DISTRIBUTION AUTOMATION SOLUTIONS – IMPACT ON SYSTEM AVAILABILITY IN DISTRIBUTION NETWORKS

Oliver SCHROEDEL
Siemens AG – Germany
oliver.schroedel@siemens.com

Michael SCHWAN
Siemens AG – Germany
michael.schwan@siemens.com

Sven KOEPPE
Siemens AG – Germany
sven.koeppe@siemens.com

Robert ROSENBERGER
Siemens AG – Germany
robert.rosenberger@siemens.com

ABSTRACT

With customers and also regulators increasing their focus on supply reliability in electricity supply, this important aspect of power quality is coming more and more into focus of system operators – especially in distribution networks. In this context, cost-effective measures and concepts to improve supply reliability are becoming a key factor for economic system operation. A basic prerequisite for the planning and implementation of such measures and concepts is a thorough understanding of the correlations between the various factors influencing a system's supply reliability performance.

This paper presents the results of a related study analyzing the impact of different intelligent automation solutions on the reliability performance of different medium voltage distribution networks. The respective system topologies are modeled and the resulting system reliability performance is determined by probabilistic reliability calculations, delivering e.g. the SAIDI and SAIFI values. The results show that the distribution automation solutions can have a very significant impact on both the SAIDI and SAIFI performance of the systems – typically even if only a small share of ring main units is automated.

INTRODUCTION

A major requirement on electricity supply systems is high supply reliability for the customers – which is mainly determined by the distribution networks [1]. In general, customer expectations on supply reliability are steadily increasing – in some cases, explicit power quality criteria are even included in negotiated contracts between customers and utilities. Moreover, regulators often require the utilities to report on the reliability performance, or define explicit performance targets – that may even be penalized in case of violations.

Given this background, the power quality performance of distribution networks is coming more and more into focus of system operators. Cost-effective measures and concepts for system development and operation that support meeting the required performance targets are becoming a key factor for economic system operation. Understanding the correlations between the respective measures and their quantitative impact on the system's reliability performance is therefore becoming ever more important.

This paper presents results of a related study analyzing the impact of different intelligent automation solutions on the reliability performance of different medium voltage (MV) distribution networks, considering a variety of different aspects. The respective system topologies are modeled and the resulting system reliability performance is determined by probabilistic reliability calculations.

Further, selected details related to the implementation of such intelligent automation schemes are presented. Also, additional benefits from linking intelligent automation schemes to other smart grid topics such as smart metering, power quality monitoring, or e-mobility, are discussed.

STUDY METHODOLOGY

The study is to analyze the impact of different intelligent automation solutions on the reliability performance of medium voltage distribution networks. The study considers the following types of networks:

- Radial MV distribution network
- Open ring MV distribution network
- For each of the above network types, different network sizes with 12, 24 or 84 ring main units in each feeder / open ring are considered.

For better comparability, the length of each line between two ring main units, as well as the total load and total number of customers in each feeder / open ring are considered identical in all network models.

Six different automation concepts are investigated:

- Concept 0 – Reference
  A remote-controlled circuit breaker (together with its assigned protection device) is installed in the HV/MV substation in each outgoing feeder. All other switching operations are manually controlled only, including the normally open point.
- Concept 1 – Remote-controlled open point
  As concept 0, but in addition the open point is remote-controlled.
- Concept 2 – Remote-monitored short circuit indicators
  As concept 1, but in addition all short circuit indicators are remote-monitored.
- Concept 3 – Remote-controlled disconnectors
  As concept 2, in addition remote-controlled disconnectors are modeled in selected ring main units.
- Concept 4 – Autonomous disconnectors
  As concept 3, but the disconnectors (and the circuit breakers in the HV/MV substation) are not remote-controlled but are operating autonomously.
- Concept 5 – Remote-controlled circuit breakers
  As concept 2, in addition remote-controlled circuit breakers are modeled in selected ring main units.
- Concept 6 – Autonomous circuit breakers
  As concept 5, but the circuit breakers (also in the HV/MV substation) are operating autonomously.

The automation concepts 3 to 6 are applied to either 1, 2, 3, 5 or all ring main units in one feeder / open ring; in addition, the reference case without any automated ring main units is considered as well. Neglecting certain combinations of network types, automation concepts and number of automated ring main units, in total 119 different network variants are modeled and evaluated in the study.

For each network variant, the respective automation concept is implemented in the network model and the respective parameters for the restoration process simulation in the probabilistic reliability calculation [2] are set. The calculation, based on a homogenous Markov algorithm implemented in the PSS®SINCAL network calculation tool [3], then delivers probabilistic supply reliability indices for each ring main unit and for the network variant in total.

STUDY RESULTS

The presentation of study results in this paper focuses on the networks with 84 ring main units per open ring. The following diagrams present the results indices SAIFI (System Average Interruption Frequency Index) and SAIDI (System Average Duration Index) for the different automation concepts in open ring networks, and for comparison also in radial networks:

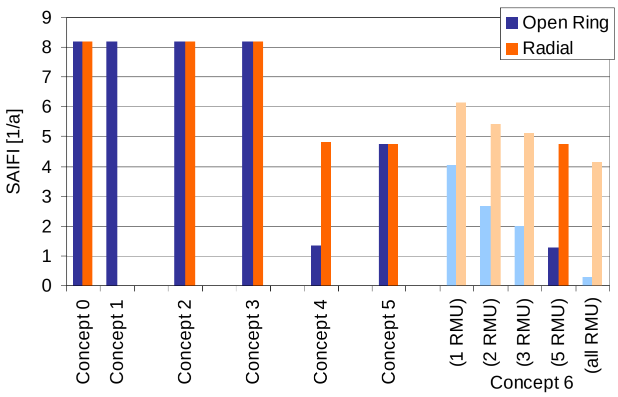

Figure 1: SAIFI in networks with 84 ring main units per feeder / open ring in different automation concepts applied to 5 (concepts 0, 1 and 2: all) ring main units

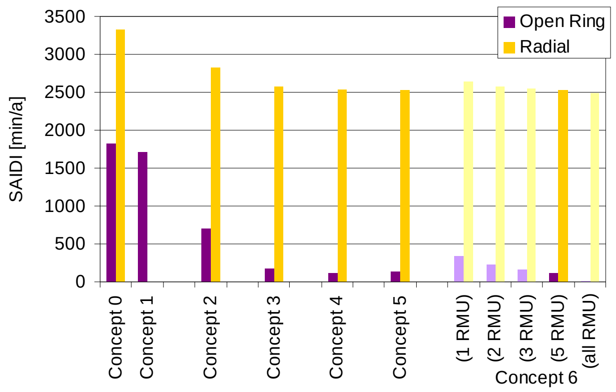

Figure 2: SAIDI in networks with 84 ring main units per feeder / open ring in different automation concepts applied to 5 (concepts 0, 1 and 2: all) ring main units

The diagrams illustrate that in general, the biggest impact is on SAIDI due to the faster supply restoration to interrupted customers in networks with increased automation. Also, the SAIDI impact in open ring networks is significantly higher than in radial networks due to missing backup supply.
Some concepts, e.g. remote-controlled disconnectors, have no impact at all on SAIFI.
Especially the use of remote-controlled or autonomously operating disconnectors or circuit breakers allows significant reductions of both SAIFI (not for remote-controlled disconnectors) and SAIDI values. As expected, the highest impact is realized by the autonomously operating circuit breakers (concept 6) – although the autonomously operating disconnectors (concept 4) enable almost identical system performance, especially in large networks. Here, it is to be noted that the use of circuit breaker offers additional operational benefits beyond the reliability performance. The high impact of the automation concepts based on the autonomous operation of breakers is mainly related to the much faster execution of switching operations, compared to the remote-controlled automation concepts.
The results show clearly that already the application of these automation concepts to a low number of ring main units has a significant impact on the reliability performance. Of course, the impact is increasing with an increasing automation degree (i.e. number of automated ring main units), but the additional reliability benefit per additionally automated ring main unit is saturating quickly. Figure 3 shows an example for the impact of the automation degree (number of automated ring main units related to total number of ring main units per feeder / open ring) for selected automation concepts on SAIFI and SAIDI:

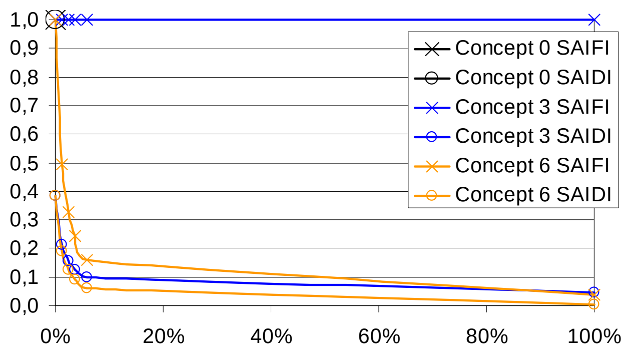

Figure 3: Impact of automation degree for selected automation concepts on SAIFI and SAIDI in open ring networks with 84 ring main units per open ring (relative to reference scenario)

The results and conclusions as presented above are valid in principle as well for the other open ring and radial networks with lower numbers of ring main units – partly to a lower extent due to the lower number of ring main units.

It is to be noted that the study analyzed fictive example networks, featuring a fully homogenous network structure. The results and conclusions thus can not be applied directly to real networks – but rather indicate basic correlations between different automation concepts and automation degrees on the network's supply reliability performance.

IMPLEMENTATION

General

"Smart" protection and control systems in distribution networks have developed in recent years from the classical approach of monitoring the short circuit indicator status to the three point automation where the operational data are sent to the substation control or to the SCADA system in order to enable the autonomous control of circuit ties – realizing a "self-healing" distribution grid. Such advanced concepts, based on intelligent devices installed in the field level and linked to central control systems, are nowadays technically feasible and in many cases also economically viable [4].

Any such concept is based on the availability of appropriate primary equipment, of communication links and of the actual intelligent electronic devices (IEDs) in the secondary distribution system. It is noted that the required primary equipment does not only comprise switching devices (disconnectors, load breakers or circuit breakers) as actuators, but also current and voltage transformers, power quality monitors or smart meters as sensors to identify the current system operating conditions.

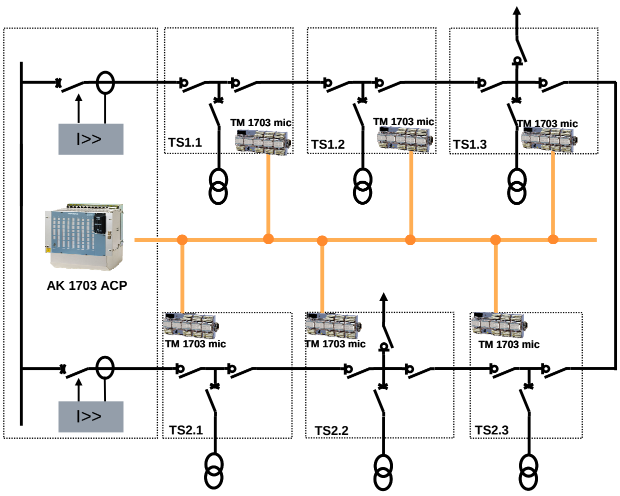

Figure 4: Example for distribution network automation, comprising both primary HV/MV substation and secondary substations

This paper discusses an implementation concept for distribution automation aiming at improving the system's supply reliability performance by implementing "self healing" functionality, and at delivering additional synergies with other smart grid technologies. The logic resides in individual IED groups located in the feeder sections, and detailed operational data is conveyed back to a SCADA or substation control system. Together, this allows the control of circuit ties to isolate failures and to restore supply to interrupted sections of the distribution grid in case of faults.

Communication

In order to realize the full scope of "self-healing" functionality, and to enable certain synergies as discussed later, a two-way communication system covering the different secondary substations and the primary substation or distribution control center is required for control, monitoring and automation. However, even without, or with limited communication, already a certain level of distribution automation and self healing functionality would be possible.

Modern communication systems use open standards rather than proprietary technology, especially the IEC 61850 standard. IEC 61850 provides the required logic and flexibility for the realization of self healing functionality. The Ethernet backbone can be linked over a twisted pair or fiber-optic cables, radio systems, mobile communication systems (e.g. GSM, UMTS), broadband over power line (BPL) or digital subscriber line.

Peer-to-peer functionality via IEC 61850 generic-object-oriented substation event (GOOSE) messages provides not only binary data, but analog values as well. Each device contains extensive programmable logic to realize the automation functionalities – using input data such as voltage, current, time-current characteristic curves or load. The IEDs then handle the self-healing functionality and attempt to clear and isolate faults, and to then initiate the supply restoration logic.

Application

The intelligent distribution automation application provides fault detection, isolation and restoration logic in a network section equipped with a group of breakers – disconnectors, load breakers or circuit breakers. The biggest advantages for system operation and the highest impact on system availability are achieved by the installation and automation of circuit breakers (together with respective protection functionality). Also, certain of the synergies discussed later require, or at least benefit from, circuit breakers.

Effective automation requires that on the one hand, control logic resides as deep inside the grid as possible. On the other hand, also a higher level control – on either substation control or distribution control level – needs to be realized. The individual self-healing loop breaks the grid into manageable segments and allows the utility to further define the healing process logic for its distribution system.

Each loop can be set to operate in a completely automated state, in a remote manual mode via SCADA or in manual mode for users in the substation. Remote mode is an override that allows the operation center to perform closing and opening operations to reconfigure the grid.

The system is designed to work using independent automated device groups. The IEDs located at each secondary substation are associated with a circuit breaker or disconnector and include current and voltage sensors to provide the necessary input data used to determine logical sequences. This information is then made available to each of the other IEDs, starting over the communications channel located within that particular loop and then back to the substation(s) and up to SCADA.

There is no need for a master-slave arrangement since IEC 61850 uses peer-to-peer communications. This means real-time control, a fast-healing grid and fault location information being processed within seconds. Since the devices all communicate in a peer-to-peer manner, it is possible to eliminate some of the necessary input devices that would normally be required in a loop automation system.

Synergies

The primary aim for improving a system's availability performance is the reduction of interruption durations and the fast supply restoration to as many consumers as possible. An important driver is also the reduction of possible penalties for supply interruptions (e.g. energy not served).

With respect to economic viability, it is important to offer a stepwise upgrade of the protection and control system from the current status to the fully automated solution. In addition, economic viability is improved, or actually enabled, by realizing synergies with other "smart" applications:

- Integration into infrastructure for smart metering
  Synergies are possible through integration of distribution automation systems and smart metering. Using one common infrastructure for communication, e.g. BPL and also common usage of hardware, e.g. date concentrator for both systems, reduces the costs.
- Power quality monitoring of decentralized generation
  Renewable and distributed generation, e.g. photovoltaic panels on roofs or small combined heating and power units, are often connected directly at the low voltage level. This infeed has great impacts on the load of lines and the protection scheme of the distribution system. Also, special attention has to be paid to power quality standards and to system protection and operation, where e.g. the inversion of power flows has to be managed. These areas offer high synergies with distribution automation systems.
- Integration into infrastructure for e-mobility
  Distribution automation can support the new infrastructure for e-mobility and can connect to charging terminals and active administration of power storage in e-cars.

To fulfill all these new requirements in a smart grid distribution automation system, a modular concept for the protection, monitoring, automation and communication equipment is needed. Therefore, a big advantage of such solutions comes from the use of flexible components by the same system family in all these different distribution automation applications.

CONCLUSION

Today's electricity supply systems face massive needs for substantial changes – e.g. due to liberalization, increasing economic pressure, higher quality requirements of customers, stricter environmental regulations, massive installation of renewable energy generation etc. These trends will also affect distribution systems – which for example are responsible for a high share of the total system's cost or for power quality, especially supply availability. In this context, cost efficient methods to fully utilize the installed capacity and to improve power quality are of ever increasing importance.

In distribution networks, advanced and "smart" distribution automation solutions can provide substantial technical and commercial advantages to network operators – being much more cost-effective compared to solutions based on primary technology only. The results of a study have shown that different distribution automation concepts can have a very significant impact on a system's supply availability performance – e.g. both SAIFI and SAIDI performance can be reduced by autonomously operating circuit breakers or disconnectors below 10% of the respective values in the non-automated system configuration. The study delivered basic correlations on the quantitative impact of the separate distribution automation concepts applied to a certain share of the system's ring main units on the overall system reliability performance.

With today's distribution networks typically featuring a rather low degree of automation only, the use of such advanced distribution automation concepts opens large potentials for cost-effective improvements of system performance. Even the automation of a smaller share of ring main units in a system only can already realize significant impact. Explicit analyses of existing distribution networks can identify the specific locations in the system where appropriate automation solutions can achieve the highest benefit.

Such advanced distribution automation concepts – up to the "self healing" functionality offered by autonomously operating breakers – can be realized using technologies and equipment that is readily available today. Besides the appropriate intelligence implemented in IEDs that are installed within the distribution feeders, implementations of these concepts of course require appropriate primary equipment (actuators (i.e. breakers) and sensors (e.g. instrument transformers or smart meters)) and communication links between the separate IEDs on field level, and to higher level substation or distribution control systems.

While economic viability of such smart distribution automation solutions can often be achieved by its immediate benefits only, additional synergies can be realized with other smart grid technologies.

REFERENCES

[1] M. Schwan, 2006, "Störungen und Versorgungsunterbrechungen im Mittelspannungsbereich", *Proceedings ETG Fachtagung Diagnostik elektrischer Betriebsmittel (Kassel)*, VDE

[2] M. Schwan, A. Altunordu, 2008, "Probabilistic Supply Reliability Analysis and Application in Advanced Asset Management Methods", *Proceedings 14th ICCI Conference (Istanbul)*, ICCI

[3] Siemens AG, 2010, *PSS®SINCAL 7.0 Utility and Industry Network Analysis Tool*,
See also www.siemens.com/energy/pss-sincal

[4] Siemens AG, 2011
www.siemens.com/energy-automation
www.siemens.com/smart-grid