Overview of Power System Reliability Assessment Techniques

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SUMMARY

Reliable electric power supply is essential for modern society. The extensive use of electricity has led to a high susceptibility to power failures. In this way, reliability of supply has gained focus and it is considered increasingly important for electric power system planning and operation.

In this paper, an overview is given of the state of the art of analytical power system reliability assessment techniques. The paper is addressed to readers with interest in the possibilities and limitations by these models.

The motivation behind this paper is to establish a comprehensive overview of the field of analytical power system reliability assessment techniques and to serve as input for further research and development in the area of applicability.

KEYWORDS

Power system reliability – State space methods – Markov processes
1. INTRODUCTION

This article provides discussion of different aspects of reliability, description of details regarding modelling, examples of reliability assessment techniques, and an introduction to the concept of reliability worth. The focus is on analytical power system adequacy methods. The paper is structured in the following manner:
In section 2 several of the issues involved in the framework of a power system reliability assessment study are discussed.
Section 3 is the main part of the paper, and holds a description of the most common analytical methods for reliability assessment, presenting details on: the state space method, the contingency enumeration method, and the minimal cut set method.
In section 4, the network reduction technique is described, which can be used to simplify the analysis of large networks containing parallel and serial structures.
The concept of reliability worth is described in section 5, discussing its usefulness in the areas of value based system operation and investment planning including comments on reliability worth indices.
In section 6 a summary of the described methods is given together with a discussion of their practicability and directions of future work.

2. POWER SYSTEM RELIABILITY ASSESSMENT

To assess the reliability of a power system, aspects of multiple disciplines have to be considered. An analysis framework needs to be specified, consisting of:
- Identification of which aspect of reliability to consider
- Definition of system boundaries to limit the extent of the analysis
- Selection of the level of modelling detail and analysis method, in order to be able to study the correct phenomena
- Selection of proper reliability indices to compute
These concepts are further described in the subchapters of this section.

2.1 Reliability, adequacy, security and quality

Power system reliability describes the overall ability of the power system to perform its function. Typically power system reliability discussions are divided into two separate aspects, adequacy and security [1].
Adequacy can be defined as the existence of sufficient facilities to satisfy the demand. Adequacy of a power system is related to static conditions, and is typically analysed through power flow simulation studies.
Security reflects the ability to respond to disturbances, hence, the security of a power system relates to the system dynamic response and can be analysed through dynamic studies.
The word reliability is often used instead of adequacy, which leads to a distinction between reliability and security (rather than security being a part of reliability). This less accurate but more common perception of reliability is also used in this paper, where power system reliability assessment techniques are described from an adequacy perspective. A good overview of the concept of power system security is given in [2], and the description of some security assessment indices can be found in [3].
In reliability analysis, power quality usually is disregarded. Power is seen to be either delivered (within acceptable quality limits), or not supplied (also including the case of the power quality being unacceptable low).

2.2 Power system hierarchical levels

In reliability analysis, power systems are often divided into three parts to define the boundaries of the reliability assessment. These parts are referred to as hierarchical levels, and can be described as shown in Figure 1, [1].
Hierarchical level I (HL I) includes only generation and load of the system. A reliability study of HL I is an evaluation of the total system generating capacity necessary in order to satisfy the expected system demand.

Hierarchical level II (HL II) is in the power system reliability field often referred to as the “bulk power system”, including generation and transmission. Hence, a reliability study of HL II evaluates the generation and transmission capacity to supply the system load (distributed in bulk load points).

Hierarchical level III (HL III) includes the whole power systems (generation, transmission and distribution). Due to the size and complexity of the power system, a reliability study of HL III is typically only practical for small systems.

A common solution is to utilise the results from a HL II evaluation as input for a separate evaluation of a specific distribution system. In such procedure the effects that the distribution system may have on the reliability of the transmission and generation systems are neglected.

### 2.3 Markov models

If a large system is subject to assessment, the applied model easily can become impossible to handle if components are modelled in detail. The Markov model gives a simple description of a component, which can be handled well with mathematical methods.

In order to be able to utilise the techniques presented in section III, the components of the system must be able to be described as a Markov model. This means that the system should be represented as a system lacking memory of previous states with identifiable system states [4].

Markov models can be represented either as discrete or continuous models, both in time and space. In power system reliability assessment it is common to use stationary Markov models which are discrete in space while continuous in time. Implying that the components are modelled in steady state in a continuous time space, where transitions between discrete states occur at constant transition rates.

### 2.4 Analytical and numerical methods

In general, reliability analysis can be performed either analytically or numerically, while this overview only treats analytical methods.

In analytical methods, the system is represented by mathematical models, which are typically based on Markov models. The expectation values of reliability indices are calculated by solving an equation system.

The most common numerical method is the Monte Carlo simulation method. In this method, the random behaviour of the system is analysed through simulation of physical relationships. The outcome of a Monte Carlo simulation is the expectation value probability distributions of reliability indices, i.e. not only the average values as in analytical methods. The method offers the possibility to apply more sophisticated component models, e.g. including effects of component aging. However this leads to increased computation time, why Markov models are often used also here.
2.5 Reliability indices

Results from a reliability study can be expressed using different reliability indices. There are many possible reliability indices, which often are interdependent. Depending on the application, a suitable set of indices has to be chosen, to perform the reliability evaluation.

As an example three basic indices are introduced in this paper: The failure probability, the failure frequency and the mean failure duration. These indices are suitable for simple systems, which can be either in operation of failed.

For the analysis of complicated systems like electric power systems, more sophisticated indices have to be used. This is due to the fact, that an electric power system does not only have two possible states, but an enormous variety of partially failed states, where a part of the load is lost.

A good way to address this is to use the indices named annual energy not supplied (ENS), also called loss of energy expectation (LOEE), or the annual power not supplied (PNS), also called loss of load expectation (LOLE). These indices are based on the concept that power is either supplied or not. Power quality issues, which are not treated in this article, cannot be described with those indices. Further description of several reliability indices is given in [3].

If interruption cost (or reliability worth) should also be taken into account, indices like the cost of energy not supplied (CENS) and the cost of power not supplied (CPNS) can be used. These are further described in section 5.

3. ANALYTICAL POWER SYSTEM RELIABILITY ASSESSMENT METHODS

The most common analytical methods for reliability assessment are described in this section:

- State space method
- Contingency enumeration method
- Minimal cut set method

3.1 State space method

In this section, the most important parts of the state space method are presented. For further details, references [5] and [6] are recommended.

The modelling of a component is typically based on an Up and a Down state. The relationship between \( m \) (up-time or mean time to failure: MTTF), \( r \) (down-time or mean time to repair: MTTR) and \( T \) (cycle time which is the sum of the up-time and down-time), is illustrated by Figure 2.

The state space is a set of all possible systems states, and can be described using a state space diagram. For a single component system, the state space diagram would look like shown in Figure 3, where \( \lambda \) and \( \mu \) are the systems transition rates (failure rate and repair rate, respectively).

![Figure 2](image)

**Figure 2.** State cycle for one component having two states

![Figure 3](image)

**Figure 3.** State space diagram for one component with two states

The standard probability distribution function which is often used in the Markov model is the exponential function. Using the exponential probability distribution function makes calculations a lot easier, since it represents a time independent failure rate. This is a good assumption for devices under their regular life time. If aging should be taken into account, more complicated functions have to be used.
The exponential function and the probability distribution are defined as shown in (1) and (2), where $X$ is the up-time of a device.

$$f(x) = \lambda e^{-\lambda x}$$  \hspace{1cm} (1)

$$F(x) = \int_0^x \lambda e^{-\lambda y} dy = 1 - e^{-\lambda x}$$  \hspace{1cm} (2)

The mean value is then calculated as:

$$m = E(x) = \int_0^\infty x\lambda e^{-\lambda x} dx = \frac{1}{\lambda}$$  \hspace{1cm} (3)

The relationship between the repair rate $\mu$ and the down-time $r$ of a device is defined similarly resulting in:

$$r = \frac{1}{\mu}$$  \hspace{1cm} (4)

The probability that the system is in the $Up$ state or in the $Down$ state ($P_U$ and $P_D$, respectively) can then be defined as shown in (5) and (6).

$$P_U = \frac{m}{m + r} = \frac{\mu}{\lambda + \mu} = \frac{f}{\lambda}$$  \hspace{1cm} (5)

$$P_D = \frac{r}{m + r} = \frac{\lambda}{\lambda + \mu} = \frac{f}{\mu}$$  \hspace{1cm} (6)

Where $f$ is the frequency of encountering a state, and is defined as the inverse of the cycle time:

$$f = \frac{1}{T} = \frac{\mu\lambda}{\mu + \lambda}$$  \hspace{1cm} (7)

This representation of a single component can be used to derive the state space diagrams for systems consisting of $n$ components with $2^n$ states. A system with two components and four states is used in this paper to illustrate the main principles.

For a better understanding of the possible states and transitions, it is helpful to draw a state space diagram, which comprises all possible system states and all possible transitions (Figure 4).

**Figure 4.** State space diagram for two components, each with two states

The full system state space for the two component system can be defined as:

$$S = \{(1_U, 2_U), (1_D, 2_U), (1_U, 2_D), (1_D, 2_D)\}$$

An event is a subset of states of the system state space. A possible selection of events is:
These separate events represent the system states where the system is fully up ($A_1$), fully down ($A_4$), not totally down ($A_2$), and not fully up ($A_3$).

$A_1$ is in this case a subset of $A_2$ which is a subset of the whole system state space $S$.

\[ A_1 \subseteq A_2 \subseteq S \]

In order to calculate the three basic reliability indices (failure probability, failure frequency and mean failure duration), it is necessary to define what a system failure is. In the example case it could either be that at least one component is down, or it could be that both components need to be down. For example, if the system can only operate when both components are up, failure is equal to event $A_3$ and the failure probability is equal to $P(A_3)$.

If the failure and repair rates of all devices are known, the probabilities for the device states can be calculated. Based on this, the probabilities of all system states and events can be found.

\[ P(A_3) = P(1_U, 2_U) + P(1_U, 2_D) + P(1_D, 2_D) \]

\[ P(A_2) = P_{1D} \cdot P_{2D} + P_{1D} \cdot P_{2U} + P_{1U} \cdot P_{2D} \]

The frequency of an event is based on the products of the transition rates that lead to the event, and on the probabilities of the states, where those transitions start.

\[ f_{A_3} = P(1_U, 2_U) \cdot \lambda_1 + P(1_U, 2_D) \cdot \lambda_2 \]

Alternatively, it is also possible to multiply the transition rates leading away from the event with their originating states. Logically, the frequency of encountering and leaving a state or event must be identical.

\[ f_{A_3} = P(1_U, 2_U) \cdot \mu_1 + P(1_U, 2_D) \cdot \mu_2 \]

The mean duration of an event is dependent on the other two reliability indices and is given by:

\[ d_{A_3} = \frac{P_{A_3}}{f_{A_3}} \]

Due to the high computational effort of the state space method, simplified methods, such as the network reduction technique are required when studying large systems.

### 3.2 Contingency enumeration method

The contingency enumeration method (sometimes called the state enumeration method) is another analytical method, which, as the name implies, assesses the reliability through analysis of a selected number of contingencies.

A good description of the contingency enumeration method can be found in references [3], [8] and [9]. In reliability evaluation of distribution systems, simplified contingency enumeration methods may be used. One such method is the RELRAD (RELiability in RADial systems) method [11], where the radial structure of the distribution systems is utilised to perform efficient reliability analyses.
For HL II reliability evaluation, the contingency enumeration method can be structured in four steps, see Figure 5, which are further described in this section.

**Figure 5. Structure of the contingency enumeration method**

In the first step, the framework of the analysis is specified. This includes the selection of: power system boundaries, operating scenarios, load flow technique, modelling detail level, etc.

In the second step, the contingencies (i.e. outage combinations) which should be regarded in the analysis are selected. A consideration of all possible contingencies is unrealistic in most cases due to extensive computational time, implying the importance of the selection procedure. The contingency selection has to be done carefully, because every disregarded contingency adds to the inaccuracy of the evaluation.

An easy manner to perform the selection is to regard all contingencies up to a specified order. If, as an example, the second order is chosen, all combinations of up to two failed components are regarded. If important contingencies of higher order are identified, these can be added to the contingency list. Components to consider as composing such important contingencies are related to system specific criteria, where an example can be a system consisting of two subsystems interconnected via three power lines. An outage of those three lines would compose an important contingency.

Single component failures often have little impact on the system and therefore on the reliability indices. Failure of multiple independent components at the same time is not very likely and does therefore often not contribute significantly to the indices, even though the impact of such a situation is large. Common mode outages, where a single event leads to failure of multiple components, are therefore generally important to identify. The failure of a substation connecting several generators or a tower carrying several power lines can significantly degrade the power system reliability.

In the third step a load flow calculation is performed for each contingency in each of the operating scenarios. These calculations identify possible system problems caused by contingencies. Load flow calculations may be either of AC or DC type, where an AC load flow calculation often is necessary to identify the most relevant network problems. In case of an extensive contingency list, for a huge power system, an approach with AC load flow might be unrealistic; instead DC load flow techniques can be used. Utilisation of DC load flow will degrade the quality of the entire evaluation, since voltage problems no longer can be identified.

A possible compromise is to run DC load flow calculation for all contingencies, to identify the critical ones, which afterwards are calculated again using AC load flow.

Some of the identified system problems might be repairable with corrective actions, such as generation rescheduling. Those minor problems will therefore not have impact on the reliability indices. If the system problems cannot be solved with regular corrective actions, evasive corrective actions like load shedding have to take place. Such actions do influence the reliability indices.

The applied load shedding strategy is highly relevant for the results for each load point, since a systems wide power deficit could theoretically be solved by load shedding at any load point. Contingencies leading to local problems are less sensitive to the chosen load shedding strategy.
In the last step, the pre-defined reliability indices are calculated (typically on both load point level and system level) and the annualised indices are summed up from all the studied operational states and contingencies.

### 3.3 Minimum cut set method

In this section, the basic functionality of the minimum cut set method is described. Reference [7] is recommended for further details.

The minimal cut set method is a good tool to utilise when assessing the reliability of specific load points in the power system. The method reduces computation time by focusing on the system contingencies which are relevant for the selected load points and not for the entire system. The minimum cut set method is sometimes called the failure mode method; since the cut sets define the failure modes of a load point.

A minimum cut set is defined as a set of system components which, if all are in failed state, causes outage at a selected load point. The logic minimum cut sets can be described as:

Components of a minimum cut set behave like they are connected in parallel, i.e. all have to fail to cause system failure (see Figure 6).

Several minimum cut sets behave as connected in series, i.e. failure of one minimum cut set causes system failure (see Figure 7).

![Figure 6. Minimum cut set consisting of n components](image)

![Figure 7. System consisting of m minimum cut sets](image)

The unavailability of a system with \( m \) minimum cut sets can be described by equation (15).

\[
P_D = P(C_1 \cup C_2 \cup \cdots \cup C_m)
\]  

(15)

This equation can be expanded to a complex expression, which is not useful for applied power system reliability assessment. However, in the case when the approximation that the mean time to repair can be neglected in comparison to the mean time to failure (i.e. \( m \gg r \leftrightarrow \mu \gg \lambda \)) is valid for all components, the unavailability can be described as shown in equation (16).

\[
P_D \approx \sum_{i}^{m} P(C_i) = \sum_{i}^{m} \prod_{j \in C_i} P_{id}
\]  

(16)

In (30) \( P(C) \) is the probability that minimum cut set \( C \) fails.

The minimum cut set calculations can be further simplified if utilising the series and parallel equations described in section III B.

Minimum cuts sets can also be used as a technique in the contingency enumeration method, in order to define the contingencies constructing minimum cut sets.
4. NETWORK REDUCTION TECHNIQUE

Network reduction is a technique to construct a simplified equation system through identification of parallel and series system structures. Here, approximations are often used making the equations a lot easier to solve, and the technique has a large influence on reducing the size of the equation system. In the following, the most relevant equations for the series and parallel systems are described. For further details, reference [7] is recommended.

4.1 Series structures

First equivalent equations for serial components are developed. The system logic and state space diagram for a two component series system are shown in Figure 8 and Figure 9.

From the logic of the series system, it is intuitive to realise that the system is down for all states where one component is down, i.e. the only state where the system is up is when all components are up. This implies that the probability of the series system being in Up state equals the product of the probability of all components being in Up state, as shown in (17), where λS and μS are defined as the transition rates of the series system.

\[ P_{SU} = P_{1U}P_{2U} = \frac{\mu_1\mu_2}{(\lambda_1 + \mu_1)(\lambda_2 + \mu_2)} = \frac{\mu_S}{\lambda_S + \mu_S} \]  

(17)

Similar, it is also intuitive that the transition rate from the Up state (i.e. the failure rate of the series system) equals the sum of the failure rates for all components, as shown in (18).

\[ \lambda_S = \lambda_1 + \lambda_2 \]  

(18)

Solving (17) and (18), the series system repair rate can be described as:

\[ \mu_S = \frac{\lambda_S P_{SU}}{1 - P_{SU}} = \frac{\lambda_1 + \lambda_2}{\left(1 + \frac{\lambda_1}{\mu_1}\right)\left(1 + \frac{\lambda_2}{\mu_2}\right) - 1} \]  

(19)

It can be shown that, for a system with n components in series, (17), (18), and (19) can be generalised as shown below.

\[ P_{SU} = \prod_{i=1}^{n} P_{1U} = \frac{\mu_S}{\lambda_S + \mu_S} \]  

(20)

\[ \lambda_S = \frac{1}{m_S} = \sum_{i=1}^{n} \lambda_i \]  

(21)
\[ \mu_S = \frac{1}{r_S} = \frac{\lambda_S P_{SU}}{1 - P_{SU}} = \frac{\sum_{i \in n} \lambda_i}{\prod_{i \in n} \left(1 + \frac{\lambda_i}{\mu_i}\right) - 1} \] (22)

Utilising the approximation that the mean time to repair can be neglected in comparison to the mean time to failure (i.e. \( m \gg r \leftrightarrow \mu \gg \lambda \)) for all components, further simplifications can be done and the series system repair rate described by (22) can be approximated to:

\[ \mu_S \approx \frac{\lambda_S}{\sum_{i \in n} \lambda_i} \] (23)

### 4.2 Parallel structures

The equations of the parallel system can be developed in a similar manner as for the series system. The probability for a parallel system to be in Down state and the transition rate from the Down state (i.e. the repair rate of the parallel system) can be intuitively identified from system logic and the state space diagram shown in Figure 10 and Figure 11.

Thus, the set of equations describing the probabilities and transfer rates of a two component parallel system can be defined as:

\[ P_{PD} = P_{1D}P_{2D} = \frac{\lambda_1 \lambda_2}{(\lambda_1 + \mu_1)(\lambda_2 + \mu_2)} = \frac{\lambda_P}{\lambda_P + \mu_P} \] (24)

\[ \mu_P = \mu_1 + \mu_2 \] (25)

\[ \lambda_P = \frac{\mu_PP_{PD}}{1 - P_{PD}} = \frac{\mu_1 + \mu_2}{\left(1 + \frac{\mu_1}{\lambda_1}\right)\left(1 + \frac{\mu_2}{\lambda_2}\right) - 1} \] (26)

Similarly as for the series system, it can be shown that for a system with \( n \) components in parallel, equations (24) – (26) can be generalised to:

\[ P_{PD} = \prod_{i \in n} P_{1D} = \frac{\lambda_P}{\lambda_P + \mu_P} \] (27)

\[ \mu_P = \frac{1}{r_P} = \sum_{i \in n} \mu_i \] (28)
\[ \lambda_p = \frac{1}{m_p} = \frac{\mu P P D}{1 - P P D} = \frac{\sum_{i \in \mathcal{N}} \mu_i}{\prod_{i \in \mathcal{N}} \left(1 + \frac{\mu_i}{\lambda_i}\right) - 1} \]  

(29)

Utilising the same approximation as in the series system \((m \gg r \leftrightarrow \mu \gg \lambda)\) for all components, the parallel system failure rate described by equation (29) can be approximated to:

\[ \lambda_p \approx \mu P \prod_{i \in \mathcal{N}} \frac{\lambda_i}{\mu_i} \]  

(30)

In power system reliability assessment, networks can only be partially reduced due to the meshed grid structure of the transmission grids. The identification of the impact of a specific component on the reliability level is more complex, if that component has been replaced by an equivalent series or parallel structure [4].

Network reduction is a computation effort reduction technique, rather than a reliability analysis method. Power systems which are to be analysed can first be reduced using network reduction, in order to simplify the following analysis.

5. RELIABILITY WORTH

Reliability worth is a useful tool in value based system operation and investment planning, to optimise the reliability level versus the total cost of providing the electricity. In investment planning, reliability worth can be used to relate the value of possible investments to the worth of the reliability improvement that the investment would have. In operation planning, reliability worth can be used to identify optimum operational reserves versus the interruption cost.

The relation between cost and reliability can be described as shown in Figure 12, where the optimal reliability level can be identified as the point where the marginal increase in operating and investment costs equals the marginal decrease in interruption cost.

The reliability worth varies with several parameters, such as time of day, type of customer, and duration of interruption.

Quantification of the consumer interruption cost can be performed using three main methods, [10]:

- Analytical – through indicators in price indices
- Case studies – analysing societal costs of historic events
- Customer surveys – analysing the direct worth and willingness to pay from different customers

It is important to realise the difficulties in quantifying a true consumer interruption cost, if such a thing really does exist, when performing reliability worth analyses. This intricacy also implies further difficulties in identifying the true optimal reliability level.

![Figure 12. Reliability cost and reliability worth](image-url)
One approach to identify the optimal level of reliability in the power system is called the value of service approach and is described in [12]. Special reliability worth indices have been developed to assess the cost of power interruptions. An example is the cost of energy not supplied (CENS), which can be used for both analysis of consequence of different contingencies as well as for calculating the total system cost. CENS is based on the reliability indices duration and frequency, as well as on the expected consumer load level and the customer interruption cost (or customer damage function) which needs to be specified for the different customer groups.

The cost of power not supplied (CPNS) can provide additional information on the level of reliability worth. An example where this is necessary is when telecommunication equipment is involved. Such equipment is sensitive toward power outages, and even a short interruption of supply can cause serious malfunction. Since the CENS can often be neglected for short interruptions, the CPNS is a superior reliability index in this case.

6. SUMMARY AND DISCUSSION

In this paper, we discuss different aspects of reliability, describe details regarding modelling, provide examples of reliability assessment techniques, and we also discuss the concept of reliability worth. The studied reliability assessment methods make it possible to evaluate the power systems reliability under specified operational conditions. This is valuable for power system operation and planning, and gives the possibility to utilize the accessible resources in a more optimal way. Reliability worth is recognized as a useful tool in value based system operation and investment planning. However, the difficulties in quantifying a true consumer interruption cost and in identifying the true optimal reliability level should be realized.

The most common analytical methods for reliability assessment are:

- State space method
- Contingency enumeration method
- Minimal cut set method.

The state space method is an approach where the full state space is analysed in order to provide an accurate assessment of the reliability. A drawback to this technique is the computational effort; hence, for large systems simplified methods are required.

If not the entire system is subject of interest, but only specific load points, the minimal cut set method is a good assessment tool. The method reduces calculation time by focusing on the system contingencies which are relevant for the selected load points and not for the entire system.

Also by using the contingency enumeration method, computation time can be reduced significantly for a large system. Only the most relevant parts of the system state space, in the form of defined contingencies and operational states, are analysed. The reliability assessment is performed through load flow analysis and implementation of remedial actions. Three elements are identified as critical for the assessment results:

- **Analysis depth** – Careful selection of contingencies and operational states is highly important, since disregarded part of the state space adds to the inaccuracy of the evaluation
- **Load flow method** – Utilisation of DC load flow may significantly degrade the quality of the entire evaluation and should be used with caution
- **Load shedding strategy** – Applied strategy is highly relevant for the results and should be carefully planned

The network reduction method can be utilized to simplify calculation of systems with clear serial and parallel structures. Approximations are often used, which further decreases the computational effort. However, when assessing the reliability of a power system, this technique is often not easily applicable due to the meshed structure of the grid. A negative impact by utilizing this technique may be that the possibility to identify impact from specific components is removed.

In order to guarantee a reliable electric power supply, a few of the main challenges and opportunities that are needed to be addressed in future research are discussed below.

*Power system security assessment:* Even though this paper only focuses on power system adequacy, it should be mentioned that power system security is an important part of the total reliability assessment.
Security assessment techniques are needed in order to consider the dynamic behaviour of the system, which is required in an increasingly utilised power system.

Extraordinary events: Blackouts (occurring from a wide range of contingencies, e.g. earth quakes, hurricanes, sabotage, etc.) are not easily modelled in a reliability study. One of the reasons for this is that the general assumption of the independency of component failures is not correct for this type of events. Therefore, the impact of such events on the power system reliability cannot be assessed using the techniques discussed in this paper.

Integration of new equipment in the power system: Equipment without substantial track record is a challenge for reliability assessment. The basis of the component modelling, which is failure rate and repair time, is in this case unknown and can be difficult to estimate. Large scale installation of new equipment, like a possible North Sea Super Grid, can introduce significant uncertainties in the reliability assessment of the European power systems.

Wide area monitoring systems: One of the research fields identified to have high potential to improve the power system reliability is the application of wide area monitoring systems (WAMS). Improvements could be possible within a wide purpose range, such as state estimation, system protection and controlled islanding.

BIBLIOGRAPHY