INTRODUCTION

Distribution network organisations (DNO) are facing many different and partly even competing targets. It is their task to find a balance between the requirements of the customers concerning product and service quality at affordable prices as well as the shareholder demands for suitable returns on the capital they invest. Also potential regulatory impacts on revenues and changes in the political perception of e.g. renewable energy have to be focussed. To optimise between these demands system operators have to develop and extend “best practices” in asset management.

ASSET MANAGEMENT

Asset management is used as a synonym for operating a group of assets over the whole technical lifecycle guaranteeing a suitable return and ensuring defined service and security standards. This means to focus on sustainability. A major challenge in Germany is the increasing amount of assets which have to be replaced in the next years due to their age. Therefore, besides a business environment which honours long-dated decisions, optimised and integrated strategies for renewal and maintenance of the assets are necessary.

There is growing concern that the pressure for short-term efficiency gains and customer satisfaction has placed asset engineering in a background role. The time delays inherent in asset degeneration and between asset investment and realised benefits are sufficiently long for DNO to reduce asset investment without unduly affecting short-term performance. Additionally they are much longer than the tenure of the regulator and his political masters. However, such strategies could contribute to building an irreversible asset time bomb situation with a degree of degeneration of asset condition that might well mitigate against the very improvements that current regulator policy seeks to achieve.

In this context it is very important to have or to develop the ability to analyse the complex dependencies between maintenance and renewal as well as the costs and the quality to derive the right decisions. The ability to assess different scenarios for the whole grid or parts of the grid having the same structure or technology is a major competence in asset management. These assessments develop extensive knowledge about the effects of alternative strategies on the asset base. With this knowledge asset managers can actively develop the grid and spend the money in a way that the long term goals are reached as well as the short term budgets.

EFFECTS AND TIMESCALES

The money being spent on the grid affects the systems after different periods of time (Figure 1). While distribution revenue and quality of supply can be affected in the short term, the aim of providing a high quality grid over a long time period needs to focus on sustainability.

In performing asset management there are two different things that have to be considered: everyday business and risks. The everyday business can be described quite well with benchmark figures. But it is important not to lose effects that should be controlled due to the size of the grid. Figures like CAPEX, OPEX, CML,... depend a lot on the structure of the grid. Comparing rural areas with big cities does not gain much of a benefit. So there have to be asset segments which are comparable concerning the structure in order to get sensible benchmark results. It is also important not to mix standard activities and risk based ones. So budgets calculated for CAPEX or OPEX should not mix actions taken to prevent major risks with those actions necessary for normal operation. (Figure 2).
SIMULATION APPROACH

When exploring complex systems it is very easy to confuse symptoms and the resulting actions undertaken by different agencies to control these, with the basic root causes of the problem. Therefore it is essential when developing models of a complex problem to proceed in a logical, staged way, starting with the very basic underlying ‘physics’ of the situation and to progressively develop the role of each agency involved. The development of a model by controlled expansion enables a global perspective to be constructed. This can greatly assist with improving understanding and clarity of thinking about the merits of different actions being taken by different agencies in different places and at different times.

Causal Loop Diagram

Since the grid is basically a number of ageing assets which are being inspected, maintained, refurbished, and renewed, the model has to describe the asset ageing process (Figure 3). Additionally the strategies of doing something to the asset have to be described as a set of rules like “if the asset is >x years old and not renewed, then y will happen”. Also the costs and resources needed for these actions have to be calculated. Last but not least, the age distribution and a failure distribution of the assets are needed.

Figure 3 the link between strategy and costs

Starting with this information for a single asset or a group of assets it is possible to calculate e.g. CAPEX, OPEX for a given strategy. The following sections attempt to show in system dynamics terms, the resulting logical development sequence for a DNO.

The basic forces at work in a DNO

Figure 4 isolates the fundamental forces at work within a network of assets, as a starting point for analysis of a DNO.

Assuming the DNO would do nothing to maintain the condition of his network, two key points emerge described by the arrows in Figure 4:

First, that the network degenerates due to its age over time. Therefore the condition of the network continually degenerates as a consequence of the ageing factors.

Second, that the performance of the network depends on the condition of the network.

Obviously doing nothing to maintain the asset condition is not an option for a DNO since there is no force in fig. 4 that prevents the network performance form degeneration.

Maintaining an Asset’s Condition

The upkeep of asset condition through judicious attention to replacement, replenishment, refurbishment and maintenance engineering has long been the core competence of utility companies. The mechanisms for this have been detailed monitoring of the asset condition and selection of capital (CAPEX) and operational (OPEX) expenditures to improve the condition relative to planned internal targets. Figure 5 is a development of Figure 4, which captures the two major feedback loops. Loop B1 is the CAPEX loop and loop B2 is the OPEX loop. However maintaining this status quo is prevented by the effects of the reinforcing loop, R2. When revenue is increasing R2 is positive and network condition improves.

Figure 5 traditional solutions to asset ageing

When revenue decreases then R2 becomes negative and network condition declines.
It is very important to recognise that the time scale of the CAPEX feedback process is significant and involves delays in monitoring, project definition, capital approval and project implementation. Typically it might take consistent action over several years to significantly improve the performance of aged network assets through capital investment processes.

Using System Dynamics Models

The first purpose of a causal loop diagram is to provide clarity and shared understanding between all agencies involved of how a current situation has come about through past action and what will happen in the future if appropriate change is not made. In terms of the DNO, it should be clear from Figure 5 that there are a number of important interrelated issues that will have a serious impact on the electricity distribution industry in both the short and long term.

Whilst a DNO can exercise some control over its own future when it is able to set its own performance targets as is the case in Figure 5, deregulation will inevitably lead to external targets being set. These then become exogenous variables in the model, as is customer demand and pass beyond the control of a DNO. The result, as has been seen in both the UK and Scandinavia, is an uncontrollable shift to short term objectives for customer and financial performance at the expense on longer term asset management. In such a scenario, the loop R2 shown in Figure 5 becomes negative and asset condition goes into long term decline. Consequently the risk that the assets will be neglected for a long time, due to reduction in OPEX and CAPEX budgets, increases. This in turn leads to a higher probability that faults and interruptions will increase forcing more priority to asset repair at the expense of asset maintenance and replacement, together with more and more funding to customer services to alleviate customer complaints.

The second purpose of a causal loop diagram is to develop shared understanding of, and alignment to, the interventions that need to be made in order to avoid past mistakes and to ensure a sound future for all involved. The key words are balance, sustainability and value. That is, the stimulation of balanced performance across all stakeholders and over time. Whilst this can be done for a whole industry, it is more common for individual players in the industry to adapt the model to reflect their specific circumstances and then use it to define the optimum policies and strategies for achieving their business objectives.

This is where computer simulation and the subject of ‘system dynamics’ (which underpins ‘systems thinking’) comes into its own. Figure 5 can be relatively easily translated into a computer simulation using modern software, either in generic form to be used by the regulator in developing policy, or by specific distribution companies based on specific company data. A key ingredient to such simulations is the development of a high-level representation of the asset base of a company capable of demonstrating ageing over time and the effects of CAPEX and OPEX policies on the ageing process.

Development of the System Map and System Dynamics Model

A system map is the step between the causal-loop diagram and the full system dynamics model. Its purpose is to define the cause and effect behaviours as a series of condition states and variables.

The most crucial part is the asset model. This model describes the ageing of the assets and the actions which can be done to the assets to prevent them from reliability degradation. Figure 6 shows a simple ageing model which can be used to get first suitable results.

![Simple Ageing Model](Figure 6)

The model describes an asset with three different states: reliable, degenerated and unpredictable. For each of the states different calculations for e.g. strategic maintenance and renewal decisions, failure rates are made. The principle is that, during its life, an asset will pass through each state and spend a certain amount of time in each state. Work done by maintenance and refurbishment will slow down the rate at which an asset moves from one state to the next. Eventually an asset moves out of the system by being replaced. In each state an asset will deliver a different level of performance. The system map is shown in Figure 7.

![System Map](Figure 7)

As is suggested by Figure 7 there is one chain for each asset type and each project type in the model. Each project goes through a series of states: identified, designed, scheduled, in execution and completed.
The principles of state chains is widely used in system dynamics models and is a very powerful method for simulating how a system, such as an electricity network, changes over time and responds to external levers.

For asset strategy planning modelling the asset ageing chain correctly is the key to the success of the model. As different asset types have different ageing characteristics a chain for each asset type is logical. Development of a number of these models has shown that it is a minimum acceptable level of complexity. In this application the system dynamics model developed relies on a more complex set of asset ageing chains. For example more than one degenerating state was modelled to reflect accelerated degeneration under certain conditions. Also refurbished assets were placed in a different reliable state to model a shorter time in this state than new assets.

SYSTEM EVALUATION

To evaluate this approach a simple medium voltage test grid was set up consisting of overhead lines and cables. The age distribution of that test grid is shown in figure 8. Younger cables and overhead lines are on the left side of the figure while the older ones which are still in the grid are shown on the right side.

RESULTS

For this grid two different strategies have been compared. **Strategy one** (minimal cost) reduces renewal as well as maintenance to a minimum level. This means only failure is a suitable reason for any action. If anything has to be done in this strategy repairs are preferred to replacement as long as it is possible. Therefore, low CAPEX and possibly rising OPEX is the expected result. The failures on the network should rise with this strategy, too.

**Strategy two** (controlled renewal) sets sensible parameters to renewal and maintenance in order to keep the value and reliability of the grid within a stable range. For this second scenario a constantly low failure rate is expected, while CAPEX follows the needs for replacement of ageing assets. OPEX should be rather constant since the network is kept in a given state. Figure 9 shows a first analysis of the total expenditures on the network meaning the sum of CAPEX and OPEX.

![Figure 9 total expenditures](image)

For a closer look on that effect the OPEX for both scenarios was analysed. While OPEX is rather constant for the controlled renewal scenario it rises for the minimal afford strategy significantly (Figure 10). Independent from market regulation “cost plus fee” or “OPEX target” this OPEX rise is hard to explain to the regulator.

For a deeper analysis the CAPEX expenditures in both scenarios are evaluated. As shown in Figure 11 the CAPEX in the minimum afford strategy stays low as expected while the controlled renewal strategy shows a CAPEX rise in the upcoming years due to the ageing of the assets.
Even though this CAPEX rise seems to be a problem in the first place these CAPEX expenditures keep the company’s regulated asset base stable. This is a reasonable explanation for both, regulators and shareholders, since they should be interested in stable and foreseeable investments.

The final analysis of the two test scenarios deals with the failures of the network. Figure 12 shows an example for the customer interruptions for both scenarios. While the reasonable renewal scenario was capable to keep the customer interruptions at a low level the failure rate for minimum cost scenario rises to a nine times higher level in a few years.

As the failure chart shows it makes no sense to follow the minimum cost strategy as it was chosen for this demonstration. But these results show clearly that it is possible to analyse the future behaviour of an electric grid for different strategies for maintenance and renewal and that the chosen strategy has a strong impact on the results.

LIMITATIONS

After showing the good results that were achieved using this approach for the simulation of different strategies minor limitations of this approach should be mentioned.

The approach depends on the accuracy of the content and structure of the asset model and the precise definition of relationships and behaviours of the parameters in the model. In addition, even though system dynamics models do provide valuable results with limited and weak data, high quality input data is essential to achieve good quantitative results, instead of qualitative predictions of direction and effect.

Since the manufacturers of the assets do not provide statistical data or life cycle models of their equipments the acquisition of the necessary data and validation of the ageing models has to be performed by the DNO. If this data is not available this data acquisition process may take considerable time and effort in order to deliver the quantitative results that give the model its real value.

SUMMARY

The approach described in this paper is suitable to analyse the long term effects of complex asset management strategies for practical use in a utility. The strategy can be assessed by key figures like budget, number of assets maintained, renewed, decommissioned, or quality.

The example in this paper was kept simple intentionally to demonstrate the principles of the approach and to discuss the results of a strategy comparison. Uncertainties in the asset models have an influence on the results, but qualitative and quantitative results can be achieved if sufficient data is available.

This promising approach is already used by RWE Energy for the asset management. It is applied to decision support in strategy evaluation. Furthermore the system dynamics model developed will be used to compare different asset management strategies. Analysis on different scenarios to asset investment planning leads to a transparent and reproducible basis for the quality of a strategy and the costs resulting from it. That way the long term costs of a network can be influenced by strategic investments in the grid. The approach also has the capability to be used to identify and explore the risks associated with different strategies and how these risks can be minimised. For any DNO asset risk is a major issue which has to be addressed. Future research will address this topic.

For RWE Energy the use of this model improves the quality of investment decisions und opens up new opportunities for further work.

