SAFETY AND RELIABILITY FOR SMART-, MICRO- AND ISLANDED GRIDS

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ABSTRACT

Up to now the focus of Micro- and Smart-Grids analysis was to maintain the load flow using massive information technology to increase the supply guarantee by independent islanded-grids in regulator operation conditions but neglecting fault operation. In the paper will be shown the importance of a high short circuit power and low zero sequence impedance, listing of axioms for network planning and a listing of measures for islanded network operation .

INTRODUCTION

Micro- and Smart-grids, virtual power plants, distributed generation, large shut-downs of grid areas and "blackouts" – all these special topics are in the focus of discussions about operation and development of electrical transmission and distribution networks in the near future.
Depending on historical reasons over several years the current electricity system was developed as a large scaled technology with focus on centralized generation and control. The load flow from large power plants and strong high-voltage transmission grids to low voltage customers (figure 1) has been the base of the power-system since a long time. Nowadays besides these large scale technologies the economical and ecological use of energy is in the focus of the public awareness and the increasing connections of decentralized generations using renewable resources to bring new challenges into the power system.
The general requirements of electrical power supply are very high. In particular, the supply of the electricity has to be in sufficient quantity, with appropriate quality, economically, eco-friendly and socio-politically acceptable. From these basic requirements the following axioms of network planning [1] can be derived:

Axioms of network planning

- In the focused power grid part there must be a balance of generation and consumption. Deviations from the balance must be stabilized.
- All electrical equipment in the grid must have a sufficient transmission capacity for all relevant cases of operations.
- All electrical equipment in the grid must be able to withstand dynamic effects.
- The grid must be simple to operate complying the rules of the regulation.
- The service and maintenance of electrical equipment shall be simple.
- The power quality and the security of supply in the grid must be sufficient.
- The insulation of the components must be strong enough against overvoltage.
- Laws, regulations and standards have to be fulfilled.
- The proposed solution must be practicable and compatible with the system.
- The demands of customers must be taken into accounted.
- Social and political compatibility must be observed.
- The economy should be taken into account.
- **The supply of electrical energy must be safe!**

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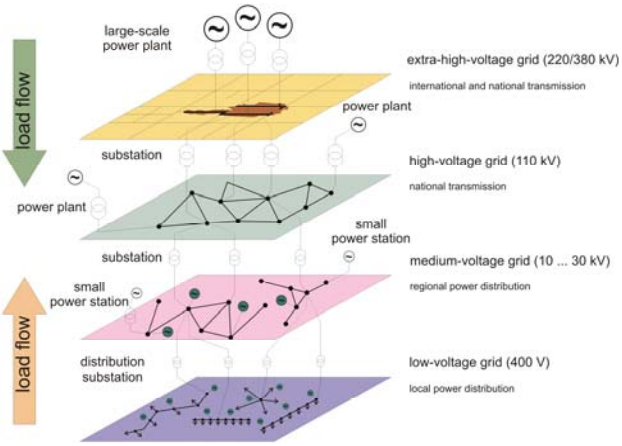

Figure 1: Electrical power system

GENERAL FAULT-SITUATION

The most common fault is, according to the fault statistics, in the low-voltage- (LV) as well in the medium-voltage- (MV) and high-voltage-system (HV) the single-phase (phase-to-earth) fault.
Due to the fact that our civilization has a high penetration of electrical energy, implemented by LV grids and MV grids, in the case of insulation fault the danger of electric shock must be prevented. The probability that the use of private or commercial LV equipment causes a risk is significantly higher than in the MV or HV systems and that is why the LV system needs special attention.

SINGLE-PHASE-FAULT

In contrast to the usually in central Europe realized earth fault compensated MV grids, where in the case of a fault the operation can be continued, faults in the LV grid will be disconnected quickly and safely. This quick disconnection will be realized by a quick tripping of an upstream over-current protection device (e.g. fuse) and therefore the fault current must be much higher then the rated current of the protection device. In the common praxis of public LV networks, the sufficient magnitude of current in case of a fault will be ensured by a low fault loop impedance $\underline{Z}_{Loop}$. Thus it must be guaranteed that $\underline{Z}_{Loop}$ is so low that the breaking current $\underline{I}_{break}$ of the primary protection (the fuse) will be reached or exceeded (equation 1). In the case of fault only sufficiently high currents will cause that the short necessary tripping time and residence time will be achieved

$$\underline{Z}_{Loop} \leq \frac{\underline{U}_L}{\underline{I}_{break}} \qquad (1)$$

$\underline{U}_L$ phase voltage

In a LV TT (figure 2) system the residual current circuit is closed by the local ground of the faulty electrical device and in the case of a TN system the electric circuit will be closed by the PEN conductor (the additional rules of the TN system must be adhered).

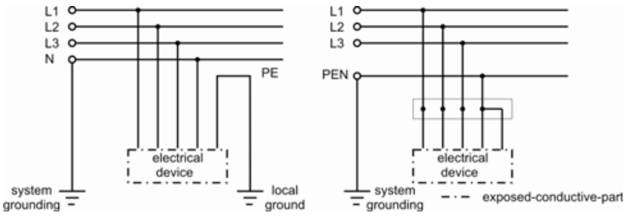

Figure 2: TT-system (left); TN-C-system (right)

Special importance for a safe clearing of the fault becomes the neutral point. The following figure 3 and equation 2 [2] show that in a three phase power system (using symmetrical components) the zero sequence impedance of the grid determines the height of the single-phase fault current ($\underline{I}_F$). For a safe fault clearing the positive- ($\underline{Z}^1$), the negative- ($\underline{Z}^2$) and the zero ($\underline{Z}^0$) sequence impedance have to be low.

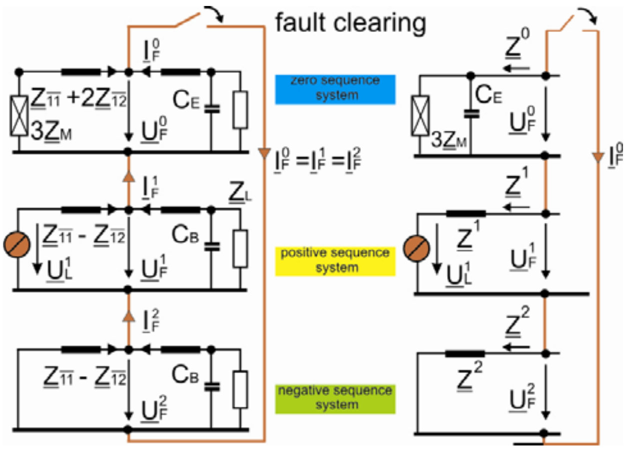

Figure 3: Model of symmetrical components

$\underline{U}_F$	voltage at fault point	$\underline{Z}_M$	neutral point impedance
$\underline{I}_F$	fault current	$\underline{Z}_L$	load impedance
$\underline{Z}_{11}$	self-impedance	C_E	earth capacitance
$\underline{Z}_{12}$	coupling-impedance	C_B	effective capacitance

$$\underline{I}_F = \frac{3 \cdot \underline{U}_L}{(\underline{Z}^0 + \underline{Z}^1 + \underline{Z}^2)} \qquad (2)$$

In practical applications, besides of the provision of a low impedance customer side earth connection, the zero sequence system impedance dominates and thus the neutral point connection. These impedances have to be supported by the distribution network operator. Because of the commitment of the network operator, to provide means for a fault management in the case of an adverse event, the management and control of the system have the character of a network service.

zero sequence impedance = network service

SHORT-CIRCUIT-POWER

In addition to the zero sequence impedance, which is depending on the neutral point connection, both positive- and negative sequence impedance become a substantial part of the short circuit scenario, expressed in technical terms by the short circuit power.
In the case of a three phase fault the positive sequence impedance Z^1 (equation 3) [3] which can be calculated for every point of fault indicates which short circuit current of an active grid can be supplied into the point of fault.

$$\underline{I}_k'' = \frac{\left(\frac{\underline{U}_N}{\sqrt{3}}\right)}{\underline{Z}^1} \qquad \underline{S}_k'' = \underline{U}_N \cdot \underline{I}_k'' \cdot \sqrt{3}$$

$$\underline{I}_k'' = \frac{\frac{\underline{U}_N}{\sqrt{3}}}{\underline{S}_k''} \qquad \underline{Z}^1 = \frac{\underline{U}_N^2}{\underline{S}_k''} \qquad (3)$$

$\underline{I}_k''$ initial symmetric short circuit current
$\underline{S}_k''$ initial symmetric short circuit power
$\underline{U}_N$ nominal voltage

All energy sources in reality are nonlinear, as the example of a voltage controlled synchronous generator shows. In the case of a short circuit neither the rms of the short circuit current is constant during this moment (depends on the positive sequence impedance of the machine) nor is the current-peak constant (depending on the field excitation and resulting from the source voltage which again depends on operation).
Thanks the automatic voltage regulator in the normal mode a change loading tends practically in no change of the voltage on the generator terminals. This suggests that the positive sequence impedance becomes very small.
In electronic power sources (inverters) there are similar nonlinear conditions. Based on the self-protection characteristics of the inverter the short circuit current will be only twofold as large as the rated current. In general, it is expected that the most standard inverters during the event of a voltage collapse (short circuit) the supply of power will stop.
The function that a grid can detect and clear a fault is the responsibility of the network operator. The protective function for the required current and thus short-circuit power comes within the commitment of the network operator which in the case of a fault must have a fault management. This management and control of the system fault source impedance, i.e. short circuit power, also have the character of a network service.

short circuit power = network service

According to the axioms of network planning the network operator is responsible for the type of neutral point connection.
In the case of TN systems the network operator provides a small zero sequence impedance and a reliable short-circuit power. In earth fault compensated networks the network operator is responsible for the coordinated use of earth fault neutralizer and their adjustment.

ISLANDED GRIDS

The different experts, organizations, standards and guidelines define and describe islanded grids and the operation of islanded grids in many different ways. From all the different definitions it can be summarized: A grid is islanded if an independent electrical (small) network has an appropriate frequency- and voltage-control and the mandatory standards for the protection of persons, animals and equipment can be observed.
In the discussion of the pros and cons of decentralized power generation in distribution networks, many times the possible increase of the reliability and availability is argued. In principle it must be differed between intentional and unintentional islanded network operation. To increase the reliability of supply a coordinated network splitting is necessary.
An uncoordinated island grid can occur when a power switch of the network supply is opened and a decentralized generator feeds into the remaining grid. This case of an islanded network operation must be avoided definitely because usually the safety of persons cannot be guaranteed. Furthermore without sufficient grid-control the voltage- and frequency-tolerances cannot be maintained and damages of the equipment and appliances are possible. Otherwise for the coordinated island grid operation a series of measures must be taken into account and considered.

- For the detection of an island network it must be decided whether an active (e.g. sonar/echolot) or a passive (e.g. impedance measuring, vector surge, frequency gradient, IT-based …) detection-method is suitable.
- It must be found out whether generation (one ore more generators) is strong enough to control the frequency and voltage. Furthermore the generation units control must be switchable from normal operation to islanded operation.
- In the case of overload or load variations enough power reserve must be given or an effective load management must be introduced or both must be coordinated.
- The generating plants as well as the distribution grid must have a suitable protection system so that the protection is guaranteed.
- In the moment of the system recovery or restart of supply an appropriate re-synchronizing device is necessary.
- In the case of the parallel operation of several decentralised generators an appropriate obligatory regulatory framework will be needed for the operators which includes the before listed points.

SAFETY REQUIREMENTS OF INTENDED LV GRIDS

On operation of Smart and Micro grids regarding safety and reliability two operating modes have to be differed: the interconnected operation and the isolated operation.

Interconnected operation:

By the feeding back of a fault current in a radial organized grid with an unidirectional protection system, it is possible that there is no selective tripping of the fuses (figure 4). The result can be unselective tripping and a confusing fault-interpretation leading to delayed clarification of the fault.

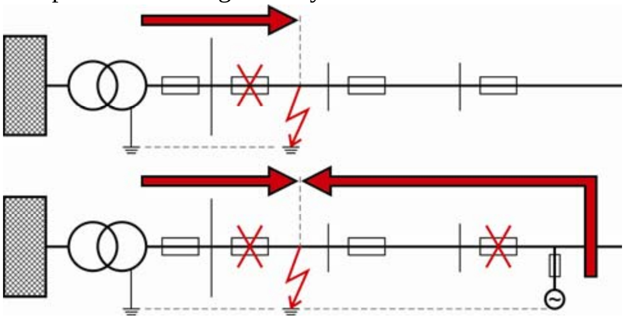

Figure 4: selective/unselctive tripping of fuses

Because of the fact that fuses only have a time-related over-current characteristic and no direction selectivity, it may be necessary to exchange fuses. New protection concepts become necessary and it will be a challenge to combine them with the existing protection devices while keeping the current standards.
As previously described the treatment of the grids neutral point connection is very important and as well of the neutral point of the decentralized generation plant.
Up to now most of the neutral points of decentralized generation plants are not connected with the neutral conductor.

Isolated operation:

In the case of three phase power generation without any neutral-point connection of the generators the phase to neutral voltage (phase to neutral conductor) is only defined by the loads (comparable with the break oft the neutral conductor).
The phase voltages (argument and absolute value) are built by the inverse proportion to the loads and thermal overload of the electrical equipment is likely, which can be a threat to appliances and to the general population.
Another critical situation arises during the formation of an islanded grid because the grounded neutral point of the distribution transformer gets lost and no current can be formed in the zero sequence system.
Similar to an isolated network, in case of the single-phase fault no sufficiently high breaking current can be formed and the existing protection devices (fuses) do not work and the personal protection becomes ineffective.

REQUIREMENTS TO MV-GRIDS

As mentioned before most of the central European MV grids are earth fault compensated. That means that the

neutral point of the grid is grounded by a central or decentralized Petersen-coil.
In the case of a single phase fault at the place of the fault the inductive current of the Petersen-coil will be compensated by the capacitive earth-fault-current (caused by the phase-ground-capacitance of the grid). In this way electric arcs in the overhead transmission grid will be cleared by themself.
The remaining residual current contains the not compensated resistive currents and uncompensated harmonics currents. This current causes only small touch voltages and the grid can be used without restrictions and disadvantages for the consumers.
In most cases the Petersen-coil is installed centralized in the feeding substation.
In the case of a splitting to an islanded grid the compensation of earth fault currents must be guaranteed so that there is no risk for persons, therfore it may be necessary to install decentralized Petersen-coils (figure 5) in each prospective micro-grid, especially if cables are present.

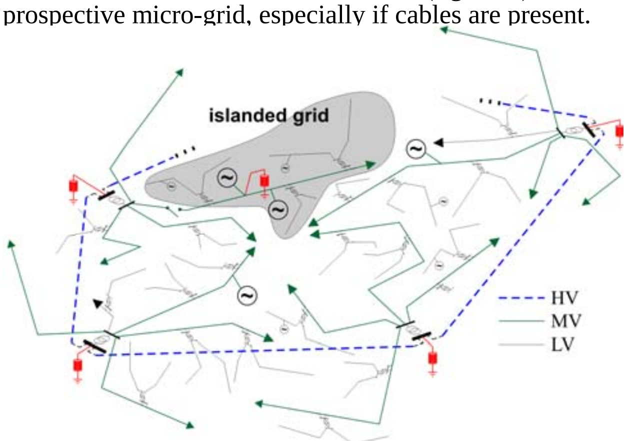

Figure 5: decentralized Petersen-coil in an islanded grid

MV grids in generally are constructed and operated as radial networks with the opportunity to close them to a ring-network.
To observe the selectivity by disconnecting a faulty feeder usually a time relay protection will be used. With the possible formation of an islanded network for a clear fault-clarification a full selective protection is necessary (e.g. directional overcurrent protection, distance protection, balanced protection, comparison schemes).
Also for the control and communication system modifications are needed. For an uninterruptible power grid switching (-detection) island-sectors must be defined, where the parameters frequency, voltage and phase position for a re-synchronising are observed and thus have to be measured and communicated in addition. The mode of the involved (islanded-operation) generation plants must be switchable from normal mode to "islanded"-mode. In the islanded mode an appropriate number of generation units (not all) have to take part on the P-f- and respectively Q-U-control. After reconnection to the grid they have to switch back to the normal (interconnected) mode.

RELIABILITY

The annual non-availability of electricity of customers (failure and fault statistics for Austria 2006 [4]) shows that the non-availability in medium voltage networks (ASIDI - Average System Interruption Duration Index) in the Austrian average total is about 70.5 min/a (planned and unplanned) and therefrom around 48 min are planned.
According to the statistics of the availability from VDN (Verband der Netzbetreiber – Germany [5]) and the estimation of Austrian experts, about 80% of non-availability is caused by faults in the MV network so this essential non-availability allows it to characterize LV-grids as potential islanded grids. The simplified adoption for the non-availability, their probability and impact of MV networks at LV networks, needs a detailed analysis of structural variables (dimension, rural/urban distribution, grade of cabling …) to find out the optimal size of islanded systems starting from single generator system up to large interconnected systems to reach a better reliability. These investigations are the current focus of research at the Institute of Electrical Powers System of the University of Technology Graz.

RESULT

The increasing interest in decentralized generation combined with a high reliability has an eminent social relevance.
In the paper it is shown that in the case of an islanded grid an efficient protection-system is quite important for a safe operation. A possible solution is the coordinated neutral point treatment of generation. Furthermore the importance of a high short circuit power and low zero sequence impedance is presented.
For an uninterrupted operation of islanded MV grids a highly technical investment must be done and so an economic operation with a high probability is not possible. Investigations concerning to the detection of islands, re-synchronizing, reliability and safety are essential for a safe and efficient operation of grids in the future.

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