FAULT CURRENT SOURCE TO ENSURE THE FAULT LEVEL IN INVERTER-DOMINATED NETWORKS

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ABSTRACT

This paper addresses the issue of ensuring the fault level in inverter-dominated islanded networks. This issue is particularly gaining significance with the advent of microgrids. It is proposed to add one component to the network which supplies the fault current when required and which keeps the network alive long enough for all inverters to resume operation, if they have switched off during the transient. This component is named a Fault Current Source (FCS).

If the network is in normal operation, the FCS charges its internal energy buffer and then remains dormant. As soon as a phenomenon is detected which is representative of a fault, the FCS attempts to restore the system voltage which was present just before the fault, thereby injecting as much current as necessary. Once the fault is cleared, the FCS provides the reference needed by all inverters to restart operation. Subsequently the FCS switches off again.

A prototype FCS has been built and tested. Preliminary test results are presented in this paper, full results are to be presented during the conference.

INTRODUCTION INTO MICROGRIDS

One of the emerging network concepts in the field of distributed generation is the microgrid. A microgrid is a network, usually at low voltage level, in which the operation of network, loads, local generation and local storage is coordinated to deliver particular services to its customers. Such services could be optimal fuel efficiency, optimal cost of electricity, or increased reliability by enabling islanded operation.

The main driver behind this concept is the increasing amount of decentralised electricity generation, e.g. from wind turbines, solar PV systems and CHP systems. These generators have been installed as a consequence of government incentives aiming to increase the use of electricity from renewable sources and to reduce the CO_2 contribution of electricity generated from fossil fuels.

The prevailing standard is to disconnect such generators from the electricity network in case of a fault in the network, in order to avoid the formation of electrical islands. In many countries network operators demand sophisticated anti-islanding detectors for every small generator.

Over recent years this standard has been abandoned for large wind farms in regions where a significant portion of the regional load is supplied by local distributed generation. It has been recognized that keeping the wind farms connected during and immediately after a fault in the network, is essential to maintain the stability of the network. There are good reasons to presume that this approach will also penetrate into the domain of medium and low voltage networks in the near future.

Many low-voltage generators like PV systems, small wind turbines and domestic CHP, are owned by individual home owners. These individuals seek ways to optimize the "profit" (which is not perceived as a financial benefit only) from their generator:

- by sharing electricity with their close neighbours without having to pay the distribution network operator disproportionally for delivering their power next door;
- by using their private generator as a back-up in case of a fault in the electricity distribution network;
- by offering some kind of control over their generator to the DNO or to an energy service company (ESCO), to be used for example as balancing power. In such cases the DNO or ESCO may offer a financial compensation in return.

The Microgrid philosophy has been developed as a set of concepts and tools with which these services can be implemented. In the EU 5th and 6th Framework Programmes, two projects have been executed covering all aspects of these concepts. The aspects addressed range from fundamental electrical issues like dynamic stability in the millisecond domain and black start sequences up to regulatory issues and market models. All publications from these projects are available from www.microgrids.eu.

PROTECTION IN A MICROGRID

One of the main benefits of a microgrid is the option to run a local or regional network in islanded mode. Nevertheless, most of the time the microgrid will be operated in grid-connected mode. Moreover islanding may involve some kind of degraded mode, such as a loss of power quality or temporary disconnection of non-essential loads.

However, even in degraded mode the safety of the network must not be compromised. In particular this means that short-circuit faults must detected and isolated within the prescribed time windows, in order to prevent overheating of conductors or unsafe levels of touch voltages. On the other hand it is desirable that the microgrid does not collapse as a consequence of a simple short-circuit fault within the premises of a single customer. That is what would happen in a microgrid which is dominantly supplied from inverters due to their ultra-fast overcurrent protection.

Analysis of these requirements for a sample low-voltage microgrid [1, 2] has led to the following conclusions:

1. Generally the size of an LV microgrid is such that there is no added value in sectionalizing the network when a fault occurs in the network itself. Only in a radial network with tapered feeders, this approach may be necessary to protect the lower-diameter conductors at the far end of the feeders. As a consequence, it is accepted that the microgrid loses power after a fault in the microgrid's network. This approach also avoids the issue of misoperation of protections as a consequence of reverse current flows.

2. The fault level of the microgrid must be sufficient to operate protection devices behind any customer's meter, so that a fault within the customer's premises does not propagate into the network.

It is strongly recommended to use standard protection devices within the customer's installation. By "standard" we refer to protection devices which are normally used in that specific country and which would be purchased by the customer at the local DIY store if he were to expand his own switchboard. The fault level provided by the microgrid must then support the operating currents and clearing times needed by such devices.

Commercially available PV inverters do not comply with this recommendation. These inverters switch off immediately whenever the output current exceeds the rated current by a relatively small percentage, for example 20%. The same argument applies to inverters used in for example microturbines and in small wind turbines. Therefore a microgrid needs preferably at least one generator delivering fault ride-through on any short-circuit behind a customer's switchboard.

In the sample network analyzed in the MICROGRIDS project [1], this role is assigned to the flywheel storage system which is used to absorb the transient after a sudden disconnection of the microgrid from the external distribution network. However from the analysis made, it follows that the flywheel's inverter must be able to sustain a factor 3 overload for several seconds. This may pose a problem when trying to purchase such a system in the market. Moreover, not all microgrids may be equipped with a storage system.

FAULT CURRENT SOURCE

A Fault Current Source (FCS) is a network component specifically intended to provide additional fault level to a network. The component was developed with inverter-dominated networks in mind, but is also applicable in networks which lack fault level because of long supply lines.

Operation

The operation of an FCS is illustrated in figure 1. Its power circuit remains dormant during normal operation of the network (1). Whenever a fault occurs (2), it is activated (3) and attempts to restore the original voltage, thereby

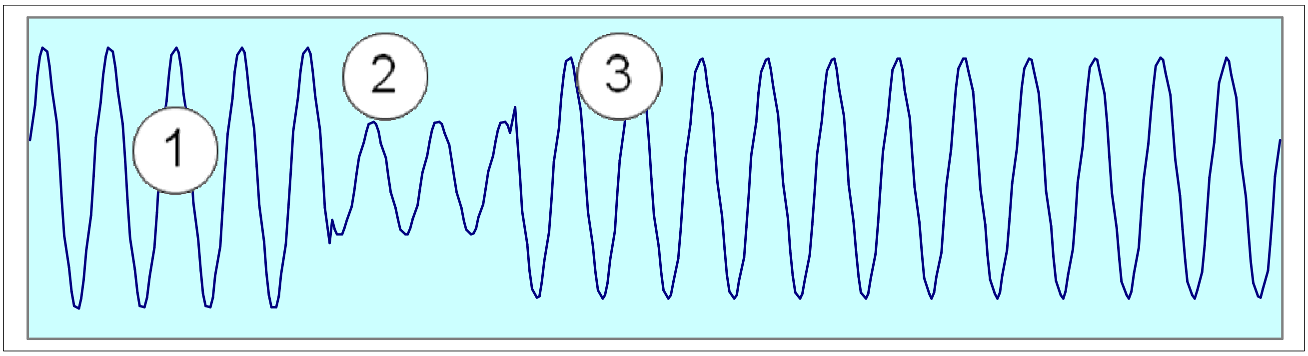

Figure 1: Voltage in the network in normal operation (1), when the faults occurs (2) and after triggering of the FCS (3).

injecting a fault current into the network. This current will cause a fuse or circuit breaker to clear the fault. Subsequently the FCS maintains the original voltage and frequency, to enable inverters which had turned off, to resynchronize and reconnect to the network. After some time, typically 5 seconds, the FCS turns off.

Location

Once triggered, the FCS acts like a low-impedance voltage source. The most logical location of an FCS in the network is therefore the main distribution busbar, which would be right next to the distribution transformer if the network is normally supplied from an MV network.

Implementation

An FCS consists of four subsystems:

- An electricity storage device
- A power electronic converter
- A triggering circuit
- A charging module

Electricity storage device

An FCS is applied if the network by itself cannot provide a fault current during a fault. As an LV network is dominantly resistive, a fault current is associated with a significant amount of real power which has to be injected into the network for the time needed to clear the fault. The energy required to deliver power during a certain time must be stored inside the FCS. The energy could be stored in a flywheel, a battery, an ultracapacitor or any other technology which is suitable for fast discharges.

Power electronic converter

When the FCS is triggered, the available energy must be released into the network in a controlled manner. The best way to do this is by trying to maintain the voltage and frequency of the network as they were prior to the fault. In this way, the original voltage is automatically restored as soon as the fault is cleared by the appropriate protection device. Therefore a power electronic converter is used as an interface between the energy storage device and the network. In many cases the electrical energy is available as DC. The distribution network is AC, so that the interface is a DC to AC inverter.

In LV distribution networks most faults behind the customer meter are single phase to earth/neutral faults. Therefore the inverter must provide a neutral connection and preferably act independently for each phase. This approach minimizes the annoyance in the other two phases during a single-phase fault.

Triggering circuit

The key component of an FCS is a circuit which senses the state of the network and starts the inverter whenever it detects a fault. In order to be able to operate an FCS as a plug-and-play device, this circuit should act only on locally measured information. Technical details of the detection algorithm will be published later because of a pending patent application.

Charging module

The energy storage device is charged with electricity from the network. This must be done in a controlled manner, because high inrush or charging currents are generally unwanted in distribution networks with a low fault level. On the other hand, after having operated the FCS must be recharged as soon as possible to be ready for the next fault. Depending on the topology of the system, the power electronic converter can be used to recharge the storage device.

Modularity

The FCS is connected in parallel to the network and acts as a current-limited voltage source when triggered. Therefore it is relatively simple to use multiple devices in parallel. For example, a typical unit would have a rating of 500 A peak current and an available stored energy of 100 kJ. If a network requires a higher current, or if for reasons of reliability the network operator prefers to have redundant units, two or more devices can be connected in parallel.

COMPARSION WITH SIMILAR DEVICES

It is helpful to define the role and design of an FCS compared with other Power Quality related devices.

Flicker compensators

The FCS is connected in parallel to the distribution network. This is very similar to the topology applied for a Power Quality Optimizer (PQO) which was introduced by EMforce in 2007 [3]. The main difference is that a PQO is in operation continuously and is rated to supply relatively small currents, whereas an FCS operates only when triggered and can supply fault currents. The devices have in common that the thermal design has been optimised for the delivery of short peak currents. A PQO needs some energy storage, but much less than required for an FCS.

Static VAR Compensators

A Static VAR Compensator (SVC) is an inverter, connected in parallel to the network to inject or absorb reactive power. An SVC is rated for continuous operation and has a thermal design which is similar to a traditional inverter. It is generally not designed to deliver fault currents. It does not supply active power and therefore its stored energy is very small. SVCs are rarely used in LV networks.

Dynamic Voltage Restorers

A Dynamic Voltage Restorer (DVR) is a device connected in series with a voltage-sensitive feeder or load. It provides correction of the amplitude and sometimes even the waveform of the voltage supplied from a network. A DVR is equipped with some electricity storage to be able reconstruct the voltage if the network does not supply enough power during a transient. A DVR operates only on transients and remains dormant during normal operation of the network. However because of its series connection, the semiconductors of a DVR have to carry the load current continuously and the device has to be thermally rated for continuous load. Generally a DVR does not significantly increase the fault level of a network.

PROTOTYPE

In order to demonstrate the concept of an FCS and test its properties in a practical configuration, a prototype was built using a 500 A single-phase inverter. A simplified circuit diagram is shown in figure 2. An ultracapacitor stack which can deliver approx. 100 kJ is used as an energy buffer. A topology has been chosen with a single half-bridge and the network neutral connected to the centre tap of the inverter's buffer capacitors. The pre-charging circuit consists of a transformer supplying 2 kW at a relatively low voltage. Once the buffer has been charged to approx. 100 V, the inverter is used as a boost converter to further charge the buffer. As soon as the buffer voltage has exceeded 600 V, the transformer is disconnected and the main contactor is closed, connecting the inverter phase directly to the network. The inverter then continues charging the buffer to a maximum value of 860 V.

The buffer consists of 320 ultracapacitor cells, each rated 140 F / 2.7 V. Proper voltage sharing between the cells is ensured by parallel resistors. As these have been chosen rather conservatively, the buffer has a relatively high self-discharge rate; the time constant is approx. 9 hours. In this application such a value is not prohibitive.

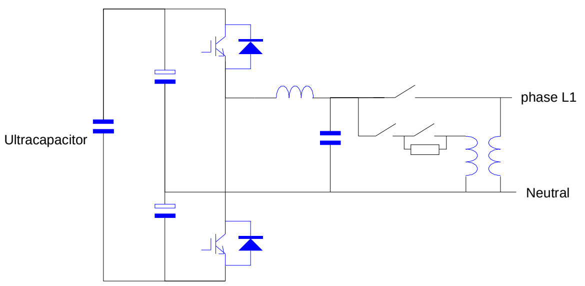

Figure 2: Circuit diagram of the prototype FCS.

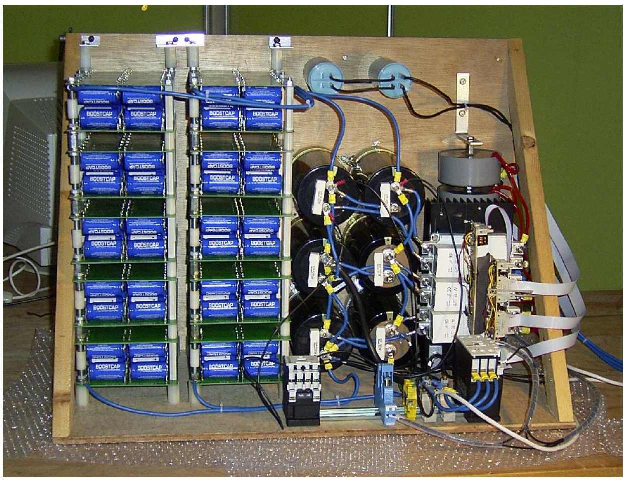

Figure 3: Prototype FCS.

Figure 3 shows the prototype in its initial assembly. From left to right the ultracapacitor stacks, the electrolyte buffer capacitors, and the inverter can be seen. The charging circuit and control electronics are mounted on the back side of the assembly and are not visible from this side.

CONCLUSIONS

A Fault Current Limiter is a promising device to provide fault level in inverter-dominated distribution networks. The concept is plug-and-play and can be used in a modular manner.

Preliminary testing of the prototype has proved the capabilities of the FCS and the quality of the detection algorithm. The correct parametrization of the algorithm is underway. Full test results will be presented during the conference.

Acknowledgement

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