LOCAL ISLAND POWER SUPPLY WITH DISTRIBUTED GENERATION SYSTEMS IN CASE OF LARGE-SCALE BLACKOUTS

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ABSTRACT

Large-scale blackouts with a long duration have serious impacts on society and can easily reach the dimension of a national crisis. Stable local island power systems, established and operated in the distribution grid and energized by the locally available population of decentralised power units can supply at the least the most critical consumers and thereby decrease the potential damage of large-scale blackouts immensely. This paper introduces the concept of these local island power systems.

INTRODUCTION

The increasing degree of electrification leads to a growing addiction to supply with electrical energy in nearby all areas of life. Based on the discussions about the consequences of the energy transition and the reporting of major blackouts in recent years, the issue security of supply is on the spot. A study by the German government [1] has shown that long-term and wide-spread blackouts can have serious impact on society and even lead to a national crisis. The comprehensive and appropriate supply with necessary goods cannot be ensured, what leads to a threat to public safety.

Furthermore, the fluctuating and not controllable feed of renewable energy sources makes the grid restoration after a blackout more complex. The decentralised generation units connect to the grid automatically, after parts of the distribution grid are reintegrated during the grid restoration process. This can lead to a power flow from the distribution grid to the main network, which can destabilise the grid restauration process. [2] With increasing complexity and recovery time until normal network operation restored, damages caused by the non-availability of electrical energy are rising. [1] Due to this fact, emergency supply systems gain significance.

MOTIVATION

In the context of the energy transition, the number of decentralised generation units has increased steadily. [3] The potential for damage of a blackout would be immensely decreased, if the provision of electrical energy for the most critical consumers could be maintained with help of those distributed power units. Generation units with black start capability and a reliable minimum performance (e.g. hydro or biomass) can be used to establish electrical islands, which are additionally energized by further locally installed generation units (e.g. photovoltaic or wind). A selective load management concept, which takes response to the fluctuating feed-in capacity of the renewable energy sources allows a stable operation of the local island grid. This load management concept takes response to the actual supply capacity and expands or limits the supplied network area. The supply of critical infrastructure has the highest priority.

RESEARCH PROJECT LINDA

LINDA is the acronym of a German research project that focusses on “Local Island Power Supply and Accelerated Grid Restauration with Distributed Generation Systems in Case of Large-Scale Blackouts”. The aim of the research project LINDA, which is funded by the German government (Federal Ministry for Economic Affairs and Energy) is the development of a concept for establishing and operating a stable local island grid, that is supplied by the available mixture of distributed generation units.

To reach this aim, the following research topics need to be addressed:

- Conceptual design and operational management for isolated power grids with a leading power plant and the locally available population of decentralised generation units for selective supply of sensitive consumers.
- Conception of a general procedure as well as general criteria for the establishment and stable operation of isolated power grids with low adjustment effort.
- Field trials, which allow new experiences of the real behaviour of electrical equipment in terms of voltage and frequency deviations.
- Identification of the requirements for the leading power plant.
- Determination of the requirements for amendment of protection devices and network control technology to meet the specific demands for operation in isolated power grids and the uninterruptible reintegration in the main grid.

The central element for the optimization of the concept and the electrical equipment is a transient simulation model of an exemplary section of a distribution grid in southern Germany. The perceptions gained with the dynamic simulation model are verified by staggered field trials.

GENERAL CONCEPT

In case of major power failures, decentralised generation units with black start capability and a reliable minimum performance should be used to establish electrical islands. Those generation units act as a leading power plant and have the responsibility for the balance of active and reactive power in the isolated grid, what is coherent with the regulation of frequency and voltage. Hydroelectric power plants are particularly suitable for this task, due to the low own requirements and the black start capability. It can be assumed that gas engines are also suitable as leading power plants, but further research is needed on this topic. Figure 1 shows the control loop of the leading power plant, which responds to the actual voltage and frequency in the islanded grid section.

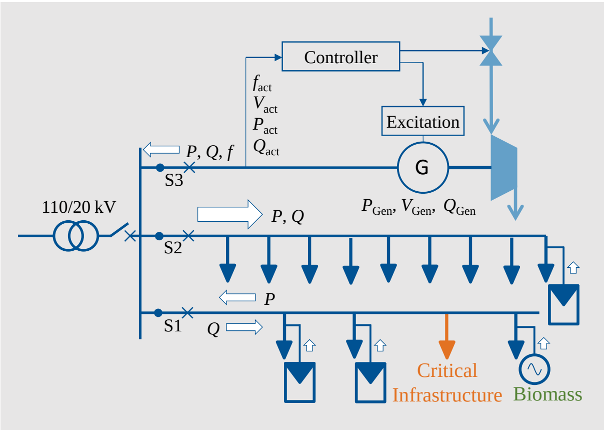

Figure 1: Isolated section of a distribution grid

The locally available population of decentralised generation units support the leading power plant to supply the grid section. Since the power output of the distributed generation units in the medium voltage and low voltage grid is usually not directly controllable, the frequency droop characteristic required by German and European standards and grid codes [4 - 10] is used for reduction of feed-in power in high frequency situations. Thus, instead of direct communication, the frequency is used for controlling the decentralised generation units. To achieve a stable operation, the control concept with *P*(*f*)- and *Q*(*V*)-droop curves is adopted to the leading power plant.

The load management system can connect or disconnect parts of the isolated network, depending on the actual feed-in of the fluctuating renewable energy sources and the power demand. This concept responds to low frequency situations and disconnects network strings or single loads temporarily, regarding to their priority and their power balance with respect to the frequency stability. This measure allows a prioritized supply of critical infrastructure in times of low supply capacity and prevents the island power supply from collapse.

Balancing of Active Power

Figure 2 shows the basic concept for balancing of active power in the operation of isolated power grids. The blue characteristic curve corresponds to the *P*(*f*)-droop curve of decentralised energy resources (DER) according to [4, 5]. P_M refers to the actual output of the supply unit, while exceeding the 50.2 Hz threshold and is the reference for the relative reduction of active power related to the required *P*(*f*)-droop characteristic of -40 % P_M/Hz. The *P*(*f*)-droop curve of the leading power plant (LPP) in relation to the rated output is represented by the purple characteristic curve. The slope of the droop curves determines the division of the total active power output between leading power plant and distributed generation units. In opposite to usual network operation, the whole frequency-range between 47.5 Hz and 51.5 Hz is used. The operation point at a certain frequency depends on the actual power conversion in the isolated grid. Figure 2 shows an arbitrarily chosen operation point. Changes of load lead to a frequency deviation, what results in a change of the operation point. At steady state, the highest frequency is in idle run of the leading power plant.

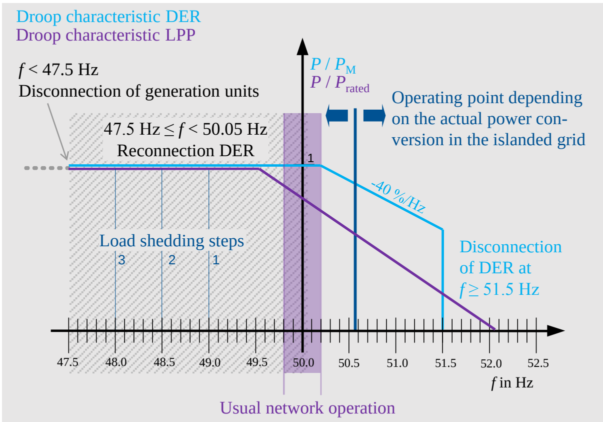

Figure 2: Control concept for active power in island power supply

In [4, 5], the stationary behaviour of the controller for feed-in reduction in over-frequency situations is defined, but not the transient. The transitional period between two steady states is a critical process for the stability in a small network. Therefore, worst case estimations under consideration of the nonlinear control performance (frequency threshold) of unknown electrical systems are necessary.

Balancing of Reactive Power

$Q(V)$-droop characteristics (Figure 3) or cos $\varphi(P)$-droop characteristics are usually used to contribute the static voltage stability according to [4, 5].

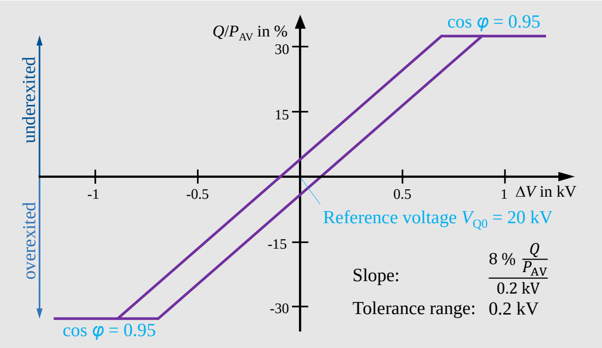

Figure 3: $Q(V)$-droop characteristic as requested from the LEW Verteilnetz GmbH (LVN) for distributed generation units in the MV-grid [11]

The leading power plant is responsible for the balance of reactive power in the island power grid. Therefore, analogue to the decentralised generation units, a $Q(V)$-droop characteristic is implemented. The slope of the droop curve controls the share of the provision of reactive power from the distributed generation units to the balance of reactive power in the island power grid. The feasible range of the slope in terms of voltage maintenance and reserves of reactive power is determined with help of the simulation tool. A fixed voltage regulation would be an extreme value of a droop characteristic, which has high requirements on generation of reactive power for the leading power plant in island operation.

Establishment and operation of the island power supply

To prepare the local grid for islanding, the relevant sections are disconnected from the main system. Furthermore, all loads are disconnected from the substation in this section. In the next step, the leading power plant is started and operated in order to supply its own demand. Following this action, single branches are reconnected in the substation. The inrush effect can cause large currents, especially if large transformer power is connected at the same time. [12] In order to prevent the generator from overloading or triggering a protection device, the (transformer-) loads are connected step by step. The resulting load step has to be determined in a way, that can be controlled by the leading power plant within the allowed frequency- and voltage range. After the transient effects have decayed, additional loads can be connected.
As loads and generation units are connected, the static operation point of the island power supply is shifted along the $P(f)$-characteristic of the leading power plant.

After the establishment of the island power supply, a stable operation is intended. In times of surplus of supply, the self-regulating effect along the $P(f)$-characteristic is responsible for the stability of islanded grid. The fluctuating supply capacity of the renewable energy sources can also lead to a shortage of supply, which results in a reduced frequency. A selective load management system should counteract a breakdown of the system with the help of frequency based load shedding steps. Aside from technical restrictions, that prevent disconnection of any loads, legal matters have to be considered. Therefore, a definition of criteria for prioritization and also for equal treatment is required. This allows the development of simple instructions, which ensure in emergency situations fast and legally compliant decisions.

If the main network is restored, the island section has to be reintegrated without interruption. Due to the fact that the connected distribution grid was already energized, effects like transformer inrush currents or load peaks which would normally occur during reconnection are diminished. Thus bigger parts of the distribution grid can be connected to the transmission grid simultaneously than established restauration processes suggest and the restauration process can be accelerated.

An uninterrupted reintegration process requires parallel switching equipment at the coupling point to the main grid. This device ensures that the voltages frequencies and phase angles of the grids are within a specific range, before reconnection is performed. For enabling the reconnection, the island grid must be resynchronised to the main network. Therefore, the control algorithm of the islanded grid changes the set point of the leading power plant and the on-load-tap-changer.

DYNAMICS OF THE ISLAND POWER GRID

In addition to the general operation concept, the dynamic behaviour of multiple components of the island power grid during the establishing process as well as during the island operation needs further investigation.

Figure 2 shows the method of reduction of active power in high frequency situations based on current grid codes. But the locally available population of decentralised generation units has grown over many years and thus have been connected to grid by conditions of different grid codes. According to [13], discontinuous methods are still allowed for many distributed supply units. The immediate reduction of generation power at fixed frequencies has the potential to destabilise the isolated grid. The stability of the island power supply related to the immediate reduction of generation power at fixed frequencies is determined with help of a transient simulation and field trials at a real supply structure.

Based on the synchronisation conditions, connection of decentralised generation units parameterized according to current grid codes takes place at frequencies $f < 50.05$ Hz [14, 15, 16]. Once connected, they increase their power output by maximum 10% per minute, what supports the system stability. In opposite to that, the increase of power output of older generation units is not limited. For a stable operation, the maximum power gradient is determined with help of transient simulation.

Furthermore, the tripping of a load shedding step may lead to oscillations of voltage and frequency, which can destabilize the system. To avoid instabilities, maximum load shedding steps are defined, which are controllable by the leading power plant within the allowed range.

Similar to the impact of the dynamic behaviour of active power control on the system stability, the dynamic behaviour of reactive power control requires further investigation. To achieve a stable control of the grid, the step response of the *Q*(*V*)-control of decentralised generation units has a PT-1 behaviour. The slow approaching of the set point avoids increasing oscillations between different controllers of power plants.

For an optimised contribution to the restauration process of the transmission grid, an uninterrupted and synchronous reconnection to the transmission grid is required. To enable reconnection, voltage and frequency at the connection point need to be kept in a range with very small deviations from a target value, even though the greater part of the generation units cannot be controlled directly. The proof that the introduced operation concept is able to meet these requirements, will be done via simulation and via field trail.

RESEARCH METHODOLOGY

The research methodology is based on a dynamic simulation model of an exemplary grid section in southern Germany and a verification of the model by staggered field trials.

A hydroelectric power plant with black start capability acts as a leading power plant in this section. The isolated grid is further supplied by biomass and photovoltaic power plants. The supplied loads are typical households as well as an industrial customer with large electric motors, which provide the option for a selective load management.

All components are modelled in a simulation tool, which allows stationary as well as transient simulation of the behaviour of the isolated grid. The simulation model has the following tasks:

- Determination of the maximum power gradient at the connection of the decentralised generation units, which can be controlled by the leading power plant within the allowed range.
- Determination of the maximum load steps for an automatic load management, to avoid instability caused by overshoots.
- Estimation of the level of robustness of the isolated power supply against critical influences caused by the real supply structure (load steps, dynamic behaviour, steep power gradients, etc.).
- Proof the feasibility of the frequency control for an uninterruptible resynchronization process.
- Optimization of the concept *P*(*f*)- and *Q*(*V*)-droop characteristics, load management).
- Determination of criteria for a generalization of the concept.

Staggered field tests in the selected grid section should verify the simulation model. During the field trials, frequency, voltages and power flows are measured at specific points. The measurement results allow the comparison of the real behaviour of the isolated grid with literature values [17] in terms of the behaviour of electrical systems to frequency deviations.

CONCLUSION

Modern societies are vulnerable to large-scale blackouts with a long duration. Such events can cause huge damage. The grown population of decentralised generation units provides the option to operate an island power supply, which allows an improved level of supply at least for critical infrastructure in case of a major disruption.

In this paper, a general applicable operation concept is introduced, which allows the stable operation of isolated power grids with help of distributed generation units. This grid sections should be reintegrated in the main grid without interruption, if it is available again, what results in an accelerated grid restauration process.

The research methodology is based on a dynamic simulation model of an existing grid section in southern Germany, which is verified by staggered field trials. The combination of dynamic modelling and field trials allow reliable conclusions of the real performance of the historical grown decentralised generation structure, especially in terms of dynamic behaviour.

The concept of LINDA is an addition to the existing grid restauration concept of the transmission system operators and minimizes the economic and social damages of a blackout.

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