AN EXAMPLE OF INVESTMENT PLANNING OF POWER DISTRIBUTION USING QUANTITATIVE RELIABILITY AND COST ANALYSES

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ABSTRACT

From 2012, there will be a new regulation of the electrical power distribution system tariffs in Sweden. Still there are uncertainties regarding the final content, but the basic concept is now settled. Known parts of the new regulation have been used as input to the economic analysis of a potential investment in a Swedish power distribution system owned by Fortum Distribution. The described method could however be applied on any European power distribution system, with adaptation to national laws and regulations.

First, a reliability model of the concerned part of the system was created for every potential investment alternative. Quantitative reliability analyses were then performed on these models. Based on calculated reliability indices and assumptions regarding the new regulation, outage costs were calculated. These costs were used as input to life cycle cost (LCC) analyses including more parameters, e.g. maintenance costs. Different investment proposals were evaluated and compared. Sensitivity analyses with respect to increasing outage compensation and WACC (weighted average cost of capital) were made, supporting the same investment. In this case, one investment alternative was clearly pointed out as the best.

INTRODUCTION

In January 2005 a severe storm hit Scandinavia, entitled Gudrun (Norwegian Meteorological Institute) or Erwin (German Weather Service), causing extensive interruptions of electricity power supply. In Sweden the storm increased the political- and media interest of how electrical power systems are managed and designed [1]. New laws have been introduced since then, intending to e.g. reducing customer outages. Individual customer will be compensated for outages longer than 12 hours and a functional requirement of 24 hours has been introduced, i.e. longer outages are forbidden. In addition, the distribution system operators (DSOs) must annually construct a risk and vulnerability report. This report shows known risks in the network, often linked to high outage numbers and an action plan on how to handle identified risks.

Furthermore, customers could be collectively compensated with decreased tariff levels, by the Swedish tariff regulation, if the mean reliability level is poor. This kind of reliability function was first introduced 2002 [2]. The result from this regulation gave indication that the tariff levels in some cases were too high, resulting in decisions on recovery. This decision was appealed and a comprehensive legal process began. In late 2008 an agreement was made. Simultaneously, an EU directive forced Sweden to shift to ex ante regulation. Instead of modifying the existing model and continue to fight legally, a completely new model will be introduced from 2012.This model also intend to include some kind of quality function [3].

A tendency in the distribution business is that focus of the DSOs to achieve optimal investments increases. This means that companies are trying harder to evaluate the benefits investments can return. A popular tool to use in the evaluation process is life cycle cost (LCC) calculation. With this tool, costs for investments, maintenance, electric losses, outage costs etc. can be evaluated during the entire life time of a component or system.

THE SWEDISH LEGISLATION

The new Swedish regulation [3] will be applied from 2012. The content is not yet fully established, but the main parts are settled. A regulation period consists of 4 years. Essential parts will be:

- **Capital cost** of a component consists of depreciations and the cost of restricted capital. The regulator intends to apply capacity conservation principles by using real annuity. A constant annuity is calculated based on the estimated net present value and economical lifetime. The constant annuity value is used despite actual age. If a component is older than its estimated economical lifetime, the compensation will be the same; this gives incentives to maintain components carefully. The required rate of return is calculated with the WACC method (weighted average cost of capital).
- **Operating costs** is divided into:
  - **Effectible costs**, this part of the regulation is not yet settled by the authority.
  - **Non effectible costs**, such as taxes. These costs will be fully compensated.

- **Quality function** is in the first period measured as changes in SAIDI compared to previous years. All customer outages are valued equally, which means a household's outage is valued equal to e.g. farms or industries. Improved SAIDI figures enable space for higher tariffs, whereas worse figures cut the tariffs for the following period. The quality function is limited to affect the compensation for cost of restricted capital (part of the capital cost) up to 3%.

Besides the tariff regulation, compensation for outages above 12 hours is handled separate by the Swedish law [4]. This compensation is, compared with other countries [5], high; a household for instance will receive 12.5 % of the yearly tariff fee for an outage between 12 and 24 hours or at least ~100 Euro. If the outage reaches 24-48 hours the return is 25 % (minimum ~200 Euro), and so on for every 24 hour period to the maxima of 300 % of the annual tariff level (the maxima is for a single outage, if a customer is affected by several outages there is no theoretical maxima). Outages ≥24 are also forbidden; this could lead to additional consequences for the DSO. The risk- and vulnerability report will be connected to the 24 hours requirement, i.e. if an ≥24 hours outages occurs, the regulator look at this report; if the DSO has identified the underlying risk and include a reasonable action plan to reduce the risk the regulator will be more comprehending. There are plans to include more quality aspects in future regulations, such as voltage quality and customer service.

STUDIED SYSTEM

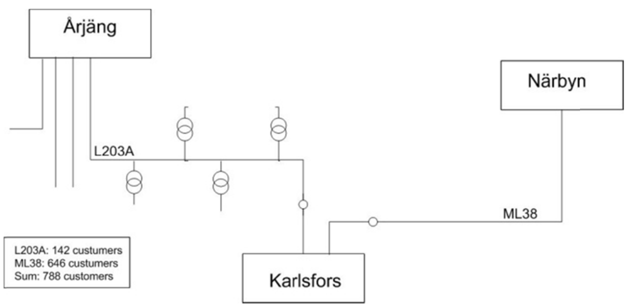

Figure 1 – Schematic of the studied distribution network

The studied object (situated in the western part of Sweden), substation Karlsfors, see Figure 1, is in normal operation mode, fed from feeder L203A, originating from substation Årjäng. System voltage is 20 kV. There are nearly 800 customers located under Karlsfors and L203A. A backup, 30 kV feeder ML38, from substation Närbyn to Karlsfors also exists, see Figure 1. The current situation is that the backup line, ML38, is in a very bad condition, it has to be either almost completely rebuilt or dismantled, which in the latter case means that substation Karlsfors lacks reserve feeding capabilities. If it is to be rebuilt there are different alternatives. Another parameter to take into account is whether Karlsfors should be fed from Årjäng or Närbyn in normal operation, given that the line will be renewed.

METHOD AND CALCULATION

Reliability model

The description of the applied method is made with an authentic example, investments planning of the supply of a substation entitled Karlsfors. The evaluated investments also affect surrounding substations in terms of availability. These effects are neglected in this article. Only one fault is assumed to occur at a time, which simplifies the problem substantially. Basic reliability theory is used [6] [7], where:

- *Customer outage* is when the electrical supply is interrupted ≥3 minutes, defined by the Swedish regulation,
- U_i [hours/year] is the sum of the length of every customer outage affecting Load Point i (LP_i) during one year,
- N_i = Number of customers in LP_i,
- *System Average Interruption Duration Index* $SAIDI = \frac{\sum_i U_i N_i}{\sum_i N_i}$ [hours and minutes/year] (1)

Since the outage cost estimation used by Fortum has the unit EUR per minute of affecting one customer, a reliability index entitled *Customer outage minutes* [minutes/year] is used defined as:

$\sum_i (U_i N_i)$ or $SAIDI \sum_i (N_i)$ (2)

Cost assumptions

The parameters considered in the calculation were investment, maintenance and outage costs. The shift in capital base was included as a yearly income or cost, depending on if network was increased or decreased. The cost for unexpected outages is in the new regulation divided in a power part, C_P and an energy part, C_W as follows:

$C_P = 2.1 \frac{EUR}{kW}$, $C_W = 6.0\ EUR/kWh$ (3)

In this paper the exchange rate 1 EUR = 9 SEK is used. The WACC is an important parameter which can highly affect whether an investment is profitable or not. In these financial turbulent times, with low repo rate and low inflationary pressure, the WACC is set to 5.2%. A sensitivity analysis with respect to increasing WACC was made to keep abreast of changing economic climate.

In order to make efficient LCC calculation possible, standardized values for outage costs within the company have been constructed. The average customer yearly consumption, E_a, in Fortum network is 16000 kWh and a typical outage, $t_{average}$, last 1.5 hours. Dividing E_a with number of hours per year gives an average yearly power outtake. An average cost per *Customer outage minutes* can be calculated as:

$$C_O = \frac{E_a}{8760}\left(C_P + C_E t_{average}\right) = \frac{16000}{8760}(19 + 54 * 1.5) = 20.3\ EUR \quad (4)$$

$$C_{O_{minute}} = \frac{C_O}{1.5*60} = 0.22\ EUR/minute \quad (5)$$

In the first regulatory period the calculated cost for an outage should be divided equally between the DSO and the customer. This means that the cost is reduced to 0.11 EUR/min when comparing solutions with LCC. For next regulatory period this cost is highly liable to increase, therefore a sensitivity analysis was performed with higher outage costs.

Investment alternatives

The network solutions that were considered for the network are:

0. **Alternative 0** Destroying the backup line, ML38, i.e. feed Karlsfors radially through L203A.
1. **Alternative 1** Changing of most poles and expanding of line corridor of ML38, making it tree safe. Also ML38 will feed Karlsfors in normal operation.
2. **Alternative 2** Destroying ML38 and rebuild it as underground cable. Karlsfors will be fed via ML38 in normal operation.

Calculations

For each alternative the total *Customer outage minutes* can be estimated. In order to calculate the outages times, historical data for the specified network reaching three years back in time was used, along with general Fortum outages data. Table 1 shows outage data for the feeders considered.

TABLE 1 – Feeder outage data

Feeder	Outage/year, $n_{yearOutage}$	Mean repair time, t_{rep} [hours]
L203A	3.3	3.9
ML38	2.3	72

The long reparation time for ML38 is explained by that it is a backup line and hence got low priority. The impact of the customer compensation law, outages exceeding 12 hours are not considered in the LCC analysis according to the reparation time in table above. Its impact, will however be discussed in the conclusion section. In alternative 1 and 2, the failure rate is assumed as 0.005 failures/year and km, regardless if three safe overhead line or underground cable is used (template values received from Fortum). The failure rate of underground cable is probably slightly lower than three save overhead line (e.g. less vulnerable to lightning). However, this is done due to lack of input data and because this not affect the result. If ML38 is rebuilt with overhead lines the length will be 30 km, but if underground cable is chosen, the length will become 36 km. The outage times for the alternatives can be calculated as:

$$T_{Alt0} = n_{costumer} n_{yearOutage} t_{rep} = 788 * 3.3 * 3.9 \approx 10\,100\ hours \quad (6)$$

$$T_{Alt1} = n_{costumer} n_{yearOutage} t_{switch} = 788 * 0.005 * 30 * 1.5 \approx 177\ hours \quad (7)$$

$$T_{Alt2} = n_{costumer} n_{yearOutage} t_{switch} = 788 * 0.005 * 36 * 1.5 \approx 213\ hours \quad (8)$$

The time t_{switch} is the mean time it takes to identify an error at ML38, sending a technician to Karlsfors and manually switch to feeder L203A. The calculated outage times and costs are summarized in TABLE 2:

TABLE 2 – Calculated yearly outage times and costs

Alt.	Outage hours	Outage costs [EUR]
0	10 100	67 000
1	177	1 200
2	213	1 400

RESULTS

Sensitivity LCC-analyses

In TABLE 3 the different network solutions are compared by applying an LCC-analysis assuming 40 years economic lifetime and q $\left(1 + \frac{discount\ rate\ [\%]}{100}\right)$ equals 1.052. The Sum of Discount Factors with constant discount rate and annual cost over 40 years is $\frac{1.052^{40}}{\frac{5.2}{100}1.052^{40}} \approx$ 16.7.

TABLE 3 – The results of LCC calculations

Present value [EUR]	Alt 0	Alt 1	Alt 2
Initial cost	55 556	1 068 904	4 232 222
Capital cost	1 174 332	-570 951	-2 858 120
Maintenance cost	0	345 120	16 699
Outage cost	1 120 364	19 739	23 686
Total cost	**2 350 251**	**862 812**	**1 414 488**

From TABLE 3 it can be seen that alternative 1 has the lowest cost in present value. That is rebuilding ML38, making it tree safe and feed Karlsfors from ML38 in normal operation. A major post in TABLE 3 is the Capital cost. In alternative 0 network is destroyed, therefore the cost is positive. In the two other alternatives network are added leading to a negative cost.

Sensitivity analyses

Sensitivity analyses are motivated by future uncertainties such as the level of WACC and changes in laws and regulation. Sensitivity analyses were performed with respect to:

(a) WACC, see Figure 2.
(b) Outage cost, see Figure 3.

It can be seen from Figure 2 that the result is sensitive to WACC, and that alternative 1 is the one to prefer while the WACC is between 5% and 13%. The interval is big enough to assume that the WACC does not override this limitation. Figure 3 shows that the result is robust to changes in outage costs.

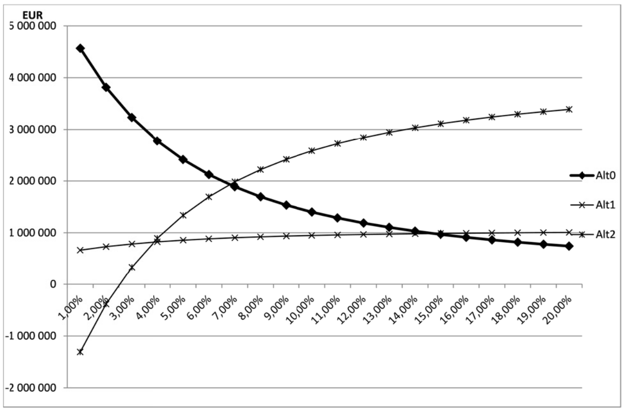

Figure 2 Sensitivity analysis with respect to WACC

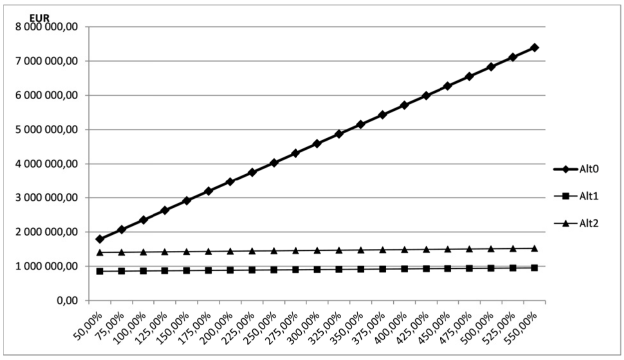

Figure 3 Sensitivity analysis with respect to outage costs

Concluding remarks on the results

In general outage costs will have a small impact on chosen network solution during the first regulatory period. This is true for outages between 0.05 and 12 hours. Longer outages do however have a sharp effect on company result. In the studied network most customers are households. A rough calculation of paid outage fees, in case of 12 hours outage and 100 Euro compensation per customer, gives nearly 80 000 EUR. If the fault was cleared just before the 12 hour mark, the cost the revenue regulation would have been roughly 58 000 EUR. Furthermore, the revenue regulation will have effect on company result no earlier than next regulatory period. Limiting outages to 12 hours is therefore desirable.

Alternative 2 is outperformed by alternative 1 because the existing feeder ML38 was destroyed and replaced with underground cable. Demolishing network is very costly due to decreasing capital base which leads to lower network tariffs. There is a risk that the DSOs will use this fact keeping as much network as possible in operation, which could lead to inappropriate network topology.

CONCLUSIONS

This paper proposes a quantitative reliability method applied to investment planning of power distribution systems. The method consists of well-established reliability indices such as SAIDI and life cycle cost calculations (LCC) including e.g. maintenance costs for the entire economical life time. The novelty of the method is to use tariff regulation as economical input combined with quantitative reliability indices.

The method is exemplified with an authentic example of an investment planning process performed by a DSO using the new Swedish tariff regulation that will be applied from 2012 as input data. Results from the example show that it is possible to receive clear and stable results that could be used by a DSO for an investment decision with several relevant alternatives. Hopefully this will inspire other DSOs to introduce more advanced planning methods enabling higher degree of cost efficiency. This will be increasingly important by the worldwide tendency of performance based tariff regulations and increased demand of reliable electricity supply in the future.

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