EFFECTS OF CONFIGURATION OPTIONS ON RELIABILITY IN SMART GRIDS

Daniel SCHACHT
FGH GmbH – Germany
daniel.schacht@fgh-ma.de

Dirk LEHMANN
FGH e.V. – Germany
dirk.lehmann@fgh-ma.de

Lukas KALISCH
FGH e.V. – Germany
lukas.kalisch@fgh-ma.de

Dr. Hendrik VENNEGEERTS
FGH e.V. - Germany
hendrik.vennegeerts@fgh-ma.de

Dr. Simon KRAHL
FGH e.V. - Germany
simon.krahl@fgh-ma.de

Prof. Dr. Albert MOSER
FGH e.V. - Germany
albert.moser@fgh-ma.de

ABSTRACT

As has been shown in various previous studies smart grid applications (SGA) may represent a cost efficient alternative to conventional network reinforcement for integrating further distributed generation units and optimizing current power systems. However SGA, such as generation side management and remotely controllable switches, are at least partly depended on an information and communication system (ICT system). Therefore interactions between power system and ICT system need consideration in the planning process. For the purpose of assessing power system reliability in smart grids enhanced algorithms have been developed [1]. The selection of configuration options however still represents a challenge due to lack of exact quantitative failure data for the ICT system and various option details. Therefore possible configuration options have been identified and sensitivity analyses have been carried out, which on one hand show the benefits of SGA and on the other hand the influence of those options.

INTRODUCTION

Currently a series of technical and political drivers influence the integration of SGA in electrical distribution networks based on conventional primary equipment. On the one hand these SGA, such as demand side management (DSM), generation side management (GSM) and remote switching, enable DSOs to operate networks closer to the technical limits, but on the other hand the network becomes dependent on their functionality. The SGA themselves are usually implemented on intelligent electronic devices (IED), which in turn are part of the ICT system. Furthermore SGA require an exchange of measuring data and control commands and hence are dependent on the ICT system. The frequency and duration, the network is depending on a certain SGA and the ICT system is determined by the network topology, the function of the SGA as well as the electricity demand and the generation. Since a decrease in reliability has significant economic effect on customers - and due to quality regulation on DSOs -, the influence of SGA and ICT system should be assessed in the planning process.
In addition to standard configuration options concerning reliability in distribution networks such as the number and location of remotely controllable switches as well as circuit breakers, in a smart grid further configuration options such as the realization form of the ICT system and fallback solutions for SGA have to be considered. For this particular purpose a new algorithm for the assessment of reliability in smart grids was developed and described in [1]. Therefore this paper focusses on the utilization of this new algorithm on differently designed smart grids to meet a predefined supply task. For this purpose the communication medium, redundancy of the ICT system and the little-known reliability of ICT equipment in electrical networks are analyzed.

CALCULATION OF RELIABILITY IN SMART GRIDS

Currently new algorithms, such as introduced in [1, 2], allow for the assessment of reliability in smart grids. The enhancements of these algorithms compared to those presently used are the modelling of ICT system and SGA, their simulation in the resupply process. Furthermore the detailed consideration of time dependency of network utilization in order to cover a temporary need of SGA and the time dependency of equipment reliability are added. An overview of the algorithm is shown in figure 1.

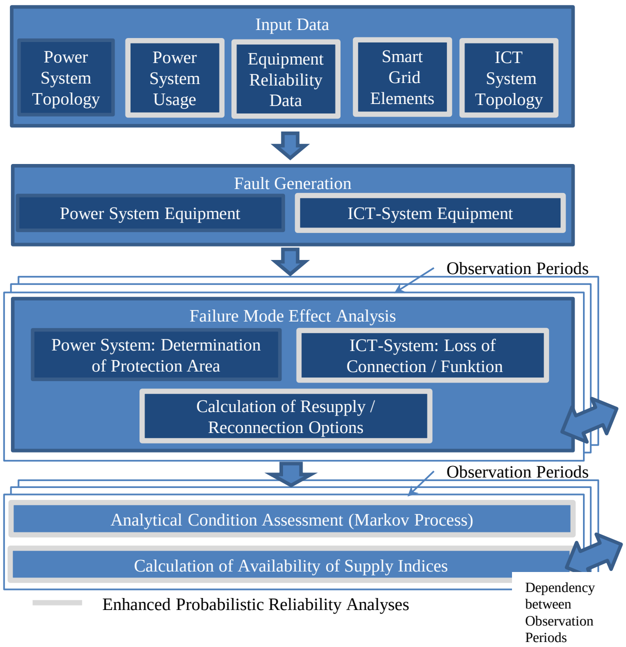

Figure 1 New Algorithm for Reliability Assessment [1]

ICT SYSTEM

The form of realization and the utilized equipment, which is characterized by its specific failure rate and time to repair, are two main configuration options for the ICT system.

Form of Realization

One possible form of realization of the ICT system is based on fiber optic cables, which can be assumed to be installed in parallel to the energy cables or overhead lines during their mounting. Figure 2 shows this form of realization for an exemplary medium voltage (MV) network.

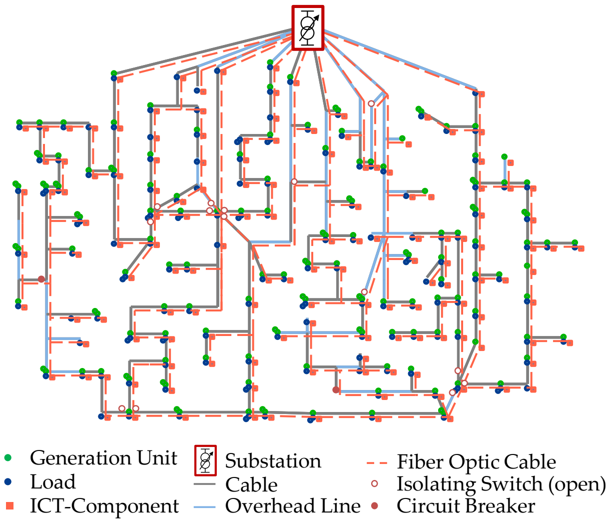

Figure 2 MV Network with ICT system (Fiber Optic Cables)

Since MV networks are often operated as open loop ring topologies, the topology of the parallel ICT system will be mainly a ring topology as well. This circumstance leads to a high redundancy in the ICT system. In case of an single equipment failure an alternative communication path is always available.

Depending on local conditions fiber optic cables may not be available. In such areas the utilization of a mobile radio communications system may represent a suitable alternative. In figure 3 the MV network from figure 2 is equipped with an ICT system based on mobile radio communication.

ICT systems based on mobile radio communication are usually configured in star topology with different degrees of overlapping between mobile radio cells. In systems with no overlapping between cells, as shown in figure 3, there is almost no redundancy in the system topology. In this case a single equipment failure may lead directly to an interruption of communication.

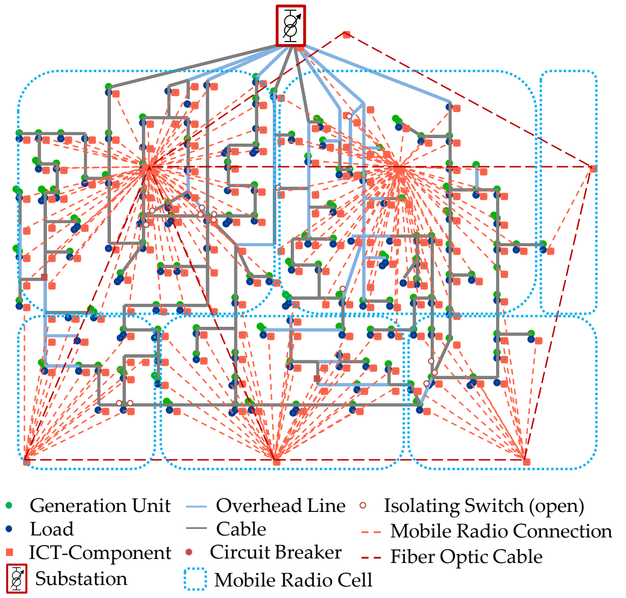

Figure 3 MV Network with ICT system (Mobile Radio Communication)

Reliability of Equipment

Data on reliability of ICT equipment (ICTE) used in electrical networks are rarely collected in central databases like data on reliability of primary power system equipment (PSE). Therefore a comprehensive analysis on available ICTE reliability data has been carried out. Information was taken from manufacturer information brochures, ICTE used in other industrial sectors, field tests as well as rarely field data and hence shows significant variations for single classes of equipment (see figure 4) [4-13].

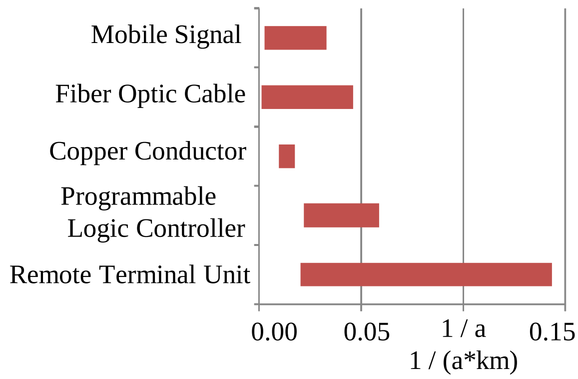

Figure 4 Reliability Data for ICT Equipment [4-13]

The large differences between the minimum and maximum values can be explained with differences in the approach to determine the values. Manufactures usually use reliability prediction methods for electronic products like the Telcordia Reliability Prediction Procedure [3]. Other sources stating reliability information use failure events in real systems to determine the values. The limited number of samples in these systems and the low probability for the event under consideration may lead to other results as the predicted values. Even though the statistical significance of all these values cannot be proven, they give a first hint concerning real ICTE reliability.

MODELLING OF SGA

According to [1] SGA can be categorized into two groups based on their main communication needs. For a reliability assessment a major difference between these groups is the fallback solution in case of communication or functional failure.
SGA with control and management functions such as online tap changer control, DSM and GSM receive commands as well as send measurements. A control of the application only based on local measurements is therefore in most cases still possible. If the communication path is disrupted, the functionality of these SGA can be realized up to a limited extend by a decentral solution. Therefore a communication failure at IED level does not lead to total loss of functionality.
However, for a reliability assessment these fallback solutions of SGA have to be considered and their parameterization gains importance for system reliability.

FALLBACK SOLUTIONS

Depending on the ICT system and its reliability different fallback solutions should be chosen for SGAs to guarantee an optimum of operational security and efficiency. As an example three different fallback solutions for a GSM application for a communication failure will be discussed in detail (Figure 5). During a communication failure the feed-in of generation units should be set to a limit, which can be handled by the network. The fallback solution should be selected depending on the general amount of feed-in reduction, which is necessary to keep the network within its operating limits, and the reliability of the ICT system. If feed-in reduction is only necessary in small amounts and during few hours of a year, a fallback solution of 95% P_n might be sufficient to handle a communication failure at single generation units.
If few large generation units are managed, a fallback solution of 80% P_n might be necessary to guarantee a secure operation of the network.
Since the number, total installed power and distribution of generation units in the network can change over time the fallback solution may have to be updated accordingly. To avoid necessary updates of the fallback solution a fallback solution with 0% P_n for GSM could be chosen. This fallback solution however may influence the reliability of the network connection of a generation unit, because the generation unit is no longer able to inject power into the network and therefore the operating state of the generation unit has to be classified as deficit state. In the following the effect of different fallback solutions on reliability indices will be evaluated.

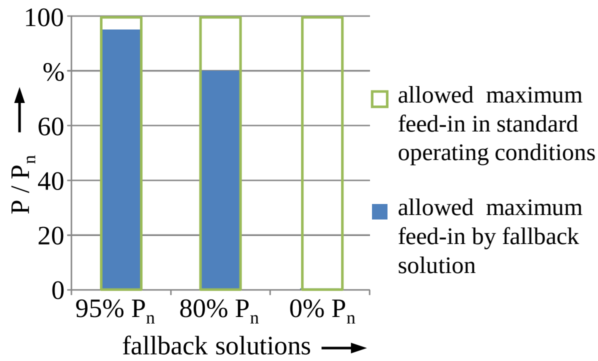

Figure 5 Possible Fallback Solutions

EXEMPLARY RESULTS

Exemplary MV Network

Calculations with the new algorithm were carried out for the exemplary MV network shown in figure 2 and 3. In the network GSM was used to integrate more generation units than technically possible without GSM. Furthermore it was assumed that all switch gear in the network could be controlled remotely. In common operating conditions during periods of maximum power injection and very low demand GSM is used to prevent cable and overhead line overloading. After faults during times of resupply GSM is needed to prevent equipment overloading, since the network's ampacity is reduced significantly. If the necessary reduction in feed-in exceeds the controllable amount provided by GSM, generation units need to be disconnected, which leads to additional deficits besides the deficits caused by network disconnection based on PSE failure. Besides, the power system different realization forms for an independent ICT system were considered. Reliability data for the PSE and ICTE for the reference scenario are listed in Table 1.

Table 1 Reliability Data for PSE and ICTE

Equipment	Failure Rate [1/a, 1/(a*km)]	Time to Repair [h]
Overhead Line	0.0197	2.4
Cable-XPLE	0.0013	3.8
Cable-Paper	0.0027	2.8
Switch	0.0001	1.4
Circuit Breaker	0.0020	6.0
Busbar	0.0001	2.0
Transformer	0.0044	2.3
IED	(0.026 / 0.016)*	4**
Fiber Optic Cable	0.004	6**
Mobile Signal	0.008	2**

*(Funktional Failure / Communication Failure)
**Estimated Value

Effect of GSM on generation unit reliability

In a first assessment the impact of GSM and ICT system on the reliability of the network connection of generation units is evaluated. Therefore it is assumed in a reference scenario (RS), that generation units are disconnected until repair or replacement of the faulty equipment. This reference scenario is compared with a smart grid scenario (FO-1), in which GSM is used to manage the generation unit's feed-in. In FO-1 an ICT system as illustrated in figure 2, a reliability of ICTE as shown in table 1 and a fallback solution for the GSM of 95% P_n were considered.

Figure 6 shows the results of the simulations with the new algorithm. The utilization of GSM leads to a reduction of the ASIDI by more than 90% compared to the ASIDI in RS. With GSM the feed-in of generation units can be managed in case of a network congestion during times of resupply and thereby enables the network operator to reconnect the generation units before a repair or replacement of the faulty equipment. This leads to significantly lower disconnection times for generation units. Failures of the ICTE lead to additional deficits for generation units which result in an increase of the ASIDI by 3 min./a. This increase of the ASIDI is tolerable compared to the described positive GSM impact.

Effect of Fallback Solutions

Scenarios

For the determination of the effect of different fallback solutions for GSM on the reliability of the network connection of generation units, additional smart grid scenarios were evaluated. An overview of these scenarios is given in table 2.

In the scenarios the communication medium, the ICT system topology and the fallback solution for GSM are varied. The focus has been set on these parameters because their effect on the overall reliability cannot as easily be estimated as the effect of an increase or decrease of the ICTE failure rate.

Table 2 Scenarios with Different Fallback Solutions

Scenario	FO-1	FO-2	FO-3	MS-1	MS-2	MS-3
ICT System Based on	Fiber Optic Cable	Fiber Optic Cable	Fiber Optic Cable	Mobile Signal	Mobile Signal	Mobile Signal
System Topology	Ring	Ring	Ring	Star	Star	Star
Fallback Solution	95% P_n	80% P_n	0% P_n	95% P_n	80% P_n	0% P_n
Failure Rate IED	(0.026 / 0.016)	(0.026 / 0.016)	(0.026 / 0.016)	(0.026 / 0.016)	(0.026 / 0.016)	(0.026 / 0.016)

Results

The results of the simulations of the scenarios listed in table 2 as well as the RS are shown in figure 6.

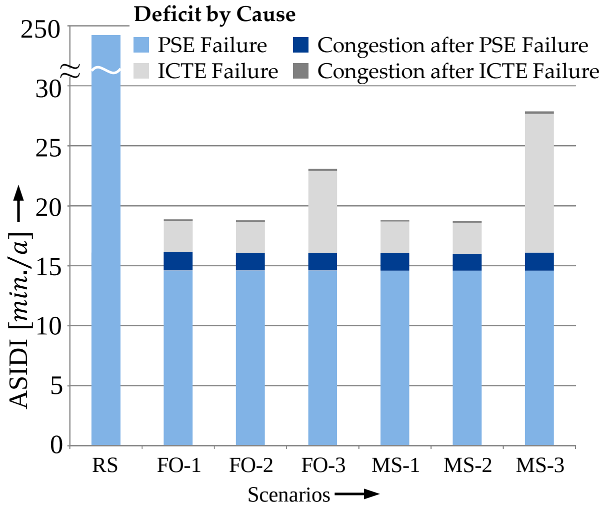

Figure 6 ASIDI for RS and Different Smart Grid Scenarios

At first it is noteworthy, that there are no significant differences in the results for scenarios FO-1, FO-2, MS-1 and MS-2. This effect is caused by two main aspects. Firstly, the result is mainly influenced by single equipment failures because of their much higher probability of occurrence compared to overlapping failures of PSE and ICTE. Secondly, the fallback position of GSM does not lead to a network disconnection of the generation unit and thereby different degrees of redundancy in the ICT system have hardly any effect on the reliability of the network connection of the generation unit. In these scenarios the result is only influenced by a failure of the ICTE on which the GSM of the specific generation unit is installed.

If a fallback solution as in FO-3 and MS-3 is chosen, in which a disconnection of the generation unit during times of communication failure is implemented, the results for an ICT system with ring topology and star topology differ significantly. This influence is caused by the different degrees of redundancy these two topologies offer. The values for the ASIDI for these scenarios however still are significantly lower than the ASIDI of the RS. The influence of the ICT system cannot be neglected in these scenarios, but the positive effect of GSM overcompensate this drawback of the SGA.

Effect of ICT System

Scenarios

In addition to the evaluation of the fallback solution a sensitivity analysis for the effect of the failure rate was carried out. The additional scenarios are listed in table 3.

Results

The results of the sensitivity analysis concerning the failure rate are shown in figure 7. For the scenarios FO-3 and FO-4 as well as for the scenarios MS-3, MS-4 and MS-5 a linear relation between failure rate of ICTE and ASIDI can be derived as expected.

Table 3 Scenarios with Different IED Failure Rates

Scenario	FO-3	FO-4	MS-3	MS-4	MS-5
ICT System Based on	Fiber Optic Cable	Fiber Optic Cable	Mobile Signal	Mobile Signal	Mobile Signal
System Topology	Ring	Ring	Star	Star	Star
Fallback Solution	0% P_n	0% P_n	0% P_n	0% P_n	0% P_n
Failure Rate IED	(0.026 / 0.016)	(0.014 / 0.016)	(0.026 / 0.016)	(0.006 / 0.016)	(0.052 / 0.016)

The contribution of the mobile signal in scenarios MS-3, MS-4 and MS-5 to the total ASIDI leads to an offset which amounts to about 1.1 min./a. The rest of the contribution of deficits caused by ICTE failure to the ASIDI can be associated to IED failures.
For scenarios FO-3 and FO-4 0.6 min./a of the total ASIDI can be associated with failures on fiber optic connections. This contribution results from few generation units, which are connected to the general ring topology over radial branches (see figure 2).
Overall the results of the second sensitivity analysis show the basic differences between the evaluated realization forms for an ICT system.

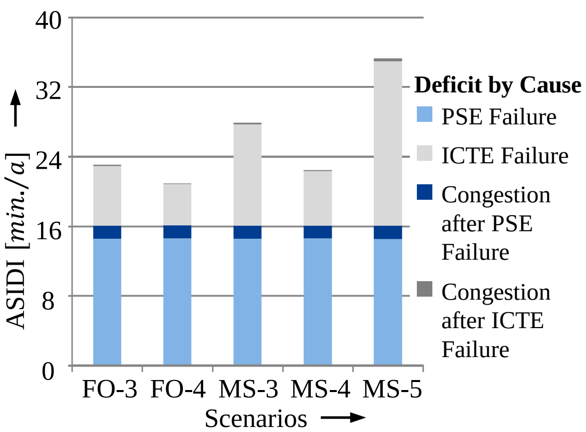

Figure 7 ASIDI for Scenarios with Different Failure Rates

CONCLUSION

The results of the reliability assessment show that the influence of ICT system and SGA must not be neglected. Thereby the magnitude of influence depends on various configuration options. In the examined smart grid the positive effect on the reliability, which the SGA have, outweighs the negative effect, which arises from a dependence on the ICT system. This is due to the chosen realization of the ICT system, the used SGA and the parameterization of the SGA. Furthermore the results show the sensitivity of reliability on certain configuration options. Therefore a check of reliability in smart grids with suitable algorithms is highly recommended within the planning process.

ACKNOWLEDGMENTS

The abstract contains results from a study, within the evolvDSO project, which describes potential future DSO roles, related services and their requirements for the development of novel tools. This work received funding from the European Union Seventh Framework Programme under grant agreement n° 608732.

REFERENCES

[1] Schacht, D.; et al.: Modelling of Interactions between Power System and Communication Systems for the Evaluation of Reliability. PSCC 2016, Genoa, 2016
[2] Schacht, D.; et al.: Selection of Relevant Failure Modes and System States for the Evaluation of Reliability in Distribution Grids Depending on ICT. CIRED Workshop 2016, Helsinki, 2016
[3] Telcordia: Reliability Prediction Procedure for Electronic Equipment (SR-332). Issue 4, March 2016
[4] Dolezilek, D.: Choosing Between Communications Processors, RTUs, and PLCs as Substation Automation Controllers, Pullman, WA USA 2000
[5] Scheer, G. W.; et al.: Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks. UTC Telecom. 2002
[6] Scheer, G. W.: Comparison of Fibre-Optic Star and Ring Topologies for Electric Power Substation Communications, Pullman, WA USA 1999
[7] Rockwell Automation: PLC-5 Controllers, (13.01.2017), Retrieved from http://ab.rockwellautomation.com/ Programmable-Controllers/PLC-5-Controllers
[8] Celli, G.; et al.: Impact of ICT on the Reliability of Active Distribution Networks. CIRED 2012, Lisbon 2012
[9] Endeavour Energy: Business cases for SCADA and Network Control Protection. Zone and Transmission Substation RTU Renewal Plan, (13.01.2017), Retrieved from https://www.aer.gov.au/system/files/Endeavour Energy - 5.06 Business Cases for SCADA and Network Control Protection - January 2015.pdf
[10] Gardan, D.; et al.: Availability modelling of the fiber optic local loop. European Optical Communications and Networks Conference, Paris 1992
[11] Hyle, R. A.: Fiber optics-failure modes and mechanisms. Annual Reliability and Maintainability Symposium 1992 Proceedings. 1992, S. 379–388
[12] Alcoa Fujikura LTD: Reliability of Fiber Optic Cable Systems, (13.01.2017), Retrieved from www.southern-telecom.com/solutions/afl-reliability.pdf, 2001
[13] CHIP Digital GmbH: Das beste Netz aller Zeiten. Der härteste Handy-Netztest Deutschlands: Telekom, Vodafone, O2 und E-Plus im Test. (13.01.2017) Retrieved from http://www.chip.de/artikel/Bestes-Handynetz-Telekom-Vodafone-und-O2-im-Test_103950592.html