SMART GRIDS – CONSIDERATIONS REGARDING PROTECTION OF ELECTRICAL INSTALLATIONS AND SAFETY IN CASE OF DECENTRALIZED POWER SUPPLY

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ABSTRACT

Parallel to the progress of information- and communication technology in recent years, energy production and energy distribution get more economic and efficient; so called Smart Grids get more attention. The focus of the Smart Grid infrastructure lies in the increased involvement of decentralized power generation, exemplarily photovoltaic plants, small hydro power generators or stirling engines in the low-voltage or medium-voltage network. Due to the increased integration of distributed (renewable) energy generation systems, a significant contribution concerning the reduction of CO_2 emissions claimed in the 20-20-20 targets and transmission losses is provided.

An important advantage of Smart Grids is the possibility of a multivalent up to a fully independent power supply for islanded grids and microgrids. In case of a failing (separation from the distribution network) a certain degree of power can be principally maintained by decentralized feed-in. Short circuit currents from distribution transformers and additional short circuit currents from decentralized sources (bidirectional current flow) can lead to a incompatibility with existing protection systems.

Therefore the increased integration of decentralized generation requires new considerations regarding protection systems in terms of personal safety and safety of electrical equipment.

The neutral point treatment of decentralized sources, transformers and uninterrupted supply units in combination with distribution transformer is important for security of networks and personal safety.

This paper shows exemplary the effects of a missing neutral point to earth connection (earthing) of decentralized generators in case of parallel supply.

1. INTRODUCTION

In addition to the information and communication technology (ICT) decentralized power generation is an integral part of intelligent networks (Smart Grids). The integration of ICT into conventional energy supply provides a contribution to increase the reliability and security of energy supply.

The increased integration of decentralized sources to fulfill the 20-20-20 targets, claimed in the climate and energy package of the European Commission, requires further considerations regarding existing protection systems. Investigations in view of personal safety and safety for electrical equipment have to be done.

A critical factor for the functionality of protection equipment is the short circuit power of the distribution network transformers and the implemented decentralized sources. Through the decentralized sources a changing of direction and magnitude of short-circuit currents can lead to an incompatibility of the protection system [1]. New approaches for protection systems to guarantee functionality in case of power supply from distribution network, in case of parallel supply with decentralized sources and additionally in case of an islanded grid (only decentralized feed-in) are important.

The missing connection between the neutral point and earth of a decentralized source can lead to uncontrolled islanding. Therefore a risk potential for security and the functionality of low-voltage networks and further for personal safety is given. Islanding within decentralized feed-in should only be maintained synchronized with the needs of the distribution power utility.

2. PROTECTION MEASURES IN THE LOW-VOLTAGE LEVEL

In Austria the obligatory protection system in low voltage networks is realized by the multiple protective earthing (TN-system). It is required and specified by the so-called "Nullungsverordnung" [2], [3]. This protection system is based on an approved three-stage concept, which provides protection against direct contact (basic protection), protection against indirect contact (fault protection) and additional protection in case of failure of the upstream protection. Additional protection is achieved by the installation of residual current operated devices (RCD) or by an additional equipotential bonding [4].

- **Basic protection** - protection against direct contact
- **Fault protection** - protection in case of indirect contact
- **Additional protection** - additional protection in case of a failure of the basic and / or fault protection (residual current operated device (RCD) or equipotential bonding)

2.1 Multiple protective earthing – TN-System

In Austria TN-systems (TN-C, TN-S, TN-C-S) also known as multiple protective earthing are required by law to keep hazards for people and technical equipment low.

The interruption current of the protection systems located before the fault, have to be high enough to trip the protection device in due time – see (1).

The first multiple protective earthing condition can be derived from (1).

The interrupting current is defined as follows [4]:

$$I_A \leq \frac{U_N}{Z_S} \tag{1}$$

I_A …	interrupting current of the over-current protection device in A
U_N …	rated voltage against earth in V
Z_S …	fault loop impedance in Ω

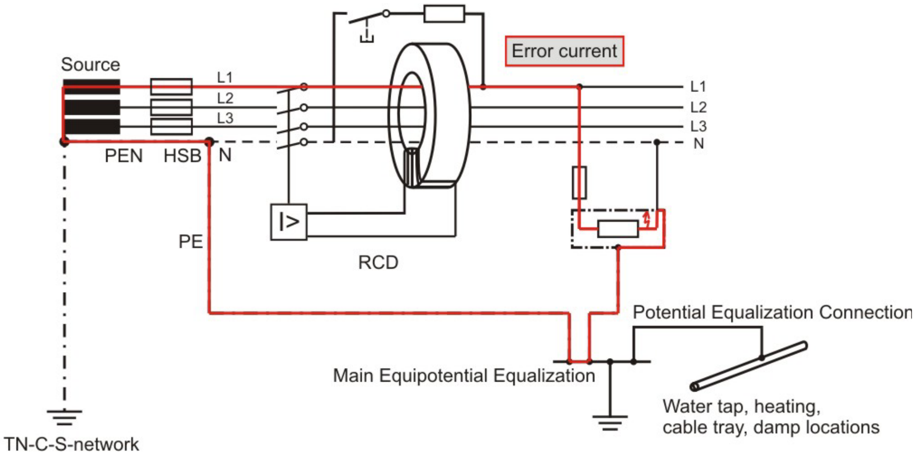

Fig.1. Simplified illustration of the multiple protective earthing with additional protection measure RCD [5], [4]

In the TN-C system neutral and protective conductors are jointly (as one lead) conducted up to the house service box (building complex, main distribution) as a single **p**rotective **e**arth **n**eutral conductor (PEN). At the house service box (HSB) the PEN conductor is split into a neutral (N) and a protection (grounding) conductor (PE).

Through the main equipotential bonding and via potential equalization connection all electrically conductive materials (e.g. system earthing, PE-, PEN-conductor, equipotential bonding conductor, lightning protective system, conductive water consumption pipes, metal pipe systems etc.) are connected to earth potential [4].

3. DESCRIPTION OF AN EXEMPLARILY SMART GRID LOW VOLTAGE-TOPOLOGY

Smart Grids are characterized by the parallel operation of transformers from the public distribution network and by distributed (small) power sources (e.g. photovoltaics).

In addition to the classical disconnecting facilities and protection devices (fuses) components with synchronization and on the outgoing lines with decentralized sources disconnections units are implemented.

The cable length is limited by the requirements for voltage scheduling (permissible voltage range) and further by the required interrupting current [6]. Conductor cross sections need to be adjusted to satisfy the requirements for a classical urban and rural low-voltage network. Furthermore requirements of inverse power flows have to be maintained. Variable compensation devices for an optimized voltage regulation have to be provided in some cases [5].

4. CENTRAL ISSUES AND QUESTIONS

The increased use of distributed sources requires new demands on existing protection systems. This chapter describes central issues and questions regarding personal safety and safety of electrical equipment in low-voltage networks. Due to the complexity of issues / problems some of them are picked out and listed in the following.

In case of a fault - without decentralized feed-in - a distinct current flow from the source to the sink exists. Otherwise - with decentralized feed-in - the short-circuit current is supplied by both the decentralized generation itself and in addition a current flow from the substation transformer (higher grid level) to the fault location appears. Due to the bidirectional current flow the possibility of an incompatibility of protection system exists (“Bauch‘sches Paradoxon”) [7].

A missing defined connection to earth of the neutral point of the decentralized source leads to a significant risk potential in respect to the functionality of the protection system. This issue is a point for closer examination in the chapter 6. To ensure functionality of network protection and further personal safety uncontrollable islanding in case of separation from the distribution network has to be avoided.

Also legal considerations regarding interaction of several decentralized sources have to be taken into account. With respect to standards regarding islanded mode challenges for working groups on the sector of ordinances and standards in Austria and further in die European context are given. Several working groups are dealing with the integration of renewable energies e.g. wind, solar, integration of electric vehicles into the distribution network and application for load management are at the focus of future considerations [5].

5. QUESTIONS DUE TO INCREASED DECENTRALIZED FEED-IN

In order to ensure secure grid operations in combination with decentralized feed-in analyses in typical low-voltage topologies have to be performed. In the frame of the project “Smart Safety” [8] a concept for a test setup to examine various network types and protection devices is developed - see Fig. 2. The test setup is realized by a five-wire system, switches, electrical protection devices (basic and fault protection), 1- and 3- phase loads, neutral transformer and decentralized sources (generators) (DG) or inverters (IV) are implemented in the test setup. With the presented test setup - see Fig. 2 - several kinds of network systems and protection systems can be simulated and further the impact of earthing and protection equipment on the resulting touch voltages can be figured out [5], [8].

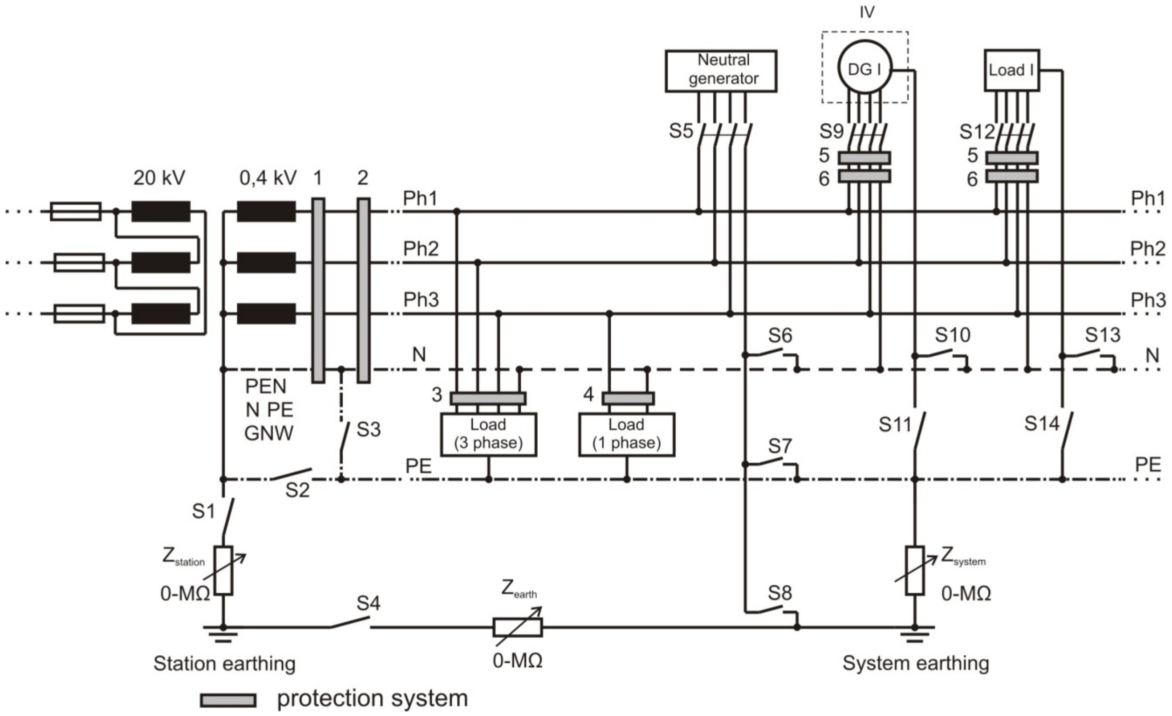

Fig.2. Test setup for simulating various low voltage network systems and protection equipment [5], [8], developed by the Institute of Electrical Power Systems, Technical University of Graz

With the test setup, different network systems (IT, TT, TN-C, TN-S, TN-C-S) and associated protections systems can be simulated. The selected network structure is realized according to different switch settings. Regarding the occurring fault currents and permissible touch voltages the grounding of the station, the grounding of the system and further the equipotential bonding are important and influence the height of the touch voltages; additionally risk potential for people occurs. To simulate the influences of the grounding system the earth return path is performed by a variable impedance Z_{earth}.

6. NEUTRAL POINT TREATMENT OF THE DECENTRALIZED SOURCES

The influence of an occasionally missing defined system neutral point earthing of the decentralized source (switch S 11 open, Fig. 2) is demonstrated in Fig. 3 and Fig. 4.

To maintain the personal safety in case of a fault the neutral point treatment of the decentralized feed-in is from high importance. For further considerations a line-to-earth-fault (e.g. phase 1 - earth) is assumed; in that case impedances of wires are assumed to be identically. In the course of this treatment the impedance of the transformer is assumed to be higher than the impedance of the decentralized source.

6.1 Case 1: Missing neutral point to earth connection of the decentralized source

The effect of a missing neutral point to earth connection of the generator concerning fault currents and contact voltages is shown in Fig. 3.

The current from the transformer flows along the blue loop, currents from the decentralized source flow along the green loop (see Fig. 3 and Fig. 4).

Under consideration of the neutral point treatment the current I_{Tr} flows from node 1 to node 2 and via earth back to the neutral point of the transformer.

The current from the decentralized source flows along the green loop. At node 4 the current is split up into two parts in dependency of the line impedances. One part flows from node 4 via node 8, 9, 10 back to node 1 and the other part follows the path from node 5 via node 9 and 10 back to node 1.

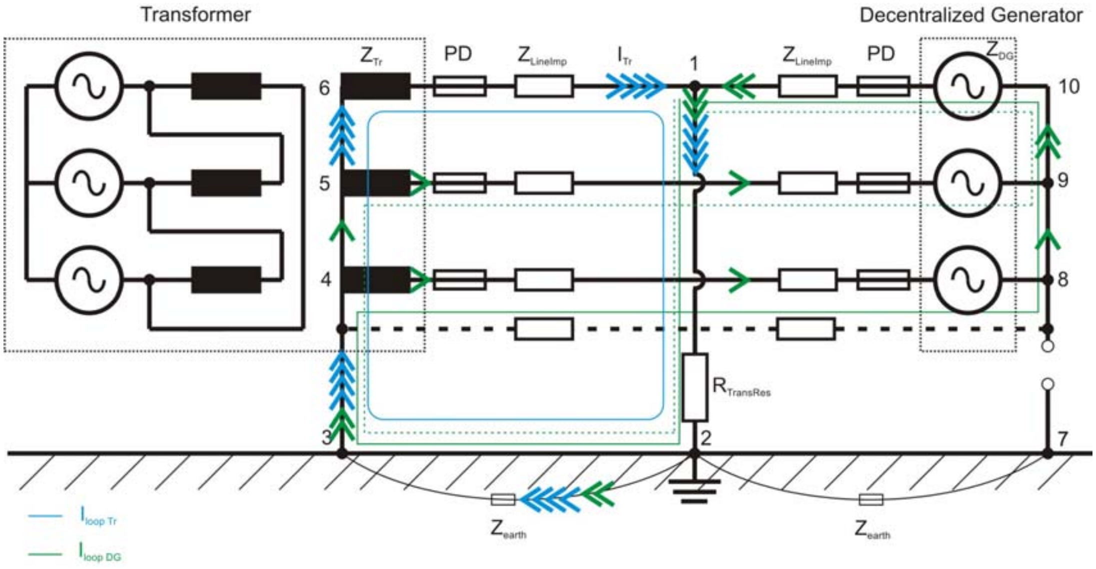

Fig.3. Parallel operation of earthed substation transformer and decentralized generation with missing neutral point to earth connection [8]

In case 1 protection devices (PD) on side of the distribution transformer -see Fig.3 - trip in time. The current for tripping the protection devices (PD) - on side of the decentralized source may not be high enough. The reason for that fact is dependent on the length of the fault loop (impedances) and the internal source impedances - see green loops in Fig. 3. The protection measure multiple protective earthing is not fully operative depending on loop impedances or the lack short circuit energy. If the protection device on side of decentralized source fails, uncontrolled islanded operations can occur. In that case safety for persons and electrical equipment cannot be guaranteed. Summarizing the first case uncontrolled islanded operations should be avoided and measures to guarantee personal safety and secure network operations have to be met.

6.2 Case 2: Defined neutral point to earth connection of the decentralized source

Fig. 4 shows the current sharing with existing neutral point to earth connection of the decentralized source. The current from the transformer flows along the blue loop from node 1 to node 2. At node 2 the current is split up into two parts in depending on of the fault position (earth impedances) and the earthing impedance of the transformer station and the decentralized source. One part flows via node 3, 4, 5 and 6 back to node 1. The other part flows via node 7 to node 8 and is split up again. One part flow via 4, 5, 6 back to node 1; the other one follows the way along part 9, 5 and 6 back to 1.

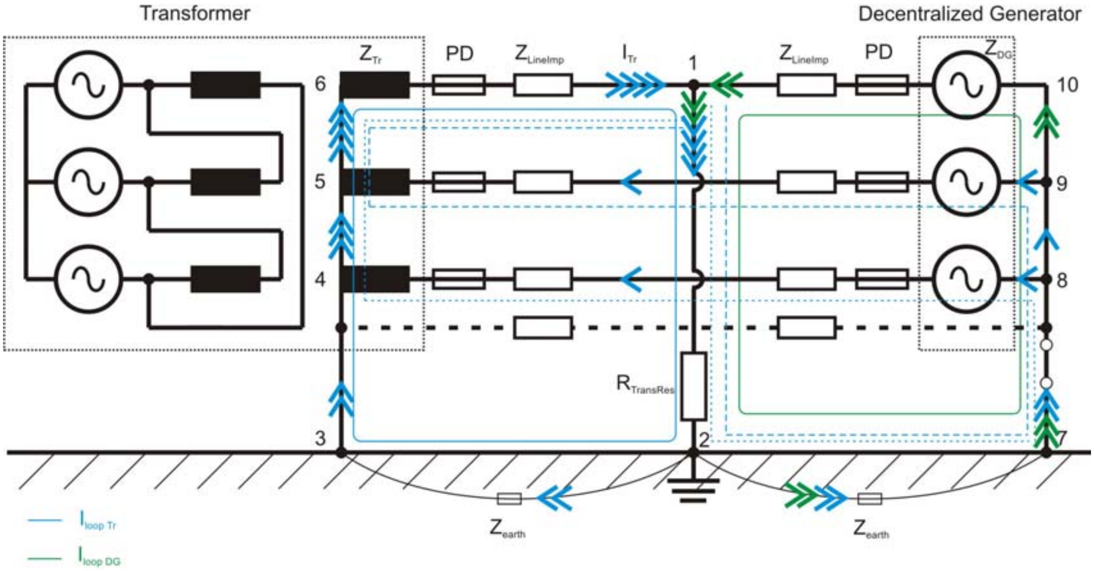

Fig.4. Parallel operation of earthed substation transformer and decentralized source with defined neutral point to earth connection [8]

In the case 2 the current for tripping the protection devices on transformer side and on side of the decentralized source are generally speaking sufficient - see Fig. 4. The decentralized source is separated immediately; uncontrolled islanded operations do not occur.

7. SUMMARY AND OUTLOOK

Smart Grids can be a part of an existing distribution network and also offer the possibility to supply small islanded networks. As shown in chapter 6 interrupting currents, in case of a missing neutral point treatment of the decentralized source may not generally speaking sufficient to trip protection equipments in time.

An important factor is the possibility that the short circuit power of decentralized sources is too low to guarantee the safe tripping of the protection devices. Requirements on protection systems, resulting from the increased integration of decentralized sources and due to the lack of short circuit power in combination with Smart Grids are of substantial interest [9].

Sufficient protective measures like RCDs or additional insulation monitoring have to be examined for their functionality. Another protection measure to reduce fault voltages is an addition equipotential bonding. Decentralized sources with integrated automatic decrease of fault voltage should also be analyzed on functionality. Innovations on the electronic sector maybe bring solutions for questions occurring in combination with decentralized feed-in. Further work in this project includes simulation of various network types in combination with associated protection systems. Also the influence of short circuit power of decentralized sources versus short circuit power of the distribution generator is focus of analyses. A further point on closer examination is the operating of inverters. If the operating voltage falls under a defined threshold the inverter generally trips out of infeed (undervoltage blocking).

A specific experimental laboratory setup to establish theories and to do analyze facts (assumptions) based on simulations is also part of the future work regarding the project “Smart Safety” [8].

With the increasing number of electronic devices, consuming reactive power, e.g. new lighting equipment, converters is growing.

The increased use of this equipment (harmonics, load unbalance and lack short circuit power) must not influence the network and further the protection system and need further investigations.

8. REFERENCES

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