemplarily an ageing model with four condition states with different residence times which are dependent on the asset type and the devices, respectively. The coherence between the number of condition states and the residence time for each respective condition state can be derived from the bathtub curve, which is a hazard function describing the expected failure rate of electrical equipment over service life time. Further descriptions regarding the bathtub curve can be taken from [1] and [2].

The number of required condition states depends on the asset behaviour over its life time. If the condition of the assets is strongly correlated with the age and changes after short intervals, more condition states are necessary, compared to assets which have long intervals without changing the condition. The outer rectangles in Fig. 1 represent the whole condition state whereas the inner rectangles describe the different age groups of the condition states. Between the condition states transition rates are necessary to calculate the circuit-breakers which have to be transferred from one condition state into the next worse one. The transition rates are denoted with µ1 to µ4 in Fig. 1 and the exact determination of the values can be taken from [2]. The value of "in" in Fig. 1 describes the yearly new installations, because of grid enlargement and replacement of circuit-breakers, which leave the ageing model ("out") [2].

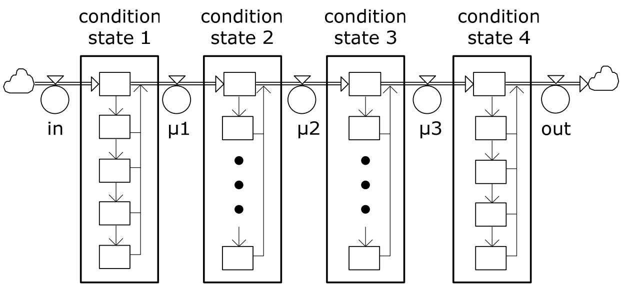


Fig. 1. Exemplary ageing model with four condition states [2].

To be able to consider for example different transition rates, failure rates as well as overhaul and inspection costs, for each circuit-breaker type an ageing model is required and the results can be summed up to obtain information about a whole asset group or a whole grid, respectively.

After the ageing model is established it has to be filled with asset data. Therefore, the technical condition of the circuit-breakers has to be determined on the basis of different criteria, like age, maximum short-circuit capability, number of switching operations etc. With this method 1000 circuit-breakers were evaluated in order to obtain the condition as a function of the asset age. More detailed information about this approach can be taken from [3] and [4].

Fig. 2 shows the distribution of condition values (plotted on the ordinate) and service age (plotted on the axis of abscissa) for the three circuit-breaker types. The black line in Fig. 2 is a frequency polygon through the circuit-breakers with the best condition values. These elements are not artificially aged, but all circuit-breakers above this line behave older than they really are. The artificial age of the circuit-breakers can be seen from the chart by using a horizontal line through the coordinate of the circuit-breaker and the interception point with the frequency polygon. An example can be seen in Fig. 2. The chosen minimum oil circuit-breaker has the condition value 37 and a real age of 25 years, but an artificial age of 27 years. For the transmission of these values into the ageing model, the real and artificial age must be considered [5].

The values shown in Fig. 2 can be transferred into the ageing model by keeping the information of real and artificial age; therefore, the condition of each circuit-breaker is retained when the information is transferred into the model. This ensures that during the whole simulation time, the information of the real and artificial age of every circuit-breaker is kept. The artificial age of the assets shows how old the circuit-breaker behaves according to the condition state. As aforementioned the optimum is to have corresponding real and artificial ages, but often the circuit-breaker behaves older than their real age. This is for example due to failures or lack of know-how.

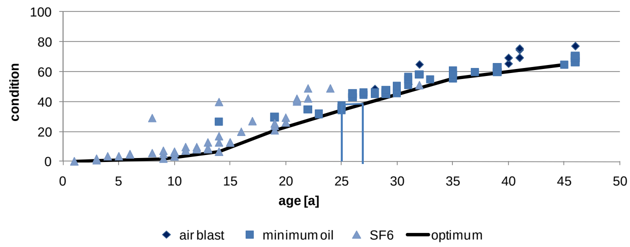


Fig. 2. Technical condition of circuit-breakers [5].

This approach ensures that each asset leaves the model and will be replaced at the latest after the maximum life time.

It is further assumed that all newly installed circuit-breakers are of $SF_6$-technology, no matter which type of circuit-breaker has to be replaced.

## RESULTS OF CASH FLOW CALCUALTIONS

Since the incentive regulation has started in Germany, the utilities have to concern two different approaches in order to satisfy the specifications given by law. Therefore, they have to prepare a trade balance and they have to calculate the balance sheet items concerning differing assumptions in order to calculate the system charges required for the Federal Network Agency.

Each balance has an assets side and a liabilities side which have to be balanced. The assets contain:

- The fixed assets (long-term, tangible asset held for business use and not expected to be converted to cash in the current or upcoming fiscal year) as well as
- the current assets (sum of cash and cash equivalents, accounts receivable, inventory and prepaid expenses) [6].

The liabilities side comprises:

- The equity (ownership interest in a corporation in the form of common stock or preferred stock) and
- the liabilities (obligation to outside creditors) [6].

In the following the assumptions for preparing a trade balance as well as to calculate the system charges for the Federal Network Agency will be compared in Table I. On the basis of this information the yearly values of the two approaches can be obtained over a long time period.

As an example the items required for the Federal Network Agency are demonstrated for two different life time scenarios in the following figures (maximum life time of 40 years and maximum life time of 45 years). The trade balance shapes can be taken from [7].

TABLE I
DETERMINATION OF THE ITEMS FOR TRADE BALANCE AND FEDERAL NETWORK AGENCY APPROACH [7]

| trade balance | Federal Network Agency approach |
|---|---|
| depreciation time for circuit-breakers is 20 years | depreciation time for circuit-breakers is 40 years |
| fixed assets are equal to the yearly residual values of circuit-breakers (using a depreciation time of 20 years) | fixed assets are equal to the yearly residual values of circuit-breakers (using a depreciation time of 40 years) |
| current assets are 50% of the fixed asset value | the values of the current assets are the same as in the trade balance |
| liabilities are the borrowed capital and equal to current values as well as the difference between residual value and stockholder equity | liability values are taken over from the trade balance |
| stockholder equity is equal to 40% of the residual value in the starting year | stockholder equity is the residual costs less the liabilities |

Fig. 3 and Fig. 4 show the shapes of the items necessary for the calculations due to the Federal Network Agency requirements for the two different life time scenarios.

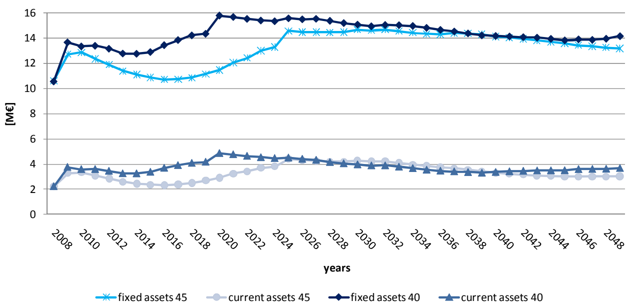


Fig. 3. Shapes of fixed and current assets for the two life time scenarios required for the Federal Network Agency approach.

Regarding the fixed assets of the two scenarios it can be seen that a longer life time leads to lower asset values in the first simulation years. This is due to the fact that, like shown in Fig. 2, there are a lot of old minimum oil and air blast circuit-breakers which have to be replaced in the first simulation year concerning a simulation horizon of 40 years. Therefore, the residual values and thus the asset value are increased compared to the second scenario which considers already depreciated circuit-breakers that are still in operation. This leads to lower residual values and therefore to lower asset values. After replacing the old air blast and minimum oil circuit-breakers by new $SF_6$ circuit-breakers the asset values converge.

This effect is even increased comparing the liability values of the two scenarios due to the fact that these values are taken over from the trade balance, which has a depreciation time of 20 years. Therefore, the assets are depreciated earlier which leads to lower residual values in both scenarios. The longer the life time, the lower is the residual value each year. These deviations are also reduced after the old and depreciated circuit-breakers are replaced by new $SF_6$ circuit-breaker.

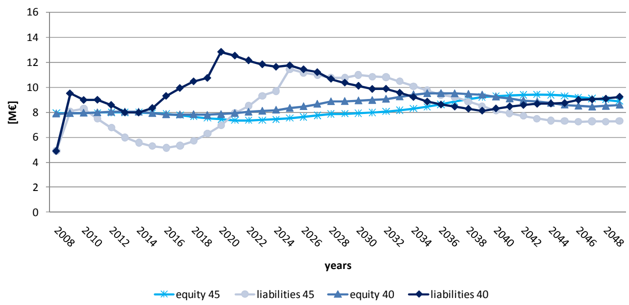


Fig. 4. Shapes of equity and liabilities for the two life time scenarios required for the Federal Network Agency approach.

Another important parameter is the grid fees, which are in a liberalized energy market those payments charged by system operators for grid usage. It is given by law that the system operator needs the acceptance for the grid fees from the Federal Network Agency. The grid fees are calculated like shown in formula (1).

$$\begin{aligned} \text{grid fees} = {} & \text{depreciations} \\ & + OPEX \\ & + \text{return on equity} \\ & + \text{interest on borrowed capital} \end{aligned} \quad (1)$$

Knowing the grid fees, the cash flow can be calculated as shown in (2) and (3), which is very important due to the fact that it is one of the main instruments to measure the corporate success.

$$\begin{aligned} \text{cash flow} = {} & \text{grid fees} \\ & - OPEX \\ & - CAPEX \\ & - \text{interest on borrowed capital} \end{aligned} \quad (2)$$

From (1) and (2), the following formula (3) can be derived:

$$\begin{aligned} \text{cash flow} = {} & \text{depreciations} \\ & + \text{return on equity} \\ & - CAPEX \end{aligned} \quad (3)$$

It is reasonable to avoid negative cash flows, due to the fact that credit institutes will increase their interests for the liabilities, if they class the utility as unreliable. Therefore, an investment limit can be introduced to the ageing model which optimizes the model and ensures that

the cash flow value will not reach negative values.
The following two figures (Fig. 5 and Fig. 6) illustrate the grid fees and the cash flow values with and without an investment limit concerning a maximum life time of 40 years.
Fig. 5 shows that from 2008 to 2012 the grid fee values concerning an investment limit are lower due to the fact that some investments in the first years have to be shifted to the following years to avoid negative cash flows (see Fig. 6).
As aforementioned the condition assessment (Fig. 2) shows that there are many old circuit-breakers which have to be replaced in the first simulation year. The investment delay leads to lower depreciation values in the first simulation years and therefore to lower grid fees (see (1)).

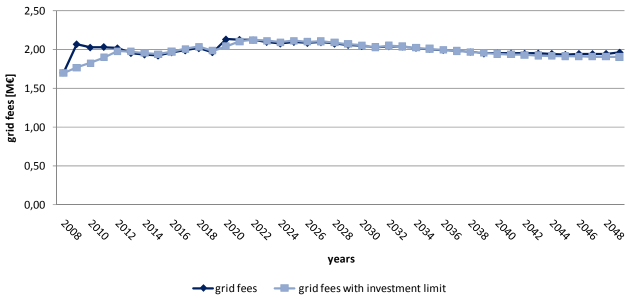


Fig. 5. Shapes of the grid fees regarding a maximum life time of 40 years.

Concerning the cash flow shapes plotted in Fig. 6 the difference of the two scenarios becomes obvious. The cash flow values without an investment limit have two negative peaks, due to the fact that a high CAPEX value leads to low or negative cash flow values like shown in (3). The two CAPEX peaks results from the condition assessment (Fig. 2). It is reasonable to avoid negative cash flows, due to the fact that like aforementioned credit institutes will increase their interests for the liabilities, if they class the utility as unreliable. The option to introduce an investment limit (shown in Fig. 6 shape of cash flow with investment limit) avoids negative cash flows and is therefore a reasonable instrument.

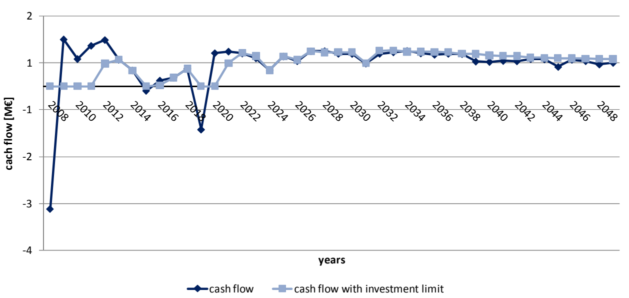


Fig. 6. Shapes of the cash flow regarding a maximum life time of 40 years.

## CONCLUSIONS

Since the incentive regulation has started in January 2009 and system operators have a predetermined revenue cap, they have the incentive to reduce costs in order to increase their profit. Therefore, the asset manager requires information about the long term cost development to be able to find the most appropriate investment strategy for the utility. For this purpose ageing models are useful in order to receive information about the asset behaviour as well as to have the possibility to make long-term cost analyses.
The results of the cost analyses had shown the importance of stable and positive cash flow values. Therefore, it is reasonable to optimize the ageing model and the cost analyses by introducing an investment limit which ensures positive cash flows and avoids too high investment peaks, which is also desirable. The investments can be shifted to the following years and lead to more evenly distributed costs.

## REFERENCES

[1] R. A. Taylor, 2008, " of System Dynamics: Jay W. Forrester and the History of System Dynamics ", *U.S. Department of Energy's Introduction to System Dynamics.*

[2] L. Asgarieh, G. Balzer and A. J. Gaul, 2009, "Condition assessment for optimal planning and operation of power systems with the aid of ageing models", *PowerTech*, Paper No. 74.

[3] G. Balzer, M. Brandl, A. Strnad, H. Röhsler, A. Schnettler, 1997, "A Computer-aided reliability-centered maintenance strategy for power networks", *ABB Review*, pp 21-25.

[4] G. Balzer, T. Orlowska, M. Halfmann, C. Neumann, A. Strnad, 2000, "Life Cycle Management of Circuit-Breakers by Application of Reliability Centered Maintenance", *CIGRE*, 13-103.

[5] L. Asgarieh, G. Balzer and A.J. Gaul, 2008, "Circuit-Breaker Estimation with the Aid of Ageing models", 10th *international conference on Probabilistic Methods Applied to Power Systems PMAPS*, Paper No. 050.

[6] InvestorWords.com, The Biggest, Best Investing Glossary on the Web, Available: http://www.investorwords.com/.

[7] L. Asgarieh and G. Balzer, 2010, "Consideration of the Incentive Regulation Requirements for Cost Analysis Based on Ageing Models for 110-kV Equipment", *CIRED Workshop, Sustainable Distribution Asset Management and Financing*, Paper No. 0025.