INVESTMENT STRATEGY STUDIES BASED ON A STOCHASTIC MODEL OF MV FEEDER QUALITY OF SUPPLY

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ABSTRACT

With the opening of the market, distribution network operators have to face new regulation schemes and to introduce them in their investment strategy studies.
The paper describes a new way to elaborate investment process to achieve this goal.

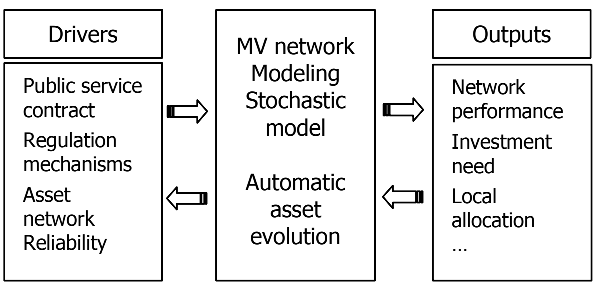

Figure 1 : Overview of the methodology

The dynamic process is based on a stochastic model giving the probability a feeder experiments k cuts in a year. This model is suited to a Poisson law the parameter of which depends on its component and environment (rural/urban, climatic). It gives the risk of overpassing a local threshold in interruptions for each and every feeder.
The model is used to carry out a risk analysis and to asses development policies. The current network is projected over the future by applying a load growth, natural extension and ageing (asset failure rate is modeled as a function of time). The simulation tool developed by EDF calculates the network performance and proposes the optimal sequence of investment over a whole network to decrease it or to face the regulatory demands.
Network development is led by drivers indicated above. The tool evaluates the optimal measure to every feeder (chosen among a set of model solutions). The competition among every solutions is ruled with a benefit (risks avoided) to cost ratio. Thus the next optimal action is assessed. The loop goes on until quality targets (average number of customer interruption, percentage of customer overstepping quality level) have been reached.
This risk management process has been effective for 2 years in EDF. Some applications have been performed. In particular it has helped the distributor to balance regulation mechanisms with investment and to allocate financial resources between local distribution area.

MODEL

First of all the methodology is based upon a stochastic model linking the probability of cuts for a feeder with its components and its environment. The way to elaborate this modelling and its main parameters was described in a previous paper [1]. Results and some more details are given below to help its understanding.
We assume the number of cuts on a feeder follows a discrete usual law, the Poisson law.

$$P(nc_{D_j}=k)=\frac{\exp\left(-\sum_{i=1}^{n}\alpha_{i,j}.\lambda_{i,D_j(env)}\right)}{k!}.\left(\sum_{i=1}^{n}\alpha_{i,j}.\lambda_{i,D_j(env)}\right)^k$$

where

- $P(nc_{D_j}=k)$ stands for the probability that feeder D_j experiences k faults during a year,
- the parameters $\alpha_{i,j}$ give the characteristics of component *i* of the feeder D_j (length of line and cable, number of MV/LV substations for instance),
- $\lambda_{i,Dj}$ corresponds to the failure rates of components *i* (overhead line, underground cable, MV/LV substations). We assume that a component that occurs in several feeders has the same random characteristics.

Feeders are split in the components selected :main lines and cables technologies, HV/MV and MV/LV substations,… and rural/urban environment for underground cables.

Calculation of the failure rates

The set of parameter of the stochastic model can't be evaluated directly feeder by feeder because of the limited experience feedback (we observe the annual values of failures over a limited period). Moreover in many case the accurate locations of faults are not saved in the available database. Thus a statistic calculation is used to extract the failure rates from limited information : Maximum likelihood estimation.
The main hypotheses of the stochastic model are the following ones :

- a component met in several feeders has the same random characteristics. In some case, this hypothesis cannot be checked. Thus, we consider several rates of failure for a same component, depending on its environment (rural, urban). Obviously, more detailed data are required in this case.

- at this stage, we don't take account of the ages of the feeder components.

The step is illustrated by the following graphs : our method makes it possible to pass from an experience feedback (figure 2) to a stochastic model (figure 3).

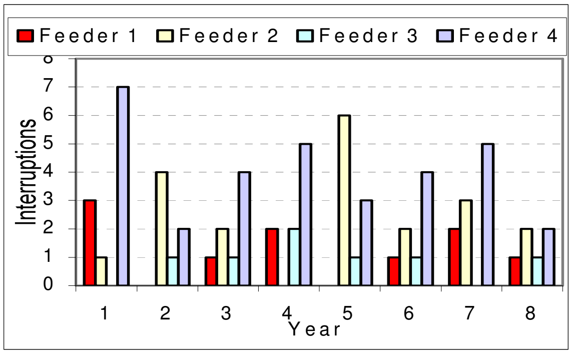

Figure 2 : Quality issues

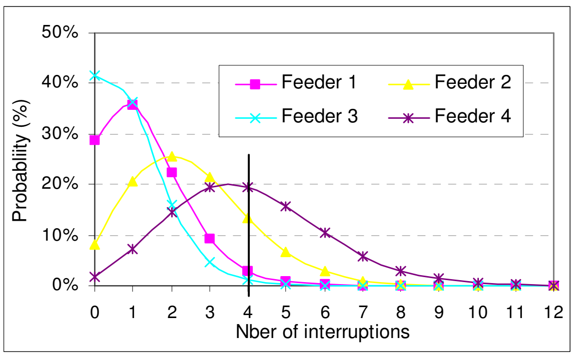

Figure 3 : Distribution probability of cuts

Risk evaluation

Risk criteria is defined as the probability that feeder oversteps a quality threshold (expressed in terms of number of cuts per year). For example the surface of the curves above from a 4 cuts - threshold quantifies the risk for the feeder experiencing more cuts than committed. It is assesed on each feeder and weighed with the low and medium voltage customers fed by the feeder. Risk can be expressed by both formula following :

$$R_i = Nbcust_i . \sum_{k=t+1}^{\infty} \Pr ob\ (nc_{feeder.i} = k).(k-t)$$

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The choice of one depends on the regulatory frame. We select the second formula (ie we don't index risk on the importance of the overstepping).

Risk on a single feeder is a random variable that follows a Bernoulli law. Its expected value and standard deviation are expressed by :

$$E(R_i) = Nbcust_i . prob.(nc_{feeder.i} > t)$$

$$SD_i = Nbcust_i^{\ 2} . prob.(nc_{feederi} > t).(1 - prob.(nc_{feederi} > t)$$

where

- t is the threshold,
- $Nbcust_i$ is the number customers connected to the feeder i,
- $nc_{\text{feeder i}}$ is the number of cuts of feeder i.

On a set of feeder, we can write :

$$E(R) = \sum_{feederi} Nbcust_i . prob.(nc_{feederi} > t)$$

$$SD(P(R)) = \sqrt{\sum_{Feeder\ i,\ threshold} (Nbcust_i)^2 . prob.(nc_i > t).(1 - prob.(nc_i > t))}$$

The sum of many independent random variables is itself a random variable that will tend to be approximately normally distributed (central limit theorem). Then the global risk on a whole area follows a normal distribution defined by the mean E(R) and the standard deviation SD(R). We can show that standard deviation is sensitive to the area size: the larger the area, the closer the variance to the mean.

Quality regulation mechanism

The distribution system operator will have to meet regulatory requirement expressed by 'no more x % of customer will suffer yearly more y cuts on an area'.

We can refer to the tabulated values of the standard normal distribution. The cumulative distribution function gives the probability of the global risk to be less than or equal to the target x. And expected value of customers overstepping the y cuts can be calculated. Therefore a relation between regulatory requirement and expected value is being built. Figure 4 provides an example of global risk for a x-value equal to 5 % applied to a set of feeders.

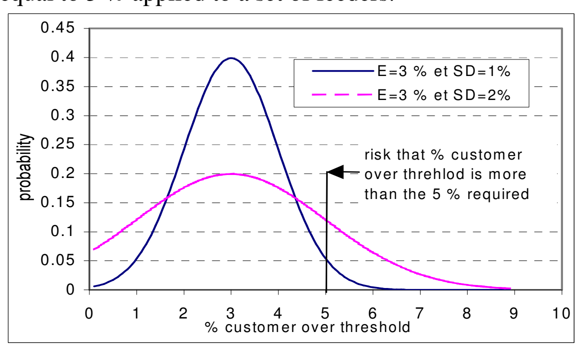

Figure 4 : normal distribution risk

SIMULATION NETWORK DEVELOPMENT

A prototype has been developed by EDF in order to simulate the impact of any development policy on the network over the requested quality requirements.

The tool performs several tasks described below.

Risk evolution in time

Global risk increases in time due to the load growth, the natural extension of the network and the asset ageing. This last parameter, a key one, could be easily assessed should it be modelled as a function of time [2]. It provides in particular :

- a deep insight into future over a large scale network,
- an identification of the most critical feeder components.

Network development simulation

Once the global risk is calculated over a large scale grid, the tool proposes different scenarii to decrease it.
It evaluates the impact on risks resulting from scenarii applied to the feeders of the grid.
A generic scenario is an asset or network evolution chosen among a set of models : replacement of overhead line and cable section, feeder split and automation are currently the generic actions modelled.
Each scenario is compared to other in terms of benefit (risks removed) to cost ratio, and the one whose benefit to cost ratio is maxima is selected on each and every feeder. All the scenarii selected are ranked, and the first action is implemented. The next following best scenario on the feeder involved is evaluated and ranked in the previous list. Then the second best action is implemented, and son on. The process goes on and stops when quality targets are met.
Such a process helps to pinpoint the best action on a feeder and enables to evaluate the investment need to reach or maintain a quality level. Moreover some design schemes may be assessed (replacement vs feeder split for example).

MAIN APPLICATION AT EDF ERD

The model has been applied on the French MV network operated by EDF. Assets have been split into 19 families, 9 of which refer to overhead lines, and 5 to underground cables in both rural and urban environment.
Relevance of model has been schecked by comparing simulation data with historic data of customers cuts. The similarity of bots distribution enables to validate the model.
The simulations performed supplied precious inputs in order to elaborate the network medium term program.
More generally, the process can help the asset management

- in its relation with the regulator to balance regulation requirement (quality threshold, penalties) with investment and tariff,
- to allocate financial resources between the local distribution areas,
- to pinpoint the worst feders and the best asset evolutions on every feeder.

DEVELOPMENT PERSPECTIVES

Developments are still ongoing both on the model and on the process.
On one hand, current modelling takes environment for underground cables. Next step will include climatic conditions (snow, frost, lightning, …) and wooded environment for overhead lines. Final model would be established as a sum of terms specific to each sensitive parameter in regards to reliability : equipment, environment, climatic, maintenance and ageing.
Other scenario will be added to the generic ones : HV/MV stations, maintenance.
Model will have to cover the other quality requirements such as short interruption and interruption duration.
Moreover in order to be complete, the process should include other drivers : consumption and climatic plan [3].
Then the prototype will evaluate the benefit of each scenario in risks, electrical constraints (overload, voltage drop, short-circuit current removed) and climatic risks (network vulnerability reduction).

CONCLUSION

The method is based on a stochastic model that connects performance of each and every feeder to its component. A prototype developed enables to evaluate any development policy in terms of risks, quality, investment on a large network and on a long-term perspective.

REFERENCES

[1] D. Dercle, G. Stawinski, L. Gauthier "Stochastic Model Of MV Feeders quality of supply for investment strategy studies”, *CIRED 2005.*

[2] C. Spelleman, L.Gauthier "Impact of ageing on the MV underground asset reliability”, *CIRED 2007.*

[3] J. Horvilleur "How to reduce the impact of major climatic events : action plan », *CIRED 2007.*