INFLUENCE OF DISTRIBUTED DECENTRAL CONTROL UNITS ON RELIABILITY OF DISTRIBUTION NETWORKS

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

Patrick NIEWERTH
FGH GmbH – Germany
patrick.niewerth@fgh-ma.de

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

Dr. Lukas VERHEGGEN
EWE NETZ GmbH – Germany
lukas.verheggen@ewe-netz.de

Dr. Thomas KUMM
EWE NETZ GmbH – Germany
thomas.kumm@ewe-netz.de

ABSTRACT

Smart grid applications (SGA) such as decentral control units, which autonomously react on different load and feed-in situations, may represent a cost-efficient alternative to conventional network reinforcement for integrating further distributed generation units and optimizing current power systems as has been shown in various previous studies. However, decentral control units are depended on an information and communication system (ICT system). Therefore, interactions between power system and ICT system need to be considered in the planning process. For the purpose of assessing power system reliability in smart grids enhanced algorithms have been developed and refined [1, 2]. The configuration of autonomously reacting decentral control units however still represents a challenge due to the lack of in-depth analyses of their influence on reliability. Therefore, possible use cases for decentral control units have been determined and an analysis has been carried out, which on one hand shows the benefits of decentral control units and on the other hand highlights the influence of configuration options.

INTRODUCTION

The ongoing integration of decentral generation units as well as new loads like charging stations and batteries into distribution networks lead to significant challenges for the distribution system operator. The high volatility and low full load hours per year of decentral generation units require a change of view on the topic of network planning and operation. Only by a rapid and optimal adjustment of the network to the steadily changing requirements of the supply task, a reliable, stable and future oriented integration of renewable energy resource can be realized. To meet this challenge, innovative solutions have been developed, which use adaptive monitoring systems, control algorithms, intelligent network control systems and available ICT-infrastructure. By these means the distribution network is being set up to autonomously react on different load and feed-in situations.
On one hand the network can be operated closer to its technical limits by distributed decentral control units but on the other hand the network may become increasingly dependent on their functionality. The distributed decentral control units themselves are part of the ICT-system, require an exchange of measuring data and control commands and hence are dependent on the ICT-system. The frequency and duration with which the network is depending on a distributed decentral control unit, its measurements and controlled actors as well as the ICT-system is determined by the network topology, the function of the controlled actors as well as the electricity demand and the generation. Since a decrease in reliability may have a significant economic effect due to quality regulation, the influence of those distributed decentral control units should be assed in the planning process.
For this particular purpose a new algorithm for the assessment of reliability in smart grids was developed and enhanced for the evaluation of control units [2]. Therefore, this paper focusses on the integration of decentral control units into this new algorithm and on the effect these control units have on reliability.

CALCULATION OF RELIABILITY

An overview of the used algorithm is shown in figure 1.

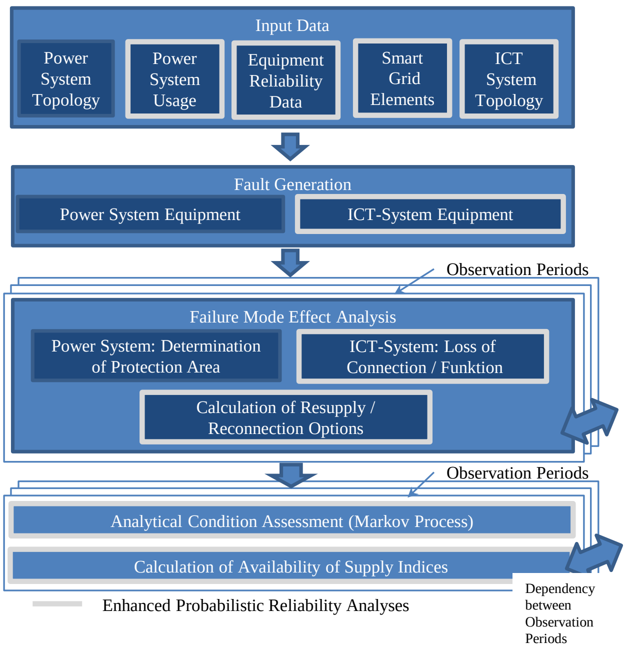

Figure 1 New Algorithm for Reliability Assessment [2]

Currently new algorithms, such as introduced in [1-3], allow 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. In the course of the project the algorithm was enhanced by the model of decentral control units.

OVERVIEW OF TEST SYSTEM

In the project Green Access [4] EWE NETZ GmbH is carrying out a field test with interacting distributed decentral control units on the low and medium voltage level, which is being supported by FGH with analytical assessments on reliability. The overall test system consists of three low voltage (LV) networks within a part of a medium voltage (MV) network, as shown in figure 2.

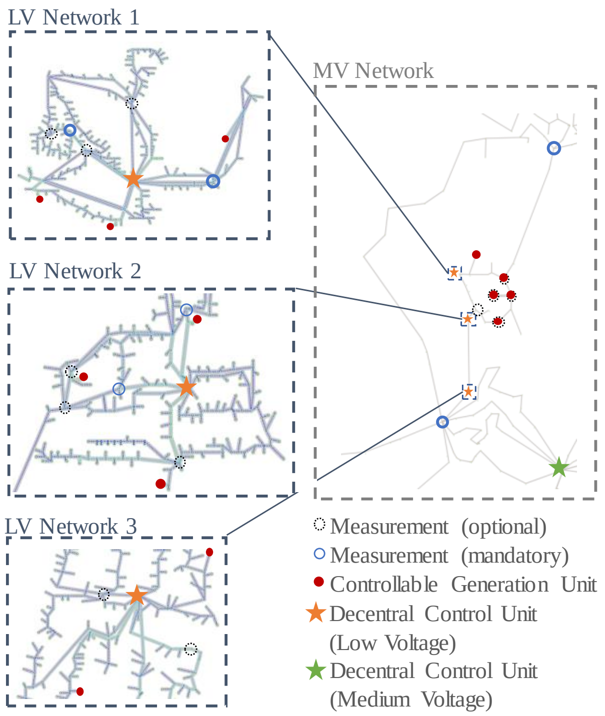

Figure 2 Setup for Field Test and Analytical Assessment

Each low voltage network as well as the part of the medium voltage network are being monitored and autonomously controlled by a decentral control unit. Whereas, the low voltage control units primarily control the LV network and secondarily provide flexibility to the medium voltage network by variating total load and feed-in. The MV control unit monitors and controls actors on the MV level as well as requests flexibility from the LV control units. LV and MV control units operate without dependencies on each other. In reality no congestion management is needed in standard operation conditions. However, in the project Green Access reduced ampacity limits are used to test the congestion management capability of the decentral control units. The following investigations are done on these test systems. This measure leads to a point of reference, which requires congestion management in standard operation conditions.

ENHANCEMENT OF ALGORITHM BY DECENTRAL CONTROL UNITS

Functionalities of the decentral control unit are the generation of a detailed information about the live status of the network via state estimation and the control of actors in such a way that currents and voltages are kept within the technical boundary conditions.

Thereby, the algorithm for the state estimation is based on a network model, measurement data and switching states as well as pseudo measurements. For increasing the robustness of the state estimation real measurements are extended by pseudo measurements, which are generated based on available information on connected loads and generation units. The results of the state estimation are used in further algorithms and routines to evaluate the current network status. Therefore, the accuracy of the state estimation has to lie within certain limits for voltage and current estimations. These limits usually lie within the range of 0.5 – 1% for voltages and 1% - 5% for currents. Based on the information provided by the state estimation the decentral control unit performs an autonomous control of the associated actors.

The SGA of decentral control unit as well as its features were implemented in the new algorithm for evaluation of reliability. Control units receive data from measurement units and need to react on failures of measurement units. For a correct implementation of the unit's dependencies measurements were classified into obligatory and optional measurements. If an optional measurement is unavailable the state estimation still works within the predefined limits. If an obligatory measurement is unavailable the state estimation is no longer able to provide information with the necessary accuracy and the control unit needs to be set in a defined fallback solution. In this case actors controlled by the control unit are set in a predefined fallback solution for communication failure as well. This fallback solution for communication failures can be defined separately for each generation unit and is set to network disconnection in the field test setup.

RESULTS

Calculations with the new algorithm were carried out for the exemplary test system shown in figure 2. In the network congestion management (CM) was used to integrate more generation units than technically possible without CM. In common operating conditions during periods of maximum power injection and very low demand CM is used to prevent cable overloading. After faults during times of resupply CM is needed to prevent equipment overloading, since some ampacity limits are reduced significantly. If the necessary reduction in feed-in exceeds the controllable amount provided by CM, generation units need to be disconnected, which leads to additional deficits besides the deficits caused by network disconnection based on power system equipment (PSE) failure. Reliability data for ICTE Equipment is listed in Table 1.

Equipment	Failure Rate [1/a, 1/(a*km)]	Time to Repair [h]
Control Unit	0.076	2**
MV Sensor	0.033	2**
MV Actor	0.012	2**
PLC Router	0.8	2**
PV Converter	0.018	2**
PV Gateway	0.04	2**
NS Sensor / Actor	0.076	2**
PLC Signal	0.008	2**
Fiber Optic Cable	0.004	6**
Mobile Signal	0.008	2**

**Estimated Value

Table 1 specific data of ICTE reliability in Green Access

Control Unit in Low Voltage Network

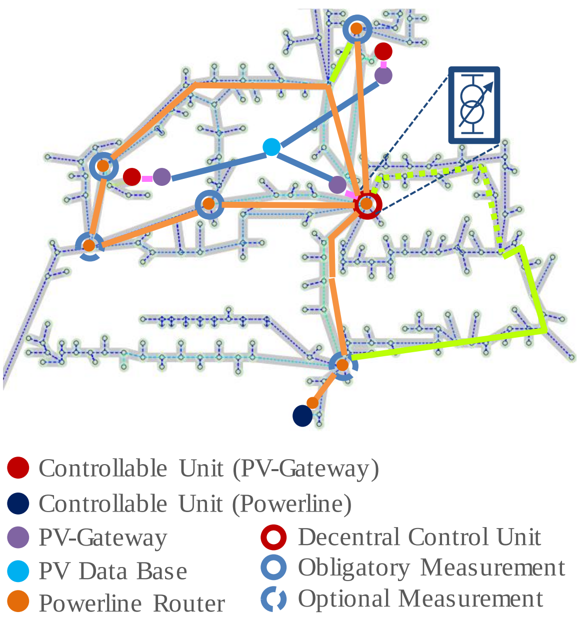

Figure 3 Field Test Setup for Low Voltage Network 2

Figure 3 shows the field test setup for LV network 2. In total 4 photovoltaic (PV) generation units can be controlled by the control unit. Three of those units are connected by mobile signal to a manufactures database. The decentral control unit receives information from this database and sends commands to the PV units by means of this database. A fourth PV unit is connected by means of power line communication to the control unit. Furthermore, measurement units are connected with power line communication to the control unit. There are in total 5 nodes with measurements, of which 3 are obligatory measurements. This means, if one of these measurements is not available the decentral control unit will go into communication failure mode and all control features will be shoot down. For this setup reliability calculations were carried out.

First of all, it can be stated that customers with power demand and generation units without a connection to the ICT system are not affected by the ICT system or its setup in any way. There are two reasons for this result. First, customers and other generators have no direct connection to the ICT system and therefore cannot be directly affected. Second, the fallback solutions for the actively controlled generation units define a network disconnection in case of communication failure, which means that in any failure event these units are disconnected from the network immediately. Situations with network overloading due to uncontrolled feed-in are thereby actively prevented.

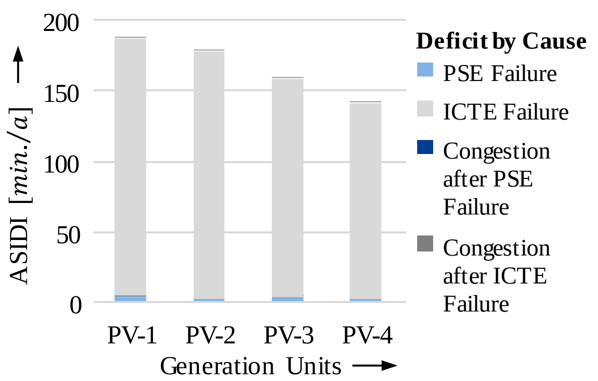

Figure 4 ASIDI Values for Low Voltage Units

The effect of the setup on generation units with connection to the ICT system are shown in Figure 4. Depending on the feed-in times of the generation units to the network the ASIDI value is increased significantly by about 140 to 180 min./a.

This sharp increase can be attributed to the use of power line communication for the connection of the measurement units. The low reliability values for the power line communication routers and the high dependence of the system on the availability of these measurements lead to this significant effect. The decentral control unit itself only accounts for an increase of 8 min./a of the ASIDI value, as shown in figure 5.

The increase in interruption duration per year is very high but this does not necessarily mean, that the reduction of feed-in by the generation units is significantly affected.

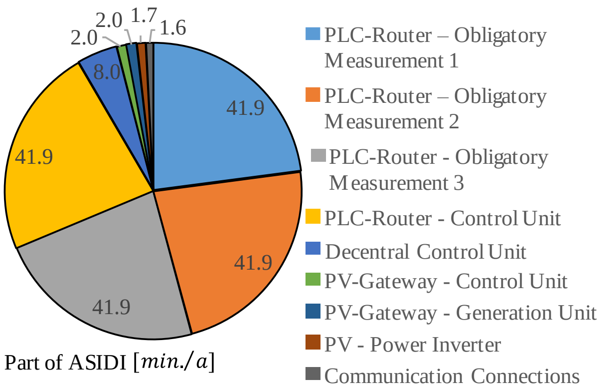

Figure 5 Contributions of ICT to ASIDI

Figure 6 shows the reduction in feed-in due to failure situations and the reduction of feed-in for purposes of congestions management.

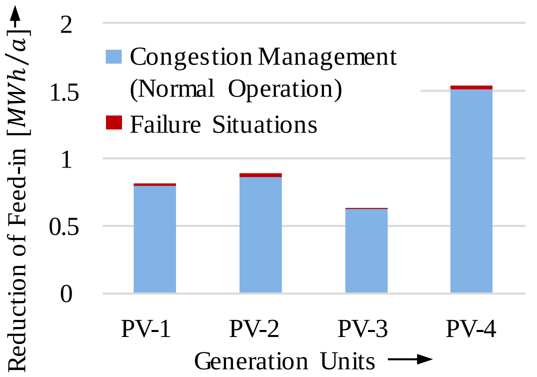

Figure 6 Reduction of Energy Feed-In

For this comparison a reduction of feed-in for congestion management of up to 3% of the yearly produced energy was assumed. The comparison shows that the feed-in reduction in standard operation modes is significantly higher than the reduction caused by failure situations.

Control Unit in Medium Voltage Network

Figure 7 shows the field test setup for the medium voltage (MV) networks. In total 6 generation units can be controlled by the medium voltage control unit. One of those units is connected by mobile signal via a manufactures database as previously explained for the low voltage network. The other five generation units as well as the low voltage control units and medium voltage measurement units are directly connected by mobile communication with the medium voltage control unit.

In total there are 9 nodes with measurements on the medium voltage level. Five of these measurements are obligatory measurements. According to the manufacturer this number could be significantly reduced by a more complex setup of the state estimation algorithm. In the field test the complex setup was not selected on purpose because on a physical level there was no actual need for the integration of CM in the network. Therefore, the configuration represents the most basic setup of the control unit's algorithm. The medium voltage control unit acts in a similar way to unavailability of measurements as the low voltage control unit. In case measurements are unavailable over a longer period of time (hardware failure of measurement unit), all control functionalities are shot down. For this setup reliability calculations were performed.

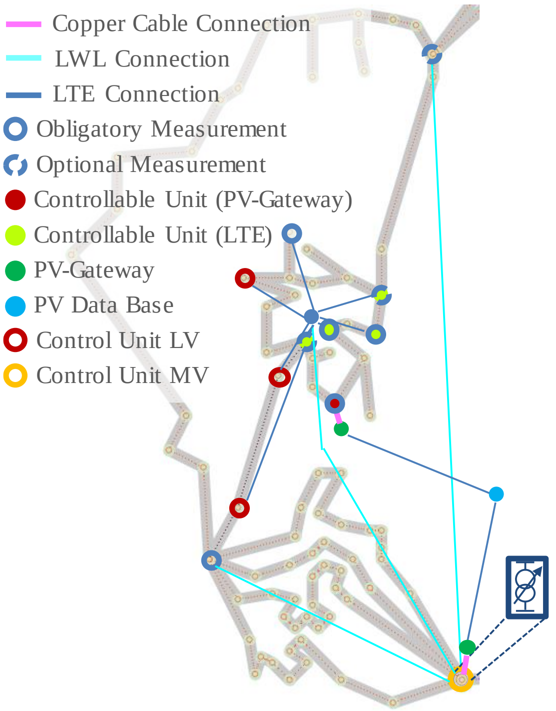

Figure 7 Field Test Setup for Medium Voltage Network

The results for customers with power demand and generation units with no connection to the decentral control system show, that they are unaffected by the new system.

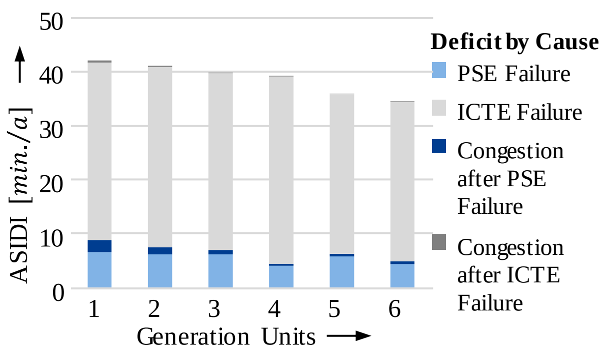

Figure 8 ASIDI Values for MV Generation Units

The effect of the setup on generation units with connection to the ICT system are shown in Figure 8. Depending on the feed-in times of the generation units to the network, the ASIDI value is increased significantly by about 32 min./a. A detailed analysis of the contribution of the ICT equipment to the ASIDI values of generation unit 1 is shown in figure 9.

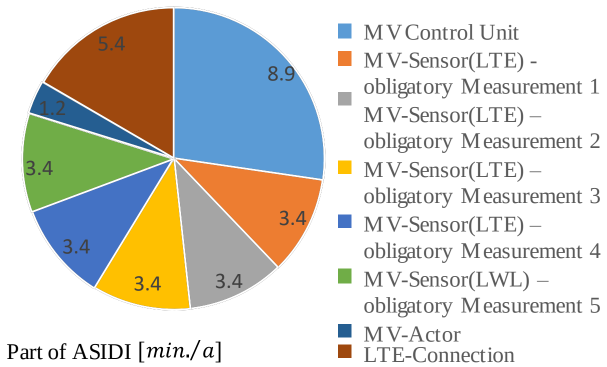

Figure 9 Contributions of ICT to ASIDI Values

The contribution of the control unit is with 8.9 min/a about 10% higher than for the low voltage level. This result is caused by the fact that generation unit is a wind energy unit, which has higher feed-in hours than the PV units on the LV level. About 17 min/a (50%) of the contributions can be linked to the obligatory measurement units. This value is significantly lower than the value on the low voltage level. However, the number of obligatory measurements in the medium voltage level could be further reduced by adding more redundancy or enhancing the state estimation with additional prognosis features for the generation of pseudo measurements. For the medium voltage level an analysis of the energy reduction of the generation units was performed as well.

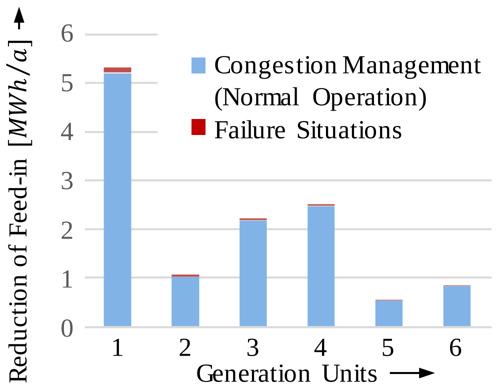

Figure 10 Contribution of ICT to ASIDI

The results in figure 10 show that the amount of feed-in reduction due to congestion management is significantly higher than the amount of feed-in reduction caused by system failures. The energy reduction due to congestion management under the field test conditions for these generation units lies between 0.1% and 0.6% of the yearly produced energy.

DISCUSSION OF RESULTS

First of all, the results show that the ICT system has a significant effect on the reliability of the overall system. Furthermore, the used communication medium and the setup of the ICT system with its dependencies has a very high impact on the performance of the system. Obligatory measurements of decentral control units influence and increase the interruption duration significantly. However, the effect of a decentral control unit itself on the reliability is very closely linked to the fallback solution for the controlled actors. If actors receive a fallback solution for the failure of the control unit, which enables them to stay connected to the network and only reduce feed-in by a certain predefined amount, the effect of the control unit on reliability can be reduced to a minimum. This solution could be used to connect customers with power demand to the system since these customers tend to have higher requirements concerning reliability. However, for generation units the field test setup seems to be a very adequate solution, since on one hand it is a technically and economically attractive solution for network operators and on the other hand the reduction of feed-in due to system failures is insignificant compared to the primary objective of managing congestions.

CONCLUSION

Overall the results show that the effect of decentral generation units on reliability can be significant, if a very basic setup and system-oriented fallback solutions for actors are chosen. But even with this basic setup the reduction of feed-in per year due to failures is insignificant compared to congestion management or the total feed-in of each generation unit. Therefore, the field test setup represents an attractive solution for network operators to implement an active control of generation units with decentral control units.

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