CONSIDERATION OF SAFETY REQUIREMENTS FOR PEOPLE AND ELECTRICAL EQUIPMENT IN SMART GRIDS

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ABSTRACT

With the integration of Smart Grid technologies (intelligent components and decentralized sources) into medium and low voltage grids issues regarding safety requirements for people and electrical equipment emerge. The basic topic for new requirements is that decentralized power generators combined with substation transformers can lead to an indefinite bidirectional fault current flow. Furthermore different initial short-circuit powers of substation transformers and decentralized power generators can cause a change of direction and magnitude of the short-circuit currents.
If the initial short-circuit power is not achieved existing protection devices are not sufficient and new requirements concerning the protection system appear. Therefore a significant question arises: Is it possible to maintain personal safety and furthermore the functionality of protection systems in case of a fault?
Exemplarily studies on a five-wire installation system including the simulation of characteristic network systems, substation transformers, decentralized power generators and protection systems have to be done. Additional characteristic elements for the experimental test setups are loads (1- and 3-phase), switching elements and electrical protection devices (additional protection, RCDs).
Considering changing short-circuit currents (bidirectional current flows) the existing protection concepts have to be examined on functionality and on the advanced requirements in case of decentralized power generators.
To avoid endangering the personal safety knowledge of fault voltages and hence touch voltage in dependency of the resistance of the contact current circuit are of interest for further considerations.

INTRODUCTION

The classical character of energy distribution in medium and low voltage power grids is changing. New strategies and approaches, intelligent components and also information and communication technologies (ICT) find their way into the conventional power supply and distribution. The integration of more intelligence into the classical electrical grid makes energy distributions systems smarter. In future these Smart Systems play an important role to increase the reliability and secure of power supply and transmission.
In connection with Smart Grid technologies two different situations in case of a fault have to be considered.
In the case of a fault – without decentralized sources – the energy flow from the high voltage section is guaranteed and the initial short-circuit power and the short-circuit current is high enough to trip the existing protection devices. In that case the expansion of the grid and the conductor cross-section are essential.
In the case of a fault – with decentralized sources – a bidirectional current flow can occur and leads to a change of the direction and the magnitude of the short-circuit current because of different initial short-circuit powers of the sources. If the initial short-circuit power is not guaranteed existing protection devices are not sufficient and new requirements to the protection system are given.
An increasing number of decentralized sources into the existing grid structure provide the possibility of a multifunctional and independent electrical power supply. Furthermore decentralized sources should support the supply in case of parallel operation, unintentional islanding and selective autonomous power systems (micro grids). Nowadays in case of a fault decentralized generators are disconnected from the grid, especially if a high number of decentralized generators is integrated, this strategy does not maintain the reliability of supply.
For the operation of these islanded small grids (micro grids) special regulatory requirements, ordinances and standards have to be established in future. New requirements to the protection systems are mandatory that the criteria for safety of people are met in case of an unintentional islanded grid with too short-circuit power.

PROBLEM SPECIFICATION

In order to supply independent and selective autonomous power systems a growing number of decentralized sources (like photovoltaics etc.) are required. In this context unintentional grids are inadmissible and measurements for a defined stand alone grid have to be taken into account. Precisely this fact provides advanced requirements to protection devices to ensure secure and efficient grid operation and disconnections criterias. In the course of this work the following questions arise [1], [11]:

- Does the changing of the direction and magnitude of short-circuit current lead to a breakdown of traditional protection systems?

- Is it possible to maintain personal safety with traditional equipment like fuses or other protection devices, RCD's, circuit breakers etc. in case of an unintentional islanded grid?

- Does the sometimes missing neutral conductor of decentralized generators in distributed power systems and selective autonomous power systems lead to a significant risk potential in respect to touch voltages and shock currents?

- Can personal safety be ensured in case of unintentional islanded power systems after disconnecting from the distribution grid?

- How to create an isolated (islanded) grid under controlled conditions?

To find solutions for the before mentioned questions and problems regarding the protection system and philosophy in Smart Grids, Smart Systems and autonomously supplied regions, analysis with simulations, laboratory test systems and field tests in specific test regions are necessary.

SMART GRID TOPOLOGY

A typical Smart Grid is characterized by the fact that substation transformers and decentralized sources feed in parallel into the distribution grid and information technologies are implemented into the grid structure. The communication between the components is depicted in Fig. 1. In addition to classical disconnecting switches and protections system components for synchronization of decentralized generators are implemented. The line length is given on the one hand by the operating voltage range and the load flow an on the other hand by the required interrupting current for tripping the protection devices [8]. The cross-sections of the conductors of the lines have to be adapted in order to the field of application like rural, urban and mixed areas. For providing a greater amount of integrated decentralized sources especially on long lines controllable voltage compensation components are provided to regulate the voltage [1], [11].
Fig. 1 shows an exemplary simplified Smart Grid low voltage topology. A bidirectional exchange of information and data enables the communication between decentralized generator units. Therefore the possibility exists that, after a fault, operation in generally unsupplied grid areas can be maintained due to decentralized sources.

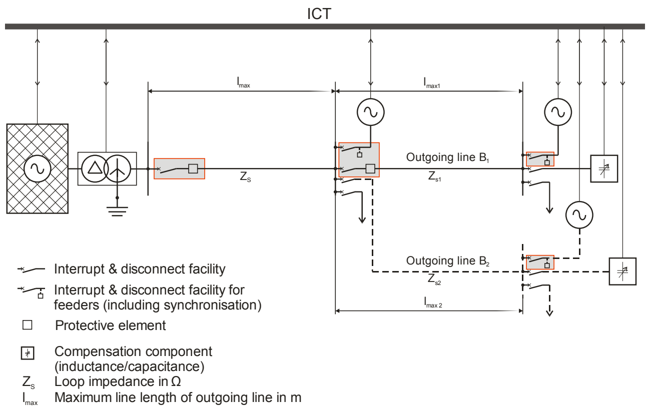

Figure 1: Simplified low voltage Smart Grid topology [1], [11]

Until now faults cause the disconnection of decentralized generators till the fault is cleared and the voltage returns to normal level. Also if the fault occurs on the medium voltage level, decentralized generators on low voltage level have to be disconnected. In connection with this feature the ride-through capability has to be mentioned. That means that decentralized generators "ride through" the fault till the voltage is falling below a defined threshold value. Therefore alternatives to substitute classical protection equipment have to be developed.

PROTECTION AGAINST ELECTRIC SHOCK

To avoid danger of people knowledge of fault voltages and hence touch voltages in dependency of the resistance of the contact current circuit are of interest. In the following shock current and touch voltage are described [6].

Shock currents

The knowledge of shock current is necessary to evaluate the effectiveness of protection systems and the risk potential for people. Detailed information is significant for specification of protection systems and for evaluation of the tripping sensitivity of fault-current circuit breakers. The tripping sensitivity has to be adopted for protection against direct contact of active parts of an electrical system [6].

Touch voltages

Shock currents and the body resistance lead to a voltage-dependent impedance from which the touch potential voltage can be determined. Also the influence of the earthing impedance has to be considered calculating the resulting touch voltage. The human body resistance is not constant, depends on the current path and on the absolute value of the voltage. Additional resistances in the current path like footwear, clothes and insulating resistances of the floor influence the current limiting resistance [6].

APPROACH FOR SPECIAL DEMANDS OF SMART GRIDS

To obtain more information about the functionality of protection equipment in Smart Grids, studies on a five-wire system including the simulation of characteristic low voltage grids, substation transformers and decentralized generators have to be done. An experimental test setup including relevant components is shown in Fig. 2.

Requirements to the experimental test setup

First the network for evaluating and testing has to be simulated (network systems, protection systems, decentralized generators). On the basis of simulations fault voltages, touch voltages, total fault currents and shock currents can be determined.
With the simulation of different fault locations, tests on protections devices like fuses etc. can be performed to get information about their characteristics in case of different fault types.

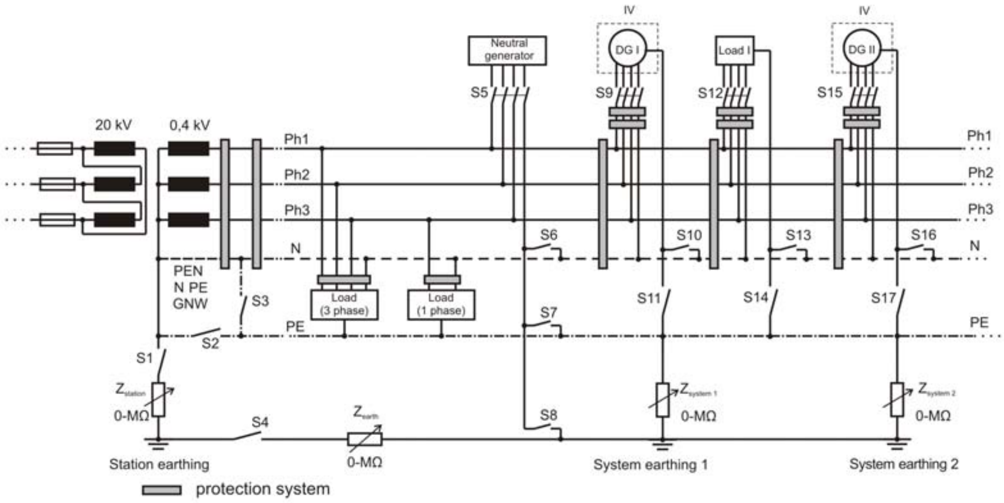

Figure 2: Test setup for investigations in low voltage Smart Grid structures regarding risk potential of people in case of faults [1], [11]

Experimental test setup

To answer the questions listed in the chapter "Problem definition" the following test setup – see Fig. 2 was developed.
The base for further analyses is the simulation of different low voltage network systems and will be done by operating different switches placed in the electric installation (see Fig. 2). In dependency of the switch settings and hence with the operating network characteristic protection elements are used. In addition to primary protection elements additional protection devices are provided. If the adjusted setting requires a neutral point generator, this is implemented into the experimental set-up by the switches S6, S7 and S8. Decentralized power generators (DG) can also be integrated into the experimental test setup. Exemplarily two decentralized generators of different engine-power classes DG I (1 kW) and DG II (10 kW) are demonstrated in Fig. 2 and are connected with the switches S9 and S15 to the experimental test setup. Requirements of the simulation model are, that on the one hand different various network systems can be simulated and on the other hand transformers, generators and loads can be simulated under normal operation conditions and in case of occurring of a 1-phase and 3-phase fault.
Loads for simulating different load cases for finding out functionality of protection systems, touch voltages and shock currents to evaluate the risk potential for people in Smart Grids are implemented. Important for considerations regarding safety for people is the fault voltage at the fault location. With the knowledge of the fault voltage and in consideration of the resistance of contact current circuit, statements regarding the height of the touch voltage can be done. To simulate the influence of different earthing impedances and earth return paths for the fault current variable resistances ($Z_{station}$, Z_{system}) are provided. Even the connection between station and system is provided by a variable resistance to analyse the influence of the earth return path.
Studies on a five-wire system including the simulation of characteristic various network types, mains supply transformer and decentralized generators are done and analyzed [1], [11].

PROPOSED SOLUTIONS

In generally the fuses and disconnecting devices are located at the beginning of the electric circuit directly at the generators side. In case of an islanding grid the classical position point of fuses are located at the opposite (false) position – see Fig. 2. Therefore an unsafe protection system occurs and accurate tripping of the fuses and disconnecting devices is not guaranteed. In this context the correct positioning of fuses and further the selectivity of the protection system due to different short-circuit powers of generators and transformers need further considerations.
If too small short-circuit currents occur, faults are difficult to identify selective. Resulting from the increased number of decentralized generators problems in medium and low voltage grids with Smart Grid technologies occur. Therefore the positioning of fuses and disconnecting devices has to be arranged considering the load flow. The development of electronic protection devices seems to be unavoidable if the supply of short-circuit power cannot be provided. Changing the protection systems into IT-systems while operating as islanded grid or considering the expansion of the grid and the use of additional RCD protection systems are another way to fulfil the safety requirements. The usages of decentralized generators with an integrated automatic device for lowering the voltage if a fault occurs have to be taken into account.

SUMMARY

Intelligent networks (Smart Grids) enable the supply of small isolated systems (micro grids); hence supply in case of interruption is feasible. In pure TN-systems (multiple protective earthing) interrupting currents are often not high enough to trip protection devices in time. To solve this difficulty the short-circuit power of feeders has to be high enough or the protection system has to be changed during the islanding grid operation. Furthermore complementary measures like an additional main equipotential system have to be taken into account.
For future protection equipment with short circuit detection and new concepts with electronic protection devices have to be integrated into the grid to fulfill the new requirements of an increasing number of decentralized generators.

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