UTILISATION OF NUMERICAL PROTECTION AND CONTROL FOR A BETTER HANDLING OF RELIABILITY OF SUPPLY AND MAINTENANCE

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INTRODUCTION

The protection and control (P&C) systems play important roles for the reliability of supply as well as the utilisation of the existing network. These aspects are subject to increased concern among network companies. The P&C solutions directly and indirectly influence the costs related to the network such as investments, maintenance and interruptions. One example of the direct influence is that P&C faults (incorrect operation) is estimated to contribute to about 12 % of the total cost of energy not supplied (CENS) in Norway.

BACKGROUND

Reduction of the number of incorrect operations of P&C equipment is certainly a challenge in the short run. However, more important in the long run may be to utilise the information provided by the numerical P&C functionality to optimise the operation of the power system as well as the maintenance on both the primary and secondary equipment. It is a hypothesis that there are large profits on the system level related to increased utilisation of the network, a better handling of faults and disturbances, but also for the maintenance of transformer stations. This is discussed in e.g. [3-5].

The basic idea in the normal state is for instance to utilise the P&C information to estimate the power system condition for a possible prevention of faults leading to forced outages. In the faulted state the information will be used for efficient restoration of supply for larger areas. To achieve the expected benefits and profits it is necessary to integrate and process the information at the system level. This requires monitoring of the components and communication between transformer stations and the IT systems for decision support.

This idea is the basis for an R&D project where the aim is to develop methods and tools to evaluate the influence of the P&C solutions primarily on the reliability of supply, but also on the maintenance costs. A key element is a better utilisation of the large amount of information collected by modern P&C equipment. In addition to the life cycle costs the methods should be able to handle the risks in a risk based operation and maintenance.

In this paper the idea is presented and discussed along with the possibilities for a risk based operation and maintenance utilising information provided by numerical P&C. Further, procedures for estimation of gross cost savings are suggested. Results from case studies (examples) show how these procedures may be used to estimate possible reductions related to operation and maintenance respectively. The case studies are prepared in cooperation with Norwegian utility companies.

NEW POSSIBILITIES FOR OPERATION AND MAINTENANCE

Viewed in the light of current regulatory framework and future challenges it is desired to utilise possibilities granted by P&C systems to optimise costs through a holistic system approach. Extensive information available from numerical P&C equipment may be combined with analyses and decision methodologies in different ways to obtain cost savings. So far, the project has focused on possibilities related to power system operation and transformer station maintenance.

In connection with power system operation there are possibilities to avoid and to limit the consequences of disturbances by introducing new or extended system control strategies. Introducing a risk based power system operation provides opportunities for increased utilisation of the existing network (and thereby postponed investments). Regarding transformer station maintenance the extensive information available open possibilities for condition and risk based maintenance of P&C as well as primary components.

It is a hypothesis that such a system may be operated with the following economical and technical advantages:

- Due to increased monitoring the system may be operated closer to its technical limits. This means that the system utilisation is enhanced and investments may be postponed.
- The risk of system collapse may be controlled and interruption costs controlled by means of active actions (manual or automatic) based on information available in the system and necessary decision support.
- Based on available information risk based maintenance of P&C as well as primary components may be enhanced.

This paper focuses on fault handling and risk based maintenance. Increased system utilisation will not be further treated here.

Information utilisation

One approach discussed in e.g. [5] is a situation where the transformer station is virtually locked and made unavailable for personnel during normal operation. The stations are fitted with numerical P&C equipment and the P&C functions are integrated at both bay level and station level. In such stations all components are monitored and information concerning operation and component condition is made available to decision makers. Risk based power system operation and maintenance will depend on making decisions that require information from various data sources. The need for decision support will typically include risk analyses, LCC analyses, technical calculations, economical calculations and safety analyses.

Key IT systems may offer both data and functionality as a basis for making the necessary decisions. Such systems are NIS (Network Information System) Scada (Supervisory Control and Data Acquisition System), ERP (Enterprise Resource Planning System) and CIS (Customer Information System). Utility companies have invested considerable time and money in purchasing and integrating such systems and there is now a need to get benefits from their investments. In addition to information from these systems, more information from P&C equipment and from primary components may be made available and stored in databases. This is illustrated in Figure 1. The principles outlined in this paper will potentially contribute to achievement of such goals.

Further research is needed to identify and describe decisions needed to achieve the goals regarding improved efficiency within operation and maintenance. Implementation of procedures for making important decisions will to some extent require extended functionality and integration between core systems. It is however important to state that existing systems offer many possibilities, but the main challenge is to identify and describe decision procedures. Secondly it is necessary to describe actions that should manually or automatically follow decisions that are made.

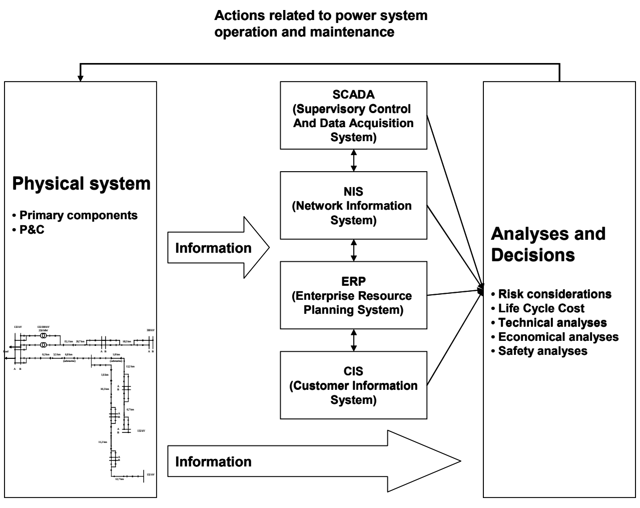

Figure 1 Information utilisation

Challenges to be met are the uncertainties in costs related to establishing a system for information handling and decision support, as well as the increased level of complexity in such a system.

Power system operation

By introducing new or extended system control strategies disturbances may be avoided or the consequences of disturbances may be reduced. New technology gives enhanced possibilities for state estimation, e.g. through:

- Monitoring of the system configuration
- Observing critical parameters
- Prioritising alarm signals, disturbance recorder information, etc.
- On-line fault analyses (fault localisation and description)
- On-line risk analyses (reliability of supply and impacts).

It is possible to analyse and evaluate information from primary equipment and P&C equipment according to criteria for risk and optimum operation. This can be realized through a passive system which continuously monitors parameters and physical states, or an active system which is enhanced with on-line control based on the knowledge of parameters and component and system states. For example self monitoring may be utilised to detect faults before a disturbance occurs, faults in progress may be detected at an early stage and automatic control routines may be established to avoid voltage collapse, instability, overload etc. Consequences of disturbances may be reduced by introducing e.g. prioritized load disconnection, automatic rerouting and power system reconstruction.

Maintenance

Function analysis [3] is outlined as a method where information from the different P&C and primary units is used to estimate the different components states. Input to function analysis is results from fault analysis, function control and function supervision, see Figure 2. Fault analysis is an investigation of performance of the power system during faulty conditions. Function control is a planned active action from the dispatch centre, like activating a breaker to check its function. Function supervision uses the signals during normal and faulty situations to check how systems or components are performing. This information is combined with fault statistics to estimate a probability of failure for the component or system. This probability of failure is subsequently input to a risk and profit analysis where the probability of failure is combined with additional information like impact of failure, maintenance cost, and probability of failure after maintenance, etc. The component or system is maintained if the risk is not within acceptable limits.

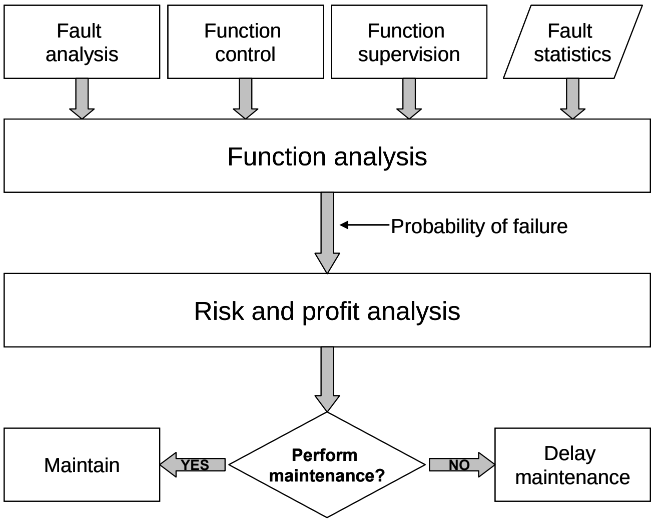

Figure 2 Function analysis

The fault statistics show that there are large numbers of incorrect protection system operations [1,2]. About 40-50% of such faults have human related causes. These are mostly incorrect settings or faults introduced by human activities during operation of the system, such as during maintenance work in the stations.

It is assumed that risk based maintenance will lead to a reduction in the number of human induced faults connected with routine maintenance. This concept requires increased focus on the installation and commissioning phase. Furthermore intensified testing is needed at system as well as unit level. A new station and system may thereby be burdened with considerably fewer faults compared with today's practice, with correspondingly increased availability and reduced cost of energy not supplied.

POWER SYSTEM OPERATION POTENTIALS

If a utility company considers implementing risk based power system operation, the first step is to quantify potential gross cost savings. To assist this, the R&D project has developed a procedure. Main elements in this procedure are faults causing customer interruptions and thus leading to cost of energy not supplied CENS [6]. Each of the faults is evaluated with respect to optimum utilisation of numerical P&C technology. The evaluation has been accomplished with support from experts having detailed knowledge of the actual networks. The goal is to reveal if the information mentioned above on a system level would contribute to improved management of faults, which again would reduce interruption time for customers and thus reduce costs for the utilities (CENS).

For each failure report collected over a representative period of time the following conditions have been measured:

- Interruption time, interruptions > 3 minutes
- Energy not supplied (MWh)
- Cost of energy not supplied (NOK)
- Material costs for fault repair (NOK)
- Personnel costs for fault repair (NOK)

Corresponding conditions have then been estimated provided optimal utilisation of the information.

Based on state estimation as mentioned above a number of actions (manual or automatic) are assumed, e.g.:

- Preventive actions as rerouting, reactive compensation, tap changing etc.
- Sectioning in a distribution network
- Test switching in a regional or transmission network.

In this way a difference in total costs is calculated as an estimate of potential benefits. Figure 3 below illustrates this approach.

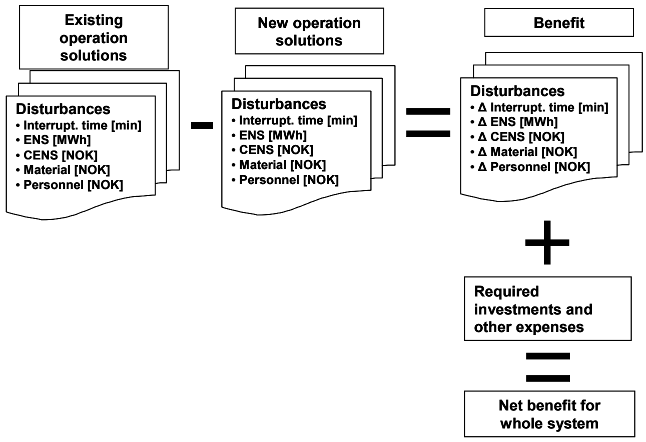

Figure 3 Power system operation – handling of disturbances

Examples. The basis for these examples is the Norwegian transmission network (132 kV – 420 kV) and a distribution/regional network (11 kV – 110 kV). For these two networks historical data for recorded faults for a selected year (2003) has been used as input, utilising the procedure above.

In the transmission network single failures will in general not cause customer interruptions due to redundancy. This means that failure of P&C equipment will be involved in a significant number of cases where customers are affected (i.e. disturbances with two or more failures). In 2003 there were 53 disturbances in the transmission network that caused customer interruptions. These represented a CENS cost of 53 million NOK. Evaluations corresponding to the procedure described above show that the CENS cost could have been reduced with about 60% to 20 million NOK in 2003. With a discount rate of 6% p.a. and an analysis period of 15 years, a cost of up to 320 million NOK may be justified.

In the investigated regional and distribution network single faults will in general cause customer interruptions. In this study interruptions causing the 33 largest CENS costs are included (interruptions with a CENS cost above 50 000 NOK). They represent 5,5 million NOK out of a total CENS of 7,9 million NOK for the utility in 2003. Evaluations based on the described procedure show that the CENS cost could have been reduced with about 70% to 1,5 million NOK in

2003. With a discount rate of 6% p.a. and an analysis period of 15 years, a cost of up to 38 million NOK may be justified.

MAINTENANCE POTENTIALS

The risk based maintenance philosophy should be built on an impact assessment with respect to economics, system availability, system condition, component condition and consequences for customers.

To be able to quantify potential gross cost savings from such a concept a procedure to estimate cost savings has been developed. The approach is applied to maintenance of components in a selected transformer station.

Selected components in the transformer station are evaluated with respect to their criticality taking into account conditions like; health, environment, economy and quality of supply. Analyses of the actual network will help understand consequences of component failure and thus enable description of a proper risk based maintenance program. Figure 4 below illustrates the principles applied in the procedure for estimation of cost savings. The "new maintenance program" assumed is as follows:

- Completely or partly substitution of preventive, time based maintenance.
- New preventive maintenance based on condition monitoring or condition control. This involves repair of critical components before failures occur.
- Significant reduction of corrective maintenance on critical components.

Total costs for existing maintenance of a transformer station are calculated, comprising cost elements for each component involved, such as preventive and corrective maintenance costs, and CENS costs.

Correspondingly total maintenance cost utilising information provided by new P&C technology is calculated. The most common failure modes for the components in the transformer station are investigated. For each failure mode it is made a judgment to decide if new technology can provide condition monitoring or condition control. Based on these assumptions network analyses are performed in order to calculate interruption costs (CENS) and costs of corrective maintenance.

When calculating gross benefits costs such as new technology are not included.

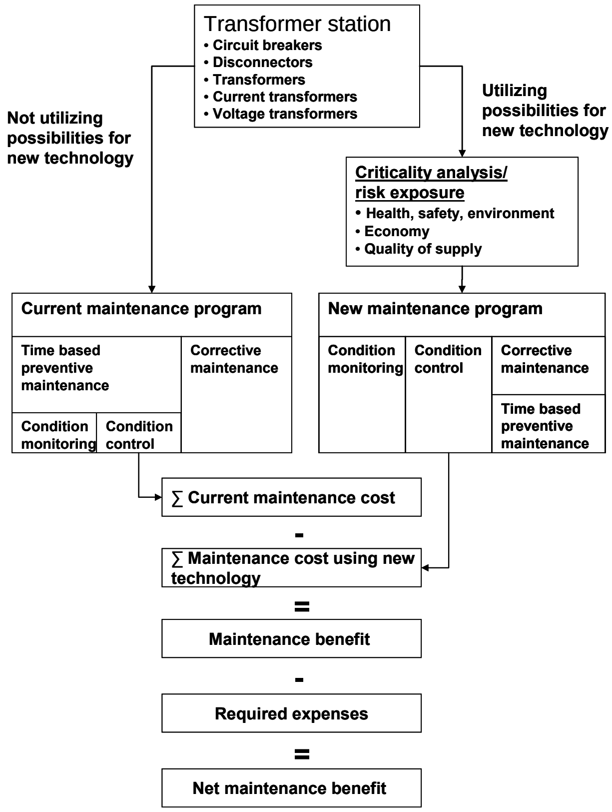

Figure 4 Maintenance

Example. To estimate possible maintenance improvements a representative 300/132 kV transformer station and regional network is used. Cost for current preventive maintenance is based on data from maintenance management system for some components in the selected network. Circuit breakers, transformers, disconnectors, current transformers, voltage transformers and P&C equipments are included. Average annual cost for preventive maintenance in the selected transformer station is approximately 300 000 NOK for these components.

The whole regional network is made up by a total of 33 transformer stations on 300/132 kV level. A very rough estimate for average annual preventive maintenance for all stations is 10 million NOK. With a discount rate of 6% p.a. and an analysis period of 15 years, a cost of up to 97 million NOK may be justified if the maintenance is eliminated. This will of course not be the case, but it indicates that there may exist a potential for reducing costs when utilising new technology due to reduction of maintenance and CENS costs.

CONCLUSIONS AND FURTHER WORK

This paper presents new ideas for power system operation and maintenance. To put this concept into operation utility companies will need to make several changes. First of all it will be necessary to utilise the extended functionality of numerical P&C equipment. This requires technical knowledge at a detailed level, and not the least knowledge of how the possibilities may contribute to improvements at system level. Further on it will be necessary to consider these aspects already during the investment phase, among other things by choosing standardised solutions and establishing commissioning procedures to ensure good quality during operation. The requirements among others comprise choice of P&C technology, communication solutions, commissioning and expertise.

If a utility company considers implementing a risk based operation and/ or maintenance the first step would be to calculate potential gross benefits. Procedures for estimation of gross cost savings regarding fault handling and maintenance are established as a part of the R&D project. Case studies concerning fault handling show a potential benefit in interruption costs (CENS) in the Norwegian transmission system of 33,3 million NOK per year, corresponding to a maximum investment of 320 million NOK. This represents a reduction in costs of energy not supplied of about 60%.

In a selected regional and distribution network the potential benefit is 4 million NOK, corresponding to a maximum investment of 38 million NOK and representing a reduction of about 70%.

The case study concerning transformer station maintenance indicates similar potential benefits. However it remains to estimate the maintenance costs in a risk based maintenance.

It is important to be aware that these are gross benefits and that investment and operating costs will incur if the new ideas shall be put into service. Examples of such costs are investments related to necessary information handling and decision support, increased need for competence, increased costs related to commissioning and testing, etc. This must be thoroughly investigated for each separate utility. As these cost elements are individual to each utility company, the R&D project has found it inappropriate to try to generalize.

The possibilities outlined in this paper represent a framework for reliability modelling and methods handling risk and life cycle costs in the R&D project. The gross benefits calculated in the case studies suggest that it may be well worth to continue the work with this concept. In this project the case studies will be further processed to include more cost elements, network analyses will be carried out and the developed models and methods for risk analyses will be incorporated.

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