ADVANCED RELIABILITY ASSESSMENT OF A DISTRIBUTION NETWORK; OBJECTIFYING OF PROPOSALS TO IMPROVE THE QUALITY OF SUPPLY

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ABSTRACT

This paper describes how Essent Netwerk, a Dutch distribution network operator, decides on improving the quality of supply of the distribution network supplying the largest city in the north of the Netherlands. A relatively large number of outages in 2005 in this city justified a closer look at the quality of supply. Several explanations have been given for this relative large number. Also several solutions have been proposed to improve the quality of supply for this distribution network. Before management took a well-founded decision about what to do, members of the asset management team were asked to address the question whether the relatively large number of outages should be regarded as a stroke of bad luck? This paper describes how this question has been addressed. Moreover, this paper shows how the impact of several solutions on quality performance indicators has been calculated. It is worthwhile to know, the calculation method also allows for operational (restoration) and maintenance aspects of the proposed solutions. The outcome of these calculations has been used to advise the management of Essent Netwerk.

INTRODUCTION

In the year 2005, Essent Netwerk had to cope with an unusual large number of power interruptions in Groningen, the largest city in the north of the Netherlands. It is useful to know that the former municipal network company, which has been taken over by Essent Netwerk in 1999, has constructed the MV network of this city. Due to the typical local circumstances in the past, the design and operations of the network differs from the usual concept as applied in other MV networks of Essent Netwerk. The main differences concern a lower level of redundancy and the absence of remote control of the HV/MV transformers.

Because a number of failures occurred shortly after each other, a closer look at the network configuration and condition of the components was required.

The expert opinion at Essent Netwerk was that the high number of failures most probably was just a case of bad luck, since the separate failures seemed to share no common properties. Because of its typical network configuration and related operation, the reliability of the network compared to that of other Essent Netwerk networks became also an issue. Therefore, the Strategic Network Development group at Essent Netwerk started to investigate the reliability of the network (reference [1]).

The central question that had to be answered was whether the high number of failures in 2005 were just a deviation of a normal average network performance or were caused by a more structural deficiency, possibly related to the different design and operation of this network. The asset management team broke down this central question into the following questions:

- What is the present reliability of the distribution network?
- How does this reliability compare to that of networks of similar cities?
- Which components in the network determine the greater part of the reliability of the network?
- What is the effect of proposed measures on the reliability of the network?

DESCRIPTION OF MV NETWORK

Similar to other city MV networks, this network has a long history, which is reflected in the network structure. This structure also reflects the operational philosophy of the former municipal network company. A limited level of redundancy and remote control could be allowed for, since the repair crews could act on faults quickly, due to relatively small geographical scale of the network. The repair crew could restore interruptions quickly by locating the faults and manually switching to alternative feeders. Further investments in (own municipal) MV networks were preferred above investing in HV/MV transformers managed by the regional network operator. The centralized network operation and repair crew dispatch that is in use today certainly is more efficient, but may also cause longer interruption times, if no additional measures are taken,

Figure 1 shows the main part of the MV subtransmission system, concerned in this study. The network has three substations, BS, HK and BH. All stations are equipped with a double rail system with three sections. To each left (A) and right (B) section a MV distribution grid is connected via a number of feeders. The mid sections (R) are interconnected by a triangle of MV cables.

Each station is connected to the surrounding HV transmission network by two transformers. The mid section R at BH has a spare HV/MV transformer. The interconnecting triangle is strong enough to allow this “R” transformer to take over the function of any of the ”A” or “B” transformers at any station. In this way, the “R” transformer provides redundancy at all stations instead of each station being “autonomously redundant”.

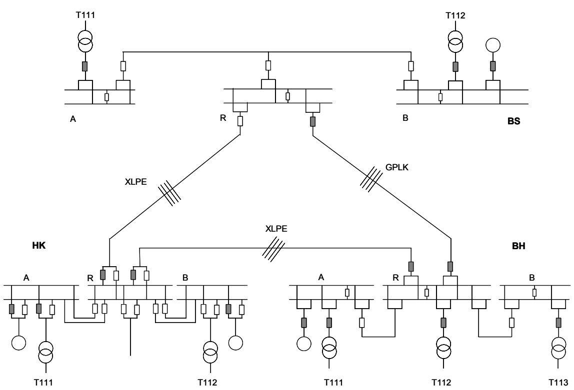

Figure 1: One-line diagram of part of the considered distribution network

The answers to the questions as posed in the introduction have been given in terms of SAIFI (System Average Interruption Frequency Index), CAIDI (Customer Average Interruption Duration Index) and SAIDI (System Average Interruption Duration Index).

MODEL FOR RELIABILITY ASSESSMENT

Figure 2 shows the general composition of a reliability assessment [2] and the inputs that are required. A model of the MV sub-transmission network was created and validated by loadflow analysis. Failure rates were taken from the Dutch annual failure statistics [3] for each MV cable and busbar. The HV stations were assumed to be 100% reliable, but the HV cables and the HV/MV transformers were populated with failure data.
The probability of a breaker failing to open was taken into account by adding the expected frequency of these events to the failure rate of the feeding bus section. This expected frequency equals the failure rate of the connected cable, multiplied by the probability of the breaker failing to open in case of a failure in that cable. A breaker failure will thus result in the isolation of the whole bus section. The probability of the breaker failing to open was taken as the probability of the protection device failing to generate a tripping signal, plus the probability of the breaker failing to open on a trip signal.
The outage analysis has been applied under the assumption that outages due to overload in the network do not occur, owing to sufficient redundancy in the network. Therefore, cascading effects due to overloading after an outage have not been modelled.

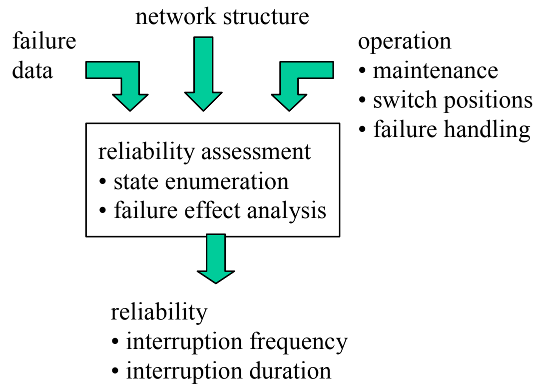

Figure 2: Reliability assessment

The failure effect analysis has been performed on the basis of an interactive heuristic FEA method. This method automatically generates switching actions for all failures, on the basis of heuristic topological analysis. This algorithm will clear faults correctly and will close normally open switches for power restoration. The list of switching actions was then checked manually and adapted where needed for those faults that require special switching actions. Manual switching actions by network operators were modelled in this way. In this manner, the FEA could be defined quickly and accurately.

Different restoration times have been assumed for different types of outages. This depended for example on whether loads could be switched to the other bus bar, or had to be transferred manually to another bus section. Most restoration times could be modelled as switching times in the breakers and sectionalizers, after which the heuristic FEA would find the correct restoration time for all failures.

The effect of the unavailability of network components due to maintenance was taken into account by calculating the reliability indices for each maintenance situation. The overall results were then calculated by summing these individual results, using the probabilities of each maintenance situation.

BASE CASE AND OPTIONS

When all 7 transformers (refer to Figure 1) are available, only 6 will actually be in service and the transformer at bus R of station BH will be stand-by. In case of an outage of any of the 6 transformers, the power to the interrupted rail section will be restored by closing the interconnecting triangle such that the “R” transformer at station BH will take over the function of the outaged transformer.
The “R” transformer is also required for performing

maintenance at any of the "A" or "B" transformers. During such maintenance, the "R" transformer will not be available for rapid power restoration. In case of a transformer outage during transformer maintenance, it will be needed to interrupt the maintenance, putting the maintained transformer back into service, after which the "R" transformer can be switched to the interrupted section. This causes prolonged interruption times, due to the time required to interrupt maintenance and take the transformer being maintained safely back into operation.

An annual total of 1% maintenance time for each transformer was assumed, which adds up to 7% unavailability for the "R" transformer.

This situation, with an unavailability of the "R" transformer of 7%, is referred to as the "Base Case". Reliability assessment was performed for the power restoration alternatives with:

- manual switching at the substations
- remote controlled switching from the control centre
- fast automated "ping-pong" switching by relays

These reliability assessments were repeated for some alternative designs.

Option 1: n-1 security at each substation

The first option is the "n-1 secure" option where the transformers have been up-graded in order to provide n-1 security at each substation individually. This means that the "R" transformer is not required in case a HV/MV transformer is outaged. One substation transformer can then feed the entire substation load. When a transformer fails while the other substation transformer is being maintained, then obviously it will still be required to interrupt the maintenance in order to restore power.

Option 2: Extra transformer to the "R" section of the HK station

In the second option an extra transformer is added to the "R" section of the HK station. In this case the third transformer of the BH station is back-up for the other two transformers of this station only. The extra transformer in the HK station is now backup for the two transformers in the HK station and the two transformers in BS station. As a consequence, the non-availability of a backup transformer in the BS station and that in the HK station equals 5 %. The non-availability in the BH stations equals 3%. Thus, in this option BH is individually n-1 secure, while station BS and HK share one back-up transformer for n-1 security.

Option 3: Transfer of distribution substations

The third option involves the transfer of two MV distribution stations from the substations BS and HK to the BH substation. In doing so, a future n-1 secure supply from substation BS and HK can be guaranteed. The interconnecting triangle is broken open and connected permanently to these distribution stations. The interconnection between station BS and HK remains intact. However, the four transformers of station BS and HK do no longer mutually back up each other during maintenance of one of these, since back-up now already exists at each station individually.

RESULTS

A reliability assessessment has been carried out for the base case. For this purpose, the quality performance indicators SAIFI, SAIDI and CAIDI have been calculated, as mentioned before. Hereupon, the reliability related to the options has been assessed. These results will be discussed in relation to the four questions posed in the introduction.

What is the present reliability of the distribution network?

Table 1 shows the calculation results. Notice, that the number of interruptions with duration of over 4 hours has also been determined. This has been considered, since the Dutch network operators are legally required to compensate their customers who have experienced an interruption longer than 4 hours.

Table 1: Comparison Base Case results

	SAIFI 1/a	SAIDI min/a	CAIDI h	> 4 h %
Groningen	0.109	13.1	2.0	12
Dutch average 2005	0.18	15.5	1.4	10
Difference	61%	85%	143%	120%

It can be seen that in 12 % of the cases the interruptions last 4 hours or longer.

How does reliability compare to that of networks of similar cities?

Having calculated this quality of supply performance, the next question became obvious: how does this reliability compare to that of networks of similar cities? The idea was to make use of the database, Nestor [3], in which the Dutch network operators register outages that have occurred in their network. However, it turned out that is was not possible to extract outage data related to cities networks due to missing geographical data. Therefore, the network concerned has been compared with the Dutch average of the MV networks.

Table 1 shows that the calculated indicators are in the same order as the Dutch average of MV networks. Although some differences can be noticed, one should be careful to draw conclusions from this. It should be recognised at this point that reliability assessment is more suitable for calculation of relative reliability changes (in case of different grid designs) rather than producing absolute reliability levels.

Which components in the network determine the greater part of the reliability of the network?

The following question needs to be answered to know the bottlenecks related to quality of supply: which components in the network determine the greater part of the reliability of the network? To answer this question, the contribution of all components to the performance indicators has been determined. Actually, a sensitivity analysis has been carried out to determine these contributions.

Table 2: Base Case results with contribution of HV/MV transformers

	SAIFI 1/a	SAIDI min/a	CAIDI H
Transformers	0.039	2.9	1.2
Other	0.069	10.2	2.4
Total	0.109	13.1	2.0

The sensitivity analysis reveals that the HV/MV transformer (and transformer cable) has a relatively high contribution to the performance indicators. Table 2 shows a 36% contribution of the HV/MV transformers (and the transformer cable) to the SAIFI, 22% to the SAIDI and 60 % to the CAIDI.

In addition, the sensitivity analysis has been carried out for remote controlled switching and fast-automated "ping-pong" switching. Table 3 and Table 4 show the outcome of this analysis.

Table 3: Base Case results with remote control

	SAIFI 1/a	SAIDI min/a	CAIDI H
Transformers	0.039	0.8	0.4
Other	0.069	10.2	2.4
Total	0.109	11.0	1.7

Obviously, remote control does not affect the interruption frequency. The effect of remote control switching is that, in case of a HV/MV transformer failure or transformer cable failure, in 93% of the cases an interruption occurs with duration of 5 minutes. Only when the back-up transformer is being maintained, an interruption duration of 4 hours occurs. As a consequence, the average interruption duration becomes 0.4 hours. The advantage of applying remote control is that the system average interruption duration drops from 13.1 minutes per year to 11.0 min minutes per year.

In the case of ping-pong switching – fast switching over of the HV/MV transformers –, because of zero switching time there is no interruption, except for maintenance. When the back-up transformer is being maintained, the ping-pong cannot work. In that case, the switching time amounts to 4 hours. Thus, applying ping-pong switching, only affects the short duration interruptions, not the long duration interruption. As a consequence, the customer average interruption duration rises, as can be seen from Table 4.

Table 4: Base Case results with ping-pong

	SAIFI 1/a	SAIDI min/a	CAIDI H
Transformers	0.0028	0.7	4.0
Other	0.069	10.2	2.4
Total	0.072	10.9	2.5

The advantage of applying ping-pong switching is that the interruption frequency due to transformer and transformer cable failure drops from 0.039 to 0.0028. As a consequence, the total interruption frequency drops from 0.109 to 0.0072 (=62%), and the average interruption duration from 13.1 minute per year to 10.9 minutes per year. Compared with the remote control, there is a considerable improvement of the interruption frequency.

What is the effect of proposed measures on the reliability of the network?

As mentioned in the previous chapter, the following 3 options have been considered to improve the quality of supply:

1. n-1 security at each substation individually
2. Extra transformer to the "R" section of the HK station
3. Transfer of two MV distribution substations to the BH station

As for the base case, these options have also been analysed for manual, remote controlled and ping-pong switching.

Table 5 shows the result of the reliability assessment related to the three options. This table also shows the Base Case results, which makes the comparison easier.

Remarkably, the options do not show substantial differences. Clearly, remote control switching provides noticeable improvements. Also note, that remote control switching almost has the same effect as ping-pong switching.

Table 5: Results of the Base Case and the three options

	Base case			n-1 secure		
	SAIFI	**SAIDI**	**CAIDI**	**SAIFI**	**SAIDI**	**CAIDI**
	1/a	**min/a**	**h**	**1/a**	**min/a**	**H**
Manual	0.11	13.1	2	0.11	12.7	1.9
Remote	0.11	11	1.7	0.11	10.6	1.6
ping-pong	0.07	10.9	2.5	0.07	10.4	2.5
	Extra transformer			Transfer MV feeders		
	SAIFI	**SAIDI**	**CAIDI**	**SAIFI**	**SAIDI**	**CAIDI**
	1/a	**min/a**	**h**	**1/a**	**min/a**	**H**
Manual	0.11	12.9	2	0.11	12.5	2
Remote	0.11	10.8	1.7	0.11	10.5	1.7
ping-pong	0.07	10.6	2.5	0.07	10.3	2.5

Since none of the options introduce noteworthy differences in improvement, other aspects, such as costs, and operation philosophy and experience, have played a role in the decision-making process. Essent Netwerk has chosen for the third option, transfer of MV feeders in combination with remote control switching.

CONCLUSIONS

This paper describes how Essent Netwerk, a Dutch distribution network operator, decides on improving the quality of supply of the distribution network supplying the largest city in the north of the Netherlands. For this purpose, reliability calculations have been carried out for the base case (the present situation) and three options that were being investigated to improve the quality of supply. For each of these cases manual switching, remote controlled switching and ping-pong switching of HV/MV transformers has been considered. Moreover, the calculation method also allows for operational (restoration) and maintenance aspects of the proposed solutions. The reliability assessment has been carried out in terms of the performance indicators SAIFI, SAIDI and CAIDI.

All considered options introduced an improvement of the quality of supply. However, the reliability exercise revealed that the considered options do not show substantial differences. Remote control switching provides noticeable improvements.

Since none of the options introduce noteworthy differences in improvement, other aspects, such as costs, and operation philosophy and experience, have played a role in the final decision. Essent Netwerk has chosen for the option (transfer of MV feeders in combination with remote control switching) that is cost effective and does not introduce (new) operational risks.

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