RELIABILITY ANALYSIS OF DISTRIBUTION NETWORK INVESTMENTS

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ABSTRACT

With the new network regulation model in Sweden, the financial reality for the network utilities has become tougher. It is more important than ever to ensure that the right investments are made. Reliability analysis is a tool to improve the basis for decision making when planning an investment. It can be seen as a way of quantifying the quality of supply. The result can then, together with economical and other technical aspects, form a thorough base for the decision-making process.

Göteborg Energi Nät AB has recently introduced reliability analysis as a tool in network planning. The method is used to compare different investment alternatives, and to ascertain whether a planned investment will result in the expected improvement in quality of supply.

This paper shows, using a practical example, how the theories of reliability analysis can be applied, what kind of results to expect and how these results can be implemented.

PROBLEM

A large industry customer, with a load demand of around 20MW, is currently fed through two parallel 50kV cables, each directly connected to a 50/10kV-transformer. Both cables and transformers are quite old, and there have been many disturbances in the supply. In addition, the 50kV-level will be converted to 130kV within a few years, which means that a new supply must be arranged for this industry, regardless of disturbances in the supply. When outlining feasible system structures, a complication that has to be addressed is that the industry has some motors with high starting current and therefore has a high demand of short circuit power to be able to start up the process after an interruption. Even though one 50/10kV-transformer would be enough for the load demand, two parallel transformers are needed for start-up. The process is also sensitive to voltage dips. On several occasions there has been a disturbance in the process due to voltage dips originating from the DSO meshed system.

SOLUTION

The current situation is compared firstly with a short term improvement, accomplished by closing breaker B1 in figure 1, which results in paralleling the two 130/50kV transformers, and secondly with the suggested 130kV network structure, se figure 2. In the 130kV alternative the power supply for the industry in question may be accomplished either through feeder 1, through feeder 2 or in meshed operation, see figure 2. In table 1 the five different cases are listed and specified.

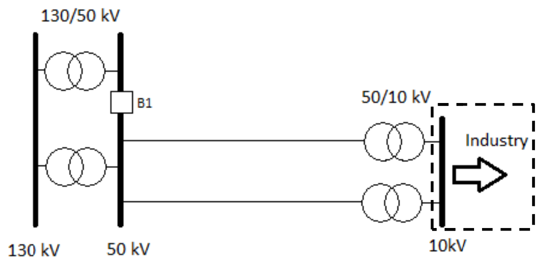

Figure 1 Current network structure (case A and B)

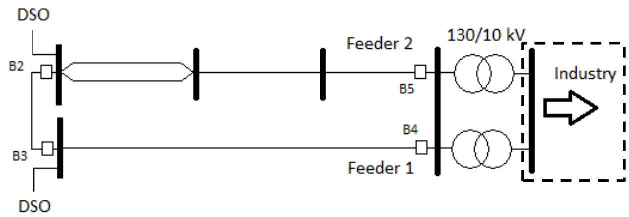

Figure 2 Suggested 130kV network structure (case C, D and E)

Table 1 List of analyzed cases

Case	Description	Configuration
A	50kV, Current situation	Figure 1
B	50 kV, Parallel transformers	Figure 1, B1 closed
C	Radial 130kV, feeder 1	Figure 2, B4 closed
D	Radial 130kV, feeder 2	Figure 2, B5 closed
E	Meshed 130kV	Figure 2, B2-B5 closed

In addition to the traditional analyses, like load flow, short circuit calculations, risk analysis etc, a reliability analysis is made. This paper only addresses the reliability analysis part.

The reliability analysis is performed in five steps:

Step 1 - Make a reliability model of the system structures to be compared. This includes choosing the level of detail of the analysis; i.e. which components shall be modelled, and which can be omitted?

Step 2 – Assign relevant reliability data to the components represented in the model.

Step 3 – Identify relevant fault events.

Step 4 – Perform the calculations.

Step 5 – Analyse and present the results.

Each step is explained further in the following paragraphs.
Case C is chosen to illustrate the analysis, since this is the basic case of 130kV-solution, but each step is performed similarly for all the five cases.

Step 1 – reliability model

In this example only the primary components are individually represented in the reliability model. Busbars, breakers, disconnectors, protection system and other auxiliary equipment are included as a group in the station-component. In figure 3 a model of case C, in which the load is supplied through feeder 1, is shown. In case of a fault on feeder 1 or station S2, the load can be supplied through feeder 2, by opening breaker B4 and closing breaker B5.
A similar model is made for all network structures in table 1.

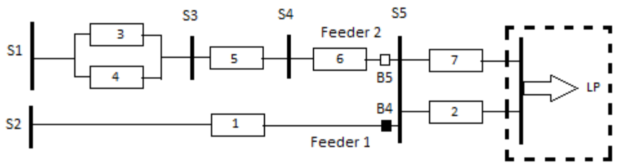

Figure 3 Reliability model of case C. Breaker B5 is open and B4 is closed in normal operation.

Each cable or overhead line and each transformer is given a component number 1 to 7. The stations are numbered S1 to S5. For case C, only components 1, 2, 7 and stations S2 and S5 is actually included in the calculations, but the other components are illustrated in the figure since they provide a back-up supply in case of a failure in the normal supply.

Step 2 – Reliability data

When the components that are to be represented in the model are identified, reliability data are assigned to each component. The reliability data for different types of components can be obtained from fault statistics or literature. The reliability data in this example is obtained from [1], [2], [3] and fault statistics from Göteborg Energi Nät AB. For some types of components, especially components which seldom fail, it can be difficult to find relevant reliability data. Therefore it is important to always perform a sensitivity analysis after the reliability analysis. Improved fault statistics will lead to more reliable results.
There are two reliability parameters required for each component to be able to perform the calculations; the average failure rate λ (faults/year) and the average outage time r (hours). The failure rate for lines are calculated from the average failure rate for the type of line per unit of length multiplied with the length of the individual line. One component may have more than one average outage time, depending on if the component is repaired, replaced or if the failure is bypassed by switching actions. In table 2 the failure rate and outage time for each component in case C are listed. Here, only the outage time alternatives relevant to this example are stated.

Table 2 Reliability data for the components in case C, normal operation.

No	Type	λ (f/y)	r (h)
1	New 130kV cable	0,0442	1 (switching)
2	Transformer 130/10kV	0,003	168 (replace)
7	Transformer 130/10kV	0,003	168 (replace)
S2	130 kV station	0,0096	1 (repair)
S5	130 kV station	0,0096	1 (repair)

A similar table with reliability data is made for all the network structures in table 1.

Step 3 – Identify fault events

In this step, all possible events that will cause a failure of the supply to the load point are identified and listed. It is assumed in this example that all the components are independent, meaning that only one component at a time will fail. Exception is made for underground cables in a common duct, the risk of failure of both cables simultaneously are considered. The reason for this exception is the relatively high risk of both cables being damaged at the same time by an excavator.

As indicated in the problem description, the industry in question has a high demand of short circuit power to be able to start up the process. Therefore, a second type of fault event is included in this analysis; faults not causing an interruption but instead a lower short circuit power and hence making process start-up impossible. If the process is running at the time of the fault nothing happens, unless the fault causes a severe voltage dip. But if the process happens to be down at the time of the fault, it will not be able to start again until the fault is removed.
The industry process is also sensitive to voltage dips. In two of the network configurations, B (parallel 130/50 kV transformers) and E (meshed 130kV) some of the fault events will cause a voltage dip, but not an interruption or a too low short circuit power. These faults are also included in the analysis.
In table 3, the relevant fault events for case C are listed together with the consequence of the fault, where the outage time is taken from table 2. No voltage dip faults are identified in case C.

Table 3 Fault events for case C

Fault No	**Comp. No**	**Consequence**
Interruption of supply		
1	1	Outage 1h, closing of B5
2	S2	Outage 1h, repair
3	S5	Outage 1h, repair
Start-up not possible		
4	2	Start-up not possible for 168h
5	7	Start-up not possible for 168h
Voltage dip		
-	-	-

A similar table with fault events is made for all the network structures in table 1. The fault event with simultaneous fault on the two parallel 50 kV-cables occurs in case A and B, since the 50kV-cables feeding the transformers are placed in a common duct. The expected outage time for this event is very high, since the cables are of an old, oil-filled type.

Voltage dip faults occur in case B and E. A voltage dip will be the result of the failure of one of the parallel 130/50kV-transformers in case B and the failure of any of the components in case E, except for the 130/10kV-transformers and the station S5. Technically, voltage dip faults also occur when a 130/10kV transformer fails and in the 50kV-cases A and B, as well, when either a 50kV-cable or a 50/10kV transformer fails. But those faults are already taken into account in the group of faults making start-up of the process impossible.

Step 4 – Calculations

In the example presented in this paper, only the reliability of the load point is of interest. The average failure rate in the load point is calculated according to equations 1 and 2 [4], [5]:

Where i is the fault number.

The unavailability of the load point, or the average annual outage time, U_{LP} (hours/year) is calculated as:

The approximation in equation 2 is valid if $\lambda r << 1$.

In table 4, the average failure rate and unavailability for the load point in case C is calculated according to equations 1 and 2.

The average failure rate and unavailability are calculated in a similar way for all network structures in table 1.

Table 4 Average failure rate and unavailability in load point for case C

Fault No.	**λ (f/y)**	**r (h)**	**U (h/y)**
1	0,0442	1	0,0442
2	0,0096	1	0,0096
3	0,0096	1	0,0096
Σ (interruptions)	0,0634		0,0634
4	0,003	168	0,504
5	0,003	168	0,504
Σ (start-up)	0,006		1,008
–	–	–	–
Σ (voltage dip)	0	0	0
Σ (total)	0,0694		1,0714

Step 5 – Analysis and presentation

To analyse the results from the calculations, diagrams or graphs can be a useful tool. In figures 4 and 5, the five different configurations are compared, with respect to the expected total number of faults and the average unavailability. When studying figure 4, note that "start-up faults" also may cause voltage dips.

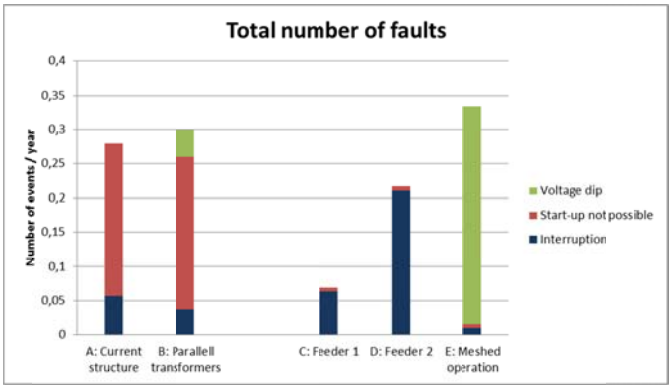

Figure 4 The expected number of fault events/year for each case

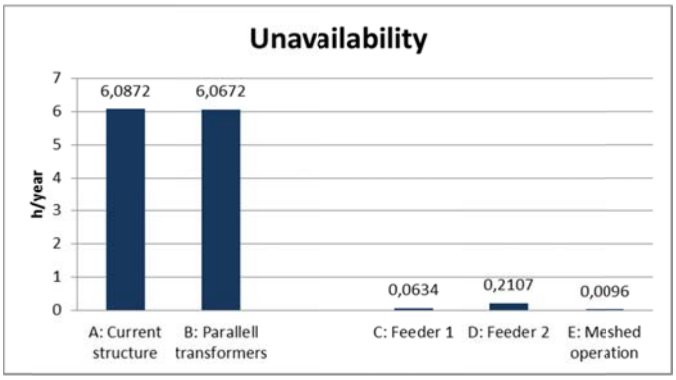

Figure 5 The expected average unavailability in hours/year for each case

A sensitivity analysis shows that the main conclusions hold when the input data (λ, r) for the different component types varies between -50% and +200%.

Regarding the presentation of the results, is it important to stress that the values of the number of fault and the unavailability is expected asymptotic values, especially if the results are presented to the customer. Over a long period of time, the average annual value is expected to converge to the presented values, but the actual outcome each individual year can deviate substantially from these values.

RESULTS

From the results of the reliability analysis, in the practical example presented in this paper, two main issues can be distinguished. For one thing, it is clear that the 130kV-structure does not result in a decreased number of interruptions, unless it is operated as a meshed system. Meshed operation will, however, lead to an increased risk of voltage dips, since failure of a line or station will cause a voltage dip instead of an interruption. Moreover, the number of component failures affecting the load point is larger in the meshed system than in the radially operated one. The amount of voltage dips may be a problem for the industry in question as well as other customers nearby.
On the other hand, the unavailability will decrease significantly for all 130kV-alternatives, due to that the duration of the interruptions will be considerably shorter. The reason is the possibility to switch to the back-up feeder in the 130kV alternatives. The number of faults causing a too low short circuit power will also decrease significantly when the system is converted to 130kV.

It can also be seen in the diagrams that the short term improvement, case B, will result in marginally lower unavailability and number of faults, but the risk for voltage dips will increase. Therefore this measure is not recommended.

CONCLUSIONS

The conclusion of the reliability analysis will be that case C, the 130kV-alternative with feeder 1 as the normal operation, is the preferred solution.

The main reason for not recommending case E, meshed operation, as the preferred alternative is the relatively high risk of voltage dips.

Case D has no benefits compared with case C, the number of interruptions are considerably higher and the unavailability somewhat higher.

The reliability analysis should be complemented with a more traditional risk analysis, where rare but severe events, like a complete outage of a 130kV-station, can be taken into account. It is difficult to assign relevant reliability data to this type of events, and hence are they not suitable to include in the performed analysis.

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