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Regulatory Control of Quality of Service Leads to Balanced Risk Based Decision Making

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***Summary*: As a consequence of the liberalization of energy markets, grid owners and operators (including industries and railways) are re-orientating on asset management and investments. The regulatory authorities, involved in sustaining security, reliability and availability of supply, represent the society's requirements that grid companies have to cope with, under their financial and corporate policies, limitations and targets.**

Quality of supply is of major social concern. Grid companies and regulators have to decide at what costs this is achieved and sustained. On the customers side there is a growing awareness for the quality of supply, of which reliability of the grid is an important factor. To balance sustaining or improving the quality of supply with the cost consequences of investments in power systems, quantification is unavoidable.

The combination of available outage data, the valuation of outages to customers and new probabilistic tools, makes it possible to find the social optimum for power system design under the new quality regulation and increasing planning uncertainties.

These analyses typically result in investment and management decisions that combine the social, legal, technical and financial risks, cash-outs and revenues.

Key words:
reliability
availability
regulation
outages
performance
costs

1. INTRODUCTION

In the first years of electricity de-regulation, the main focus was the reduction of price to the end user by controlling the costs of and investments by the Generating Companies (GenCo) and Grid Companies (GridCo). This has apparently resulted in lower end user prices, lower costs for bulk electricity and reduced margins for GenCo's and GridCo's. It has also resulted in reluctance investing in energy efficiency and quality of service. This is caused by the fact that in most cases, the regulatory period (i.e. the period during which the cost are controlled by the regulatory schemes; typically 3–5 years) are very small compared to the expected technical and economical lifetime of components and systems. This results in a large business risk for the investors, as they are not sure of return on their investment. There are signs that many regulators are beginning to think about security of supply and about how better investment decisions can be made.

The responsibility for quality of supply has been re-allocated over a number of players due to the liberalization of the industry [1]. Quality of supply is basically determined by two elements:

1. The quality of the transmission and distribution grids
2. The volume of installed and available generating capacity

The responsibility to have enough installed generating capacity available has been passed from the integrated utility to market focus. This means that generation companies have to make their own investment decisions depending on expected market price developments. High prices for electricity provide a signal to attract investment until the profitability of the industry equals that of other activities facing comparable risks.

In the context of the electricity network industry three dimensions are usually reported according to the Council of European Energy Regulators [4]:

— Continuity of supply
— Power quality
— Commercial quality

Continuity of supply is characterized by the number and duration of interruptions. A wide range of continuity of supply indicators is in use; these always relate to the frequency and duration of outages. Power quality covers aspects such as voltage and frequency stability, voltage dips, over-voltages or harmonic distortion. Commercial quality includes the quality of all relationships between a supplier and a user.

2. INSTRUMENTS FOR QUALITY OF SUPPLY BY THE REGULATOR

Figure 1 [4] provides an overview of tools a regulator can use to implement quality regulation. Considerable elements for regulation of the quality of service are implicitly included in

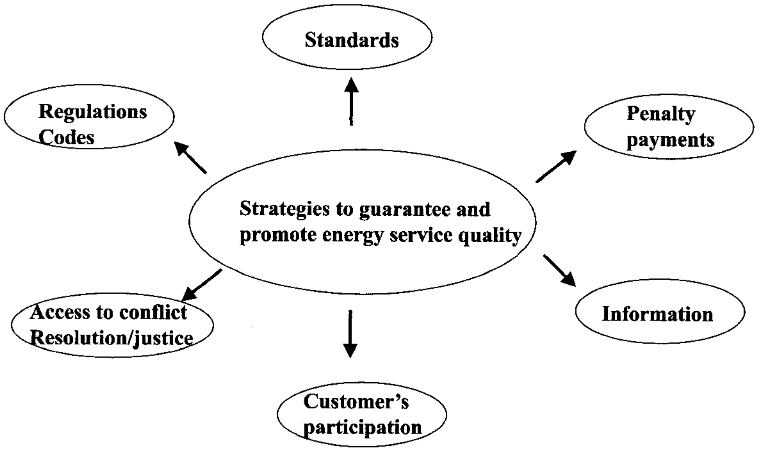

Fig. 1. Instruments for quality of supply regulation

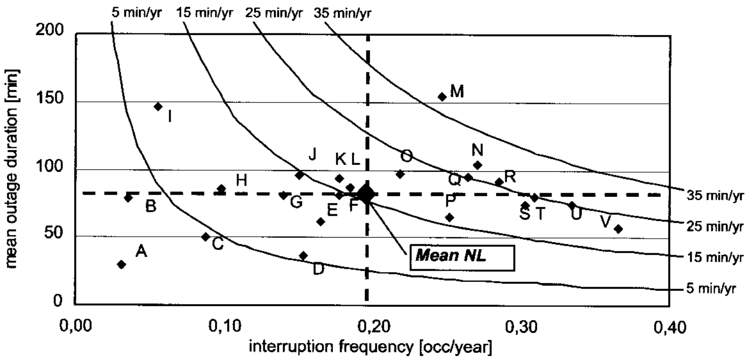

Fig. 2. Comparison of outage frequency and outage duration for Dutch utilities

conventional regulatory procedures with respect to licensing, pricing, market and system rules etc.

In addition, the regulatory authority may take further steps to ensure that certain performance and quality standards are met. This may involve prescription of certain standards. The regulator may also use financial incentives, leading to the notion of performance-based regulation.

According to [1] there are several methods for performance-based regulations.

- The simplest instrument is public exposure. The idea is that exposure to public judgment (customers, media etc.) encourages companies to maintain and if necessary improve quality.
- Another method is the use of minimum standards that come in the form of limits to the number and duration of outages. This could result in a penalty. Usually there are two types of minimum standards:
  - Overall standard: measuring the performance at system level. Overall standards will only pick-up the average performance and not provide information about differences between individual customers
  - Individual standards: level of service is related to the customer expectation. The effect of individual standards could be that companies who are expected to maximize profits, will eventually converge towards the level of the standard that might be not the optimal level
- Incentive mechanisms can be seen as an extension of a minimum standard because they introduce a direct link between the company's income (price) and the level of performance (quality). Performance can be measured at different levels.

3. COMMONLY USED INDICATORS

The most worldwide used indicators to determine the quality of supply are [1]:

- CAIFI: Customer Average Interruption Frequency Index; the average number of interruptions per year for an average customer (number/year);
- CAIDI: Customer Average Interruption Duration Index; the yearly average interruption duration for an average customer (minutes/year);
- CML: Customer Minutes Lost, product of CAIDI and the number of customers (minutes/year);
- NDE: Non Delivered Energy, product of the number of interruptions of the product of the interruption duration times the interrupted power (kWh/year).

These indicators are related to individual customers. There are also indicators based on the system, providing information for all consumers:

- SAIFI: System Average Interruption Frequency Index; (number/year);
- SAIDI: System Average Interruption Duration Index (minutes).

Sadly different countries use different indicators, different definitions and apply these indicators in different ways.

For example, the Dutch annual national report contains comparisons among the utilities, as shown in Figure 2 for Medium Voltage [3]. Each dot represents a utility, positioned according to the average outage frequency (CAIFI) and the mean outage duration per customer.

The curves indicate lines where the CAIDI has a constant value, for an average customer with an average load, in minutes per year. It is clear to see that there are a lot of differences among network operators. This does not necessarily indicate good or bad performance, because the local circumstances for each utility differ significantly.

The Dutch regulator (DTe) recently introduced quality regulation for the next regulation period [2]. Network operators will be assessed not only on the basis of a comparison with each other in relation to their economic efficiency but also in relation to the reliability of their grids. The aim of this quality regulation is to incentivise high reliability. If investment results in an increase in reliability, the network operator will be rewarded by means of an increase in turnover resulting from an increase in tariffs (CPI-X+Q). On the other hand, an operator that opts to invest less will achieve a higher profit in the short term but, if interruptions increase, the permissible turnover will be reduced and lower tariffs are inflicted. The actual reliability (expressed as SAIDI - System Average Interruption Duration Index) will be measured through the process discussed above, with the weighting based on the value of outages for the customers.

The current and expected status of Quality Regulation in Europe is as follows. Although a number of countries are developing Price and Quality regulation schemes, DTe is the first to implement a fully integrated scheme. The plan started on the 1st of January 2005. UK, Norway and Italy are developing schemes, but implementation is not yet scheduled. France, Belgium, Germany, Switzerland and Austria possess a comparable starting point in their service quality. These countries, however, are not regulating quality nor do they have intentions. It can be expected, however, that disturbances will soon lead to social and political demand for quality control from the regulator.

The new European countries face the challenge to simultaneously develop new market structures, open up for new market players and build new infrastructures. The emphasis is on the market opening for energy trading. Quality control is therefore postponed until stabilization and maturation of the energy market.

4. INSTRUMENTS FOR QUALITY OF SUPPLY BY THE NETWORK OPERATORS

The key question to grid owners and grid operators is: Prolong (upgrade or uprate), consume or replace. These decisions involve investment strategies, maintenance strategies and operational policy.

Liberalization and deregulation impose financial and social pressure to grid companies. They are therefore looking for solutions that are effective in sustaining the quality of supply while financially (not technically!) efficient. The following choices can be made:

— Upgrading and uprating

Components and systems are revised with new materials and control equipment. The idea is that the core of the assets is still very useful, while peripheral improvements increase the capacity and the remaining lifetime. An example is the plating with silver of tap changer contacts of distribution transformers.

— Dynamic rating

The capacity of components depends heavily on their circumstances. If these circumstances can be measured and used in control equipment, the capacity can be increased in the most critical situations. An example is the temporary overloading of lines and transformers, giving the operators time to re-establish outaged assets.

— Flexibilization of assets

Due the dynamic market circumstances, grid assets are not always required at the same place. It may be useful, then, to move assets from one place to another, where they are needed most. An example is the mobile capacitor bank that is placed at the substation where a large power plant is out of use.

— Standardization of assets

Tailor-made assets are expensive, although technically very efficient. When a less number of assets types is being used, knowledge will be better used and distributed and series production or procurement is established. The disadvantage of having more capacity than strictly required, is compensated by lower procurement costs. An example is a large Dutch DNO that uses only 6 types of cables in its distribution network.

At the same time, a major methodological development is coming up: Risk Based Decision Making, which can be applied at all strategies involved at a DNO: investments, maintenance, operations. With RBDM, a decision maker will use more knowledge about the chance that an event can occur (e.g. outage of a line) and the impact to its customers. Investigations are showing that the normally used n–1 criterion can be replaced with a Risk Based Reliability Index. It is shown that systems with less redundancy than the n–1 criterion would prescribe do not have less satisfied customers, because the impact is negligible.

Finally, the financial space is becoming more and more restricted. Companies are more and more interested in the total lifetime costs: Total Expenditures (TOTEX) = Capital Expenditures (CAPEX) + Operational Expenditures (OPEX). It means that investments are being judged on their investment and the operational costs simultaneously. This implies that assets are to be developed with the aim of reducing the TOTEX.

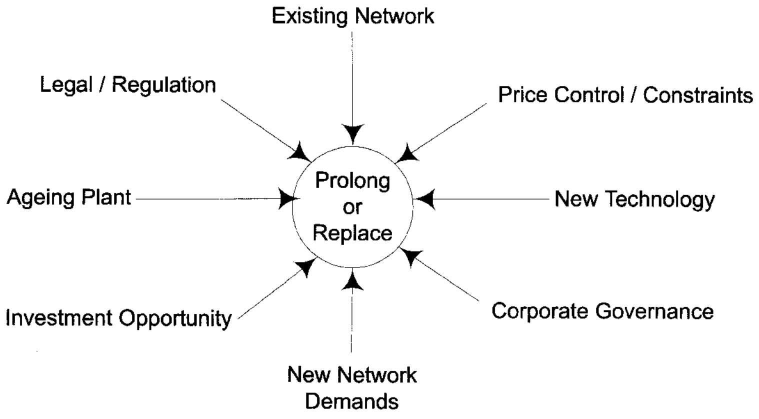

Fig. 3. Opposing pressures on DNOs

Figure 3 shows the opposing pressures that DNOs have to cope with:

- The existing network vs. new network demands.
  The existing networks are being developed and build when DNOs and TSOs were in charge of the entire strategic, tactic and operational planning of the electricity infrastructure. This has resulted in large power plants, centrally operated with (to a large extend) predictable power flows.
  Nowadays, distributed generation, sustainable generation and volatile markets ask for facilitation of unpredictable power flows.
  The challenge of DNOs is to rewire their network, without losing the benefits of the old structures. Major cash flows are involved, as the lifetime of network assets is at least 40 years.
- Price Control vs. Investment opportunities.
  Price Controls impose the financial pressure to be efficient. This includes using the financial reserves to take losses. On the other hand, these reserves may be used to invest in an efficient way, as no external capital expenditures have to be made.
- New Technologies vs. Ageing plants.
  If out of date assets are to be replaced, what should it be replaced with? The fastest alternative is using a copy of the existing one, but new technologies could be more effective and efficient. On the other hand, existing technology is proven technology, while new technology implies risks.
- Corporate governance vs. Legal and Regulation.
  Cross subsidizing may be efficient from a corporate point of view, it may also be held for unacceptable discrimination of commercial companies. DNOs should constantly look for the edge.

5. VALUE OF OUTAGES

The quality of supply is of major social concern, but against what costs. On the customers side there is a growing awareness for the quality of supply, of which reliability is an important part. In order to be able to compare their advantages of a good supply with the cost of required investments in power systems (which are recovered via customer tariffs) quantification is necessary.

In [2], both willingness to pay (WTP) and willingness to accept (WTA) were investigated, for four types of customers: households; small and medium enterprises; industries; and generating companies. The purpose of the survey was to find economic values. The survey included both written enquiries and personal interviews and included questions about the importance of voltage quality. In the questionnaires there was a direct relation between costs and performance, to avoid answers in the category "better performance at lower rates."

The survey amongst households revealed that 84% want to maintain the current level of availability. There was an expressed preference, when keeping the same annual minutes lost, for more frequent, shorter outages; rather than fewer, longer ones. There was an average willingness to accept (WTA) of 10 €/h (median value), independent of the size of the connection. An improvement of the availability above existing levels was found to be not valued, thus the WTP = 0 €. Problems with voltage quality were not an issue cited by household respondents. These results were found to be independent of both region and outage history.

For small and medium enterprises, the price of energy is the most important issue. Most of the damages due to outages (direct and indirect) are in the range up to € 100. In 13% of cases, damages exceeded € 1,000. The willingness to accept was expressed as a percentage of the annual energy bill, doubling the frequency or the duration equated to a WTA of 10% or 20%, respectively, of the energy bill. About 27% of the respondents in this group were willing to pay for a 50% decrease of outages, either in frequency or in duration: the WTP value was much lower, however, at 5%. This group does experience problems with voltage quality and related damage, nevertheless 85% wanted to keep the current level of voltage quality. There is not a significant relationship between the WTA and WTP and size of the companies, voltage level or energy use. For 51% of the enterprises, the price of the energy is the most important parameter. For 27%, both price and outage duration are important. For 22%, the order is: outage duration; price of energy and outage frequency.

Although the industrial investigation was a selective one, together the industries sampled are responsible for 29% of the Dutch industrial electricity consumption. Both small and large companies were involved, covering companies whose power demand ranged from 65 MW to 774 MW. For most industries surveyed, the cost of their electrical energy was below 10% of their total production costs. For some companies this rose to between 20 and 50% and in exceptional cases even that percentage was surpassed. Most damages due to outages were in the range € 1,000 to € 100,000. In about 10% of cases, though, damages exceeded € 100,000. Industrial customers show a large spread in their valuation of NDE.

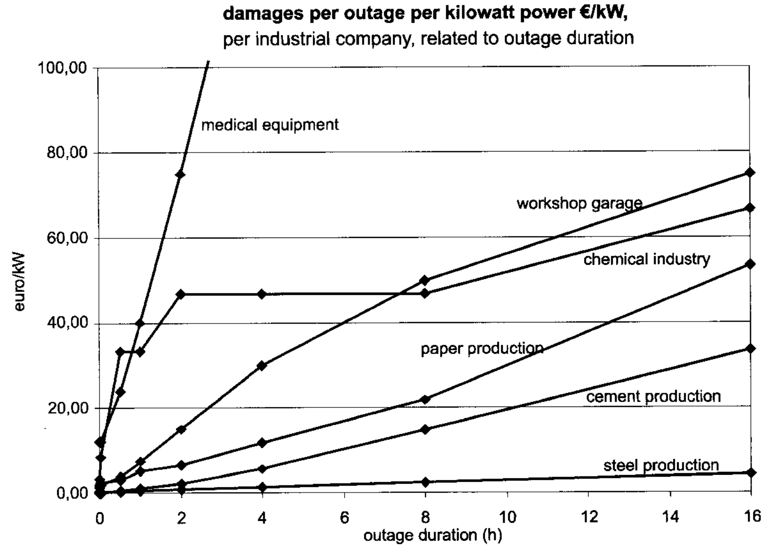

Fig. 4. Damages per industry in €/kW related to outage duration

Figure 4 shows the damages for several types of industry. With some exceptions, where damages were up to € 400/kW, most damages were in the range below 80 €/kW. The graph shows different patterns: high or low linear; increasing and decreasing slopes; stepwise increases and combinations. The WTA and WTP were similar to the previous group (small and medium enterprises). Doubling the minutes lost was acceptable if compensated with 10 to 50% of the annual energy bill, whereas a 50% reduction in minutes lost was only appreciated by 22% of the industries, at about 5% of their energy bill. For most industries the outage frequency was the most important parameter, followed by outage duration.

Voltage quality problems do lead to damages for most industries. Voltage dips are the main cause, followed by over-voltages, voltage variation, harmonic distortion and phase asymmetry. One third of the respondents said they would value an increase in voltage quality.

We found that the presence of local generation did not significantly influence the results.

Large power producers are, for historical reasons, located at reliable nodes in the high voltage network. They generally do not need a better availability (WTP =0), nor is there a want for a decrease. Outages at that level are rare, but if they occur, there is the possibility of very large damages, either for costly repairs to damaged plant or relating to additional costs incurred in covering their contractual power from elsewhere. Producers are heavily involved in discussions about voltage quality. Effects can be similar to interruptions but quantification appeared difficult. On the one hand this was due to the wide spread in possible consequences, on the other, the information is commercially sensitive and thus difficult to obtain.

6. OPTIMAL RELIABILITY

Cost reductions imposed by market and political pressure, will lead to an increasing pressure on reliability. In this environment, cost/benefit analyses are required. For assessment of new network designs or new operational procedures, performance statistics provide the input data for reliability studies, predicting the reliability consequences for customers. This may be used to estimate the damages or penalties to be expected. These results can then be compared to the investments or savings involved to determine the relative cost/benefit of the proposed new network design or operational procedure.

Since the desired quality of supply as expressed by the customers is important to the Dutch Government, KEMA has performed (in assignment of the Dutch Ministry of Economic Affairs) an investigation to develop a method to determine the optimal quality [5]. The results of this investigation have pointed out that there is a need for differentiation with respect to type of customer of what is meant by quality of supply and a need for clear responsibility for non-delivery of the desired quality of supply.

For a typical power system, KEMA has compared various approaches, as used by different network operators. The system supplied a mix of customers, households (town and villages), small enterprises, agricultural customers and medium size industries. The comparison made was with respect to the costs for the network operator (investments, losses, maintenance, etc) of delivering quality of supply versus the value for the customers (the value of NDE as defined above) all discounted to comparable annual values. It appeared that the costs of energy losses in connections and transformers are significant when related to investments.

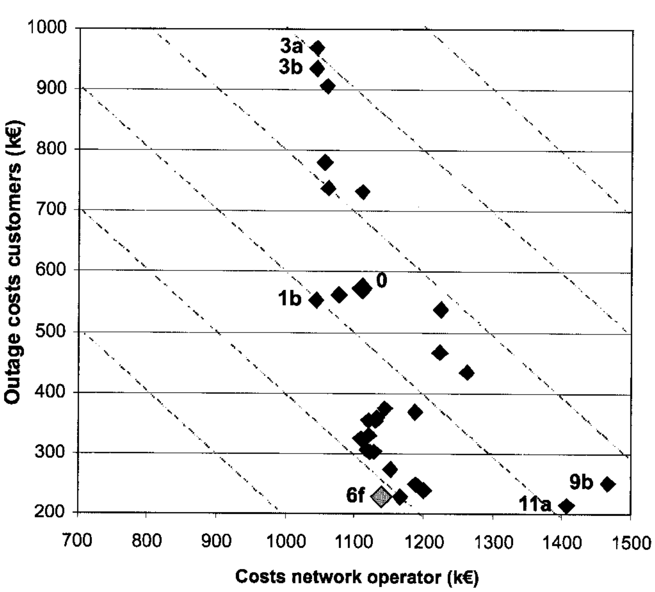

Fig. 5. Costs of network design for operator and customers

The study combined financial calculations with reliability simulations. Figure 5 shows the main result. Each dot represents a typical system design. The blue dot (case 0) is the base case, the existing conventional design. The red dot (case 6f) is the optimum design, based on the total costs. Total costs are the social costs, i.e. the sum of the costs for the network operator and the customers. In this example (case 6f) an increase in network costs of 2% results in a decrease of outage costs of 60%. The overall optimum is not the optimum for each individual customer, i.e. the best design for industry is not the best design for households and vice versa. (Thus in practice the optimum system design will vary from area to area, reflecting the mix of customers and thus tailor-made designs are needed.)

It has been made clear that a network operator can make decisions about design and investments, related to the expected availability of the resulting network, from the viewpoint of its customers. Customers may be represented by regulatory incentives.

7. CONCLUSION

Grid operators and regulatory authorities are struggling with sustaining security and quality of supply, while simultaneously achieving cost reductions if anyhow possible. This results in grid companies looking for solutions in order to comply with the regulatory rules (minimum standards) and incentives (quality regulation incorporated in the Price Control schemes). This asks for creative and innovative solutions, which can be divided into 3 categories:

1. **Technical:**

New components and system designs are being developed. Examples: electronic controlled transformers, Flexible AC Transmission Systems (FACTS), phase shifters, et cetera

2. **Operational**:

Components and systems are better utilized. They are uprated or even upgraded in order to make them more reliable. Risks are compared to financials.

3. **Measurable**:

The performance of grids is made measurable, by using statistical methodologies. This is then related to the Quality Control schemes of the regulator.

In all categories, performance, risks and financials are being balanced.

In the United Kingdom and the Netherlands, Quality Regulation schemes have already been developed and are (almost) in effect.

The combination of available outage data, the value of outages for customers and new probabilistic tools, makes it possible to find the social optimal power system design even under new quality regulation and increasing planning uncertainties.

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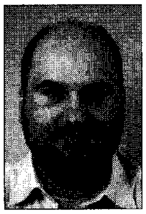

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