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Economic Benefits by the use of Function Analysis as Maintenance- and Investment Methodology in the Primary and Secondary System in High Voltage Substations

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ABSTRACT

Norway was one of the first countries in the world where a penalty for energy not supplied (CENS [1]) was introduced. ***The introduction created a drive towards more cost effective solutions and influences all financial decisions in a grid company.*** The main objective is to give incentives to the network owners to operate and maintain the system in a socio-economic optimal way. However, the principle behind this regulation is valid in all electrical network companies, even if regulations/ penalties are not (yet) introduced.

It has been a technical revolution regarding protection and control equipment the past twenty years. The technology has changed from independent units of protection, control and monitoring to the integration of these functions in one device. But in most cases, the technical and economical benefit of this change has not been fully utilized.

This paper takes a closer look at the technical and economical possibilities that numerical- and information technology can give. To illustrate the new possibilities, the concept of the "virtually locked" station is introduced, where all actions and decisions are based on remotely retrieved data from the station. The new approach is to utilize modern information technology, focusing on the cost benefits of the function- and risk analysis methodology. The function analysis will give condensed information on the status of the substation as well as the whole network, when the data are utilized in a central system. Thus the station can be "virtually locked". No actions will be based on traditional methods with regular visits to the station for maintenance testing etc.

Keywords: Electric-Power-Substation-Automation-Information-Function-Risk-Analysis-Maintenance-Benefits.

1. INTRODUCTION

Norway was one of the first countries in the world where a penalty for energy not supplied (CENS [1]) was introduced. After a long period of Rate of Return (ROR) regulation in Norway, a combination of

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incentive-based regulation and performance-based regulation of the rate (PBR) was introduced in 1997. This model combines revenue cap regulation with benchmarking and earnings sharing mechanisms. The main objective is to give incentives to the network owners to operate and maintain the system in a socio-economic optimal way. ***The introduction created a drive towards more cost effective solutions and influences now all financial decisions in a Norwegian grid company.*** However, the principle behind this regulation is valid in all electrical network companies, even if regulations/ penalties are not (yet) introduced.

1.1 Change of technology.

It has been a technical revolution regarding protection and control equipment the past twenty years. The numerical technology has facilitated the change from independent units for protection, control and monitoring to integrated, intelligent electronic devices (IEDs) The intelligent electronic devices communicates with other devices by the use of station bus systems locally and via various communication systems to the system level.
- What are the technical and economical benefits of this change of technology?
- Has this change influenced the operation, maintenance and investments in the power? system?

The conclusions are:
- The stations with modern numerical equipment are operated in a traditional way!
- The investments are still focused on individual stations and units and not on a technical system, which utilizes the technical and economical benefits of numerical technology.
- The "lifecycle considerations" are still based on traditional benefits, based on our experience from traditional equipment.

2. THE "VIRTUALLY LOCKED" STATION
- How can we improve the way the new numerical and information technology is utilized?

To illustrate the new possibilities, the concept of the "virtually locked" station is introduced, where all actions and decisions are based on remotely retrieved data from the station. The new approach is to utilize modern information technology, focusing on the cost benefits of the function- and risk analysis methodology. The function analysis will give condensed information on the status of the substation as well as the whole network, when the data are utilized in a central system. Thus the station can be "virtually locked". No actions will be based on traditional methods with regular visits to the station for maintenance testing etc.

- Is it possible to operate a "virtually locked" station and get economic and technical benefits?
- Is it possible to operate the grid closer to the technical limits by the use of modern information technology, thus delaying investments?
- Is it possible to maintain the different components in these substations by the use of remotely retrieved information and satisfy the demands on safety for personnel, customers and technical equipment?
- Is it possible to reduce the probability for system collapse by the use of information?

The answer to all these questions is yes!!

By the use of information from different units, collected in a central system, pre-planned risk- and probability considerations and pre-planned actions based on analysis based on dynamic values this is made possible.

The main economical benefits are
- Better utilization of the grid, facilitating delayed investment
- Reduced probability for system collapse.
- Reduced costs for maintenance.

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An additional benefit is the reduction of human errors. Unwanted functions caused by personnel working in the substations are a big problem in most countries including Norway. The "virtually locked" station keeps the personnel away from the substation and reduces the probability of unwanted functions. The section "risk based maintenance" presents an example of the economic impact of the "virtually locked" station.

3. THE TECHNICAL INFORMATION SYSTEM

The key words are ***information utilization***. It is necessary to create a technical information system based on the same ideas as the administrative systems. The important subject in this system is that every part has to fit together, and the glue is communication.

- System focus
- Standardized information exchange format
- Standardized communication

3.1. The technical information system architecture

In principal, there are two hierarchical levels of the information system, station information and system information level

Station Information level
The Station Information level according to figure 1 contains information from the HV-objects, the bays including the Intelligent Electronic Devices (IEDs) and the stations primary and secondary systems. A communication standard that allows free exchange of information between different vendors is important for the collection of station information. All units include self-supervision. At an internal fault, the device will block the actual functions and send a signal to the technical information system that something is wrong.

The functionality and the investment cost, using numerical technique at the station information level, is in principal the same as for traditional solutions, but are crucial to get the economic and technical benefits at the system level.

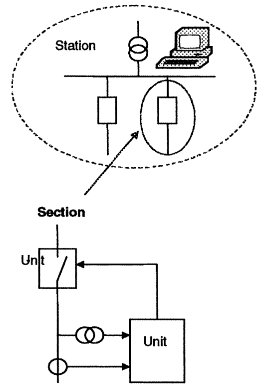

Figure 1 Station Information level

Examples of station information

- System demands regarding protection. (Important information for settings)
- Voltage and frequency values for stability evaluation, voltage collapse etc.
- Information to use in function analysis (maintenance), load shedding
- Information for presentation of different operative decisions in the dispatch center (Decision support)
- Control and interlocking functions
- Communication status on station level and system level
- Communication between different stations for protection or to achieve automatic actions in area solutions

System information level
The economical and technical benefits by the use of numerical- and information technology are mainly associated with the system information level. The only connection between the station information level and the system information level is communication.

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Thus, the "virtually locked" station and the interconnected grid are operated and maintained by the use of information. The goal must be to be to build a technical system that allows free exchange of information between the different levels and vendors, not to minimize the investment in a single station according to figure 2.

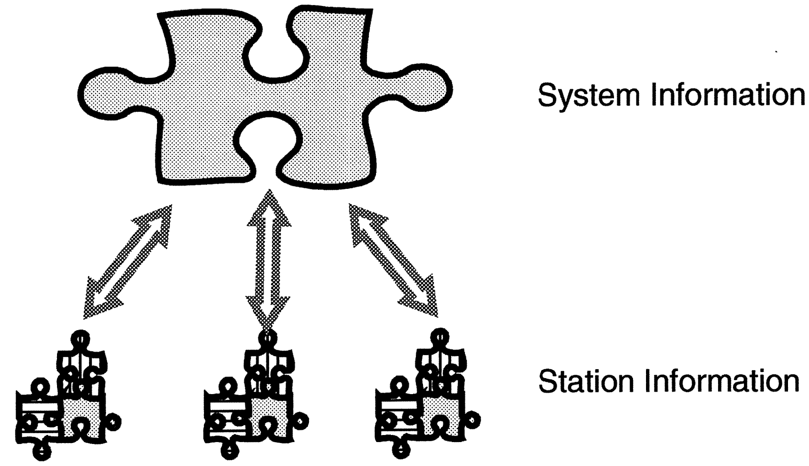

Figure 2. System information level

4. THE CONNECTION BETWEEN INVESTMENT, OPERATION AND MAINTENANCE TO GET ECONOMIC BENEFITS.

By the use of information and automatic actions in the grid is it possible to delay investment and operate the grid closer to the limits in critical situations (risk-based operation). It is also possible to change the maintenance procedures in substations by the use of information (risk-based maintenance). It is important to focus on the connection between investment, operation and maintenance. The key issues are the function analysis and the risk and probability considerations, utilizing a technical information system, see figure 3

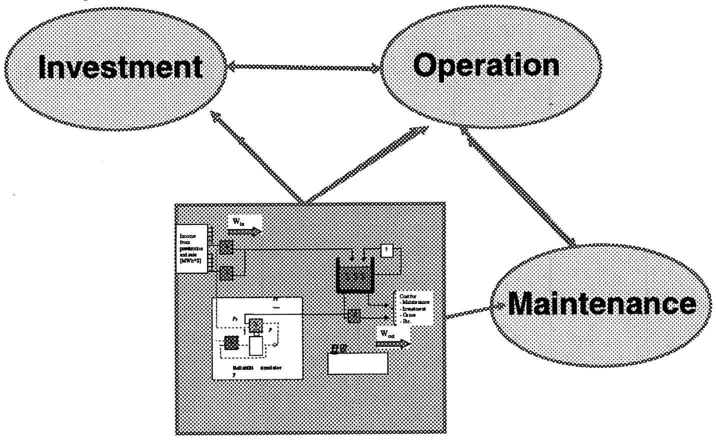

Figure 3. Co-ordination of Investment, Operation and Maintenance

4.1. Communication

Investment in reliable communication system is a key issue in the concept of the "virtually locked" station. There are of course a number of present and evolving solutions. The new IEC standard, IEC 61850 is conceived to facilitate information exchange and information handling within a station as wells as information exchange between different vendors. It is also possible to use IEC 61850 for information exchange between station level and system level. In principal, the communication system will be built up according to figure 5 below.

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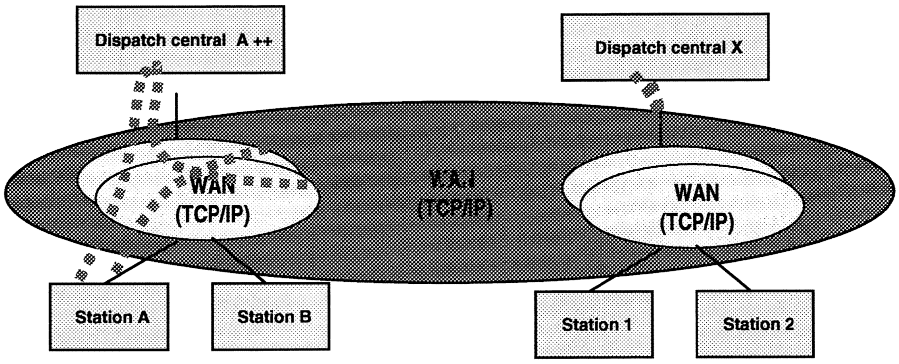

Figure 4. Communication structure

Communication requirements

- Free flow of information.
- A baud rate that can handle dynamic data
- Security
- A priority system for vital real time information (dynamic data)
- Possibility to integrate various communication systems and protocols in the same communication network.

5. RISK-BASED MAINTENANCE.

Risk-based maintenance gives a consequence analysis regarding economy, system availability, system condition, equipment condition, and consequences for the customers etc. The risk based maintenance methodology is based on a function analysis of the primary and secondary system, based on the information from station level. The methodology is based on the concept of the "virtually locked" station, which is inaccessible during normal operation. The data and the available the available information is used to estimate the systems, the stations and the equipments condition. The Function Analysis is previously described in [2, 3]. A brief description of the function analysis is given in the following.

Function Analysis

Function Analysis makes use of the available information to make an evaluation of the performance of the different systems and components in a substation. The purpose is to control the systems behavior. This is carried out from fault- and normal situations. It is possible to do this automatically or manually. The Function Analysis contains three main areas according to figure below.

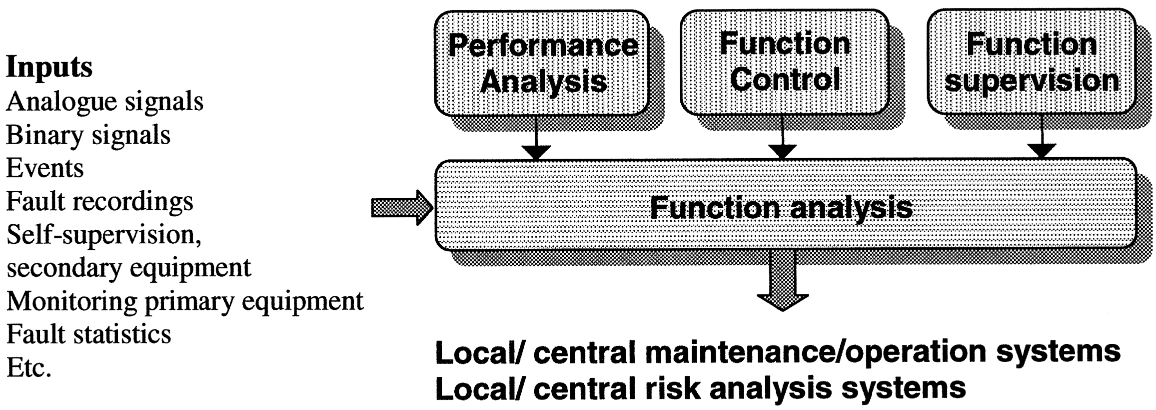

Figure 5. Function analysis system

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Performance analysis is an investigation of performance of the power system functions during normal and faulty conditions. The performance analysis will be further improved with monitoring equipment incorporated or built on-to the High Voltage Apparatus. A primary fault is the best way for the utility to test the fault clearing system including the protection settings. Using the comprehensive information in the bay units, it is possible to analyze the different faults more accurately than before.

Function control is a planned active action from the dispatch center. By activating for example a breaker and combining this information with statistical material it is possible to predict the condition of the breaker.

Function supervision uses the signals during normal and faulty situations to check that the systems or components are performing normally or out of boundaries.

The function analysis can be seen as separate system with a local platform for the substation maintenance system and a central platform for the utility maintenance systems where more than one substation is taken into consideration. In addition risk analysis can be performed both on substation level and on system level, see figure 6.

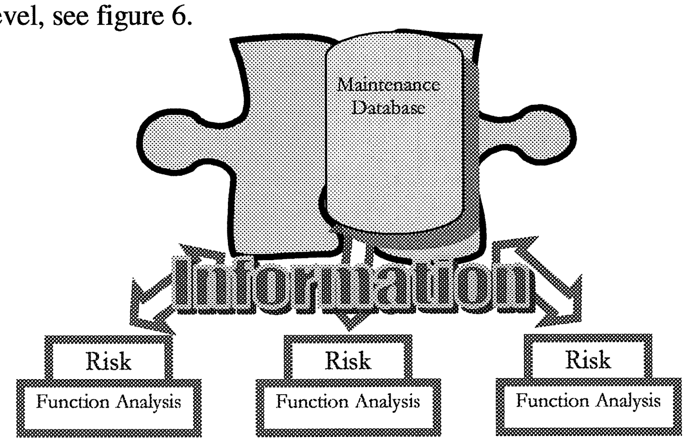

Figure 6. Function and risk analysis

6. THE ECONOMICAL BENEFITS

In Norway unwanted functions caused by personnel working in the substations are a big contributor to the cost of energy not supplied [4]. The "virtually locked" station is operated and maintained by the use of information and risk considerations, and keeps the personnel away from the stations.

- *What are the economical consequences of this change in methodology?*

The simple example below, see figure 7, with two parallel 132 kV power lines feeding a 132/11kV transformer has been used to calculate the economical benefit. Fault statistics and reliability data for primary and secondary equipment in Norway have been used. (The 11 kV busbar is the load point).

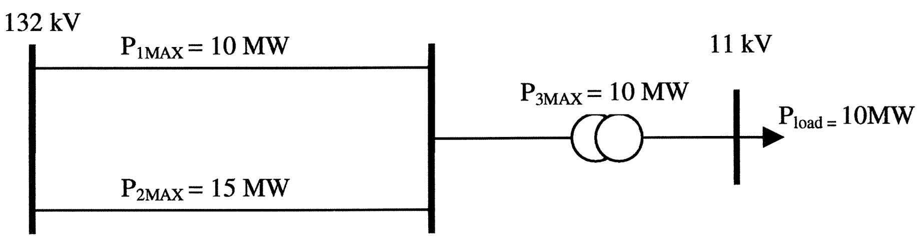

Figure 7. Calculation example

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The condition-based maintenance methodology, using function analysis instead of periodical maintenance, will increase the availability by 0,01 %. This leads to a reduction in annual interruption duration and cost of energy not supplied (CENS) as shown in the table below.

	Traditional maintenance	**The "virtually locked" station**
Interruption time	2.5 hours	1.66 hours
Availability	99,971 %	99,981 %
Cost of energy not supplied	206000 Euro	136875 Euro

7. COST OF MAINTENANCE

The presented maintenance methodology is based on information regarding the probability of a failure the different components and risk considerations according to the function and risk analysis system, see figure 8.

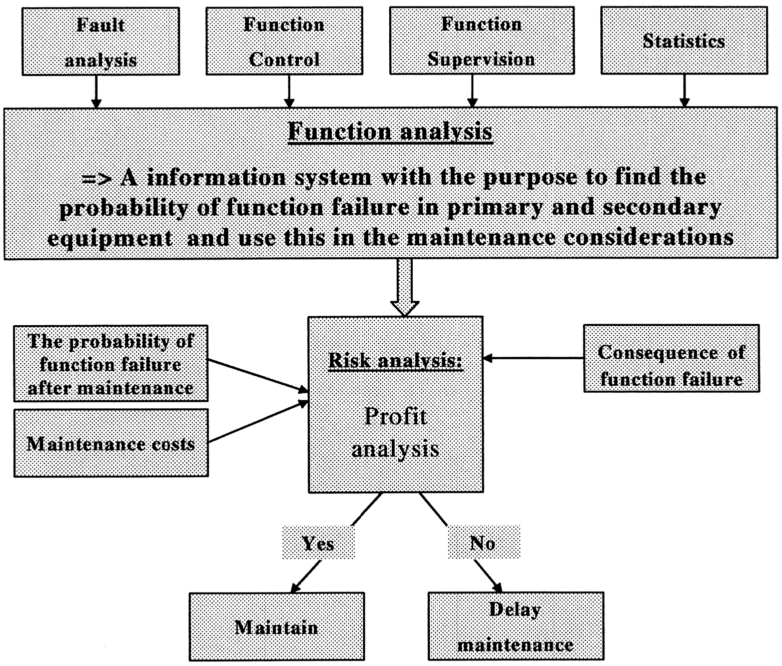

Figure 8. Function- and risk analysis system.

7.1 Maintenance of secondary equipment.

The concept of the "virtually locked" station requires stringent methods for commissioning and system testing. After the commissioning, the station shall be supervised from remote, where the Function Analysis supervises the functionality of the equipment and the self-supervision supervises the availability. Thus, it is not necessary to perform preventive maintenance of the secondary equipment. Thus, the maintenance costs and the probability for unwanted functions will be reduced. The economic benefits will of course depend on the actual maintenance cost and the cost for an unwanted function in a specific utility.

7.2 Maintenance of primary components.

The most important with this methodology is to govern the maintenance of critical components of the grid and delay maintenance on less critical components. This will give the companies an optimised maintenance on primary components with reduced operational and maintenance costs.

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8. RISK-BASED OPERATION

Risk-based operation is based on information from the technical information system. This information is used to choose actions in the grid based on risk considerations. Input values are dynamic values, status of different components and other relevant information, see figure 9 below.

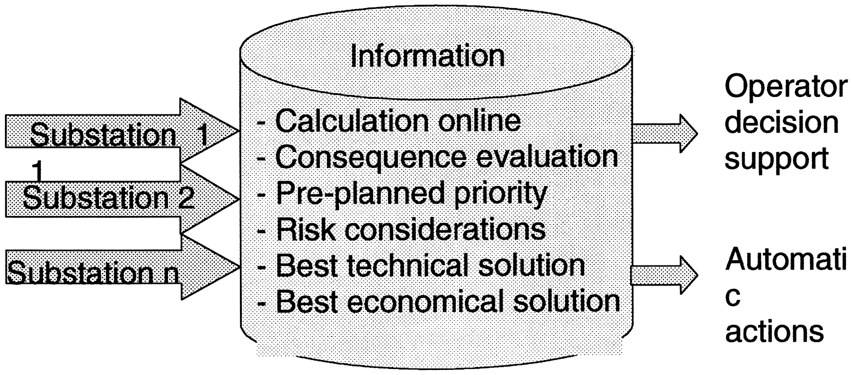

Figure 9 System for risk-based operation

9. CONCLUSION

Increased utilisation of the network may increase the risk of having extensive interruptions or even wide area blackouts like those in the western world in 2003 (North America, London, Southern Sweden, Denmark and Italy). The socio-economic costs associated with interruptions and blackouts are estimated to be about 250 million Euros per year in Norway. This amount comprises costs of the small-scale interruptions (short $\leq$ 3 and long > 3 minutes) as well as the infrequently occurring blackouts. These socio-economic costs are of the same order as the annual investments in the network in Norway. Thus, the consequences of interruptions are relatively large. This has become an incentive for better utilisation of numerical- and information technology to avoid disturbances and forced outages.

To illustrate the new possibilities, the concept of the "virtually locked" station is introduced, where all actions and decisions are based on remotely retrieved data from the station, The new approach is to utilize modern information technology, focusing on the cost benefits of the function- and risk analysis methodology. The function analysis will give condensed information on the status of the substation as well as the whole network, when the data are utilized in a central system. Thus the station can be "virtually locked". No actions will be based on traditional methods with regular visits to the station for maintenance testing etc. Most of the economic and technical benefits are on system level, illustrated with the new concept of the "virtually locked" substation. It is also possible to delay investments, when the system can be operated closer to the technical limits. The extensive information can also be used for new functions, for example automatic load shedding and restoration systems to reduce the probability of system/voltage collapse.

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