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FAULT TYPE AND LOCATION DETECTION IN ISLANDED MICROGRID WITH DIFFERENT CONTROL METHODS BASED CONVERTERS

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ABSTRACT

In this paper the fault type and location detection in an islanded low voltage (LV) distribution network based microgrid with converters applying different control methods is studied. In the future most of the distributed generation (DG) units in microgrids will be connected to network through power electronic interfaces (e.g. converters) which usually have limited capability to feed fault current due to power devices protection reasons. Also converter control methods affect to the converter fault behavior. This means that during the faults the converter cannot feed larger current than the nominal current of it or it tries to keep active power fed to grid on the reference value, so that the current of converter increases to a certain limit. Simulations show that protection of islanded microgrid with converters could be based on changes in phase voltages and voltage RMS values at the connection points of DG units. But, due to different control methods of converters, the fault location estimation is not that simple in every case. The simulation studies are made with PSCAD simulation software package.

INTRODUCTION

Microgrids are distribution systems with DG units together with energy storages and controllable loads, which can be operated either interconnected to the distribution grid or in islanded mode. Islanding process can be due to disturbances, such as a fault and its subsequent switching incidents, or due to intentional switching events. The microgrid remains operational in an autonomous mode after seamless islanding with the aid of energy storages and controllable loads, that enable microgid to meet the corresponding load requirements. The advantage for the grid is that microgrid can be seen as a single dispatchable load and from the customer point of view it meets local needs for power (and heat) and enhances local reliability and power quality. [1], [2]

This paper studies the fault type and location detection in an islanded low voltage (LV) distribution network based microgrid with converters applying different control methods. Studied microgrid consists of one battery storage/master unit converter and one permanent magnet generator equipped with frequency converter based grid interconnection. The load in the microgrid consists of eight passive loads and one induction motor. In the simulations only the fault type (3- or 2-phase fault or 1- or 2-phase earth fault) and location (two different locations) was varied.

The previous simulation studies [3], [4] about the voltage - active power and frequency - reactive power dependency in converter and LV network based microgrid showed that to maintain frequency balance in islanded converter based microgrid there should be one unit (single master mode) or many units which will determine the synchronism of microgrid. In this paper frequency of microgrid is controlled with multimaster mode and due to that the frequency of microgrid is fixed even in fault situations. Converter based storage unit acts also as master unit and it has the main responsibility to control the voltage of an islanded microgrid.

In the simulations behavior of currents and voltages (also phase values) during faults were investigated at the connection points of DG units and at the end of both feeders. Also changes in the microgrid frequency and in the DC link voltage at the frequency converter of the permanent magnet generator were studied. In this paper only the simulation results from voltage values will be shown.

Next chapter of this paper discusses briefly about protection of an islanded microgrid and different converter control methods and their effect to the fault behavior of converters. After that the studied system is introduced and the key simulation results are briefly introduced. Conclusions are stated in the last section.

PROTECTION OF AN ISLANDED MICROGRID

Faults in islanded microgrid

In the future most of the distributed generation (DG) units in microgrids will be connected to network through power electronic interfaces (e.g. converters) which usually have limited capability to feed fault current due to power devices protection reasons. Typically the limit is twice their rated output current. Also the current of the converter will not rise during fault if the control method of the converter is chosen so that it cannot feed larger current than the nominal current of it. [5] Thus questions about converter connected units behavior during faults have risen (e.g., can the behavior of the converter vary depending on the different design priorities of different manufacturers).

If the fault current is wanted to be kept up in converter-based islanded microgrid without oversizing the converter components, then one solution is to use flywheel energy storage [6]. But if flywheel storage is not used, then other protection techniques than conventional over-current protection has to be investigated when different types of faults within microgrid needs to be found and located. Since the protection in islanded microgrid cannot be based on fault currents, one solution could be protection which is based in voltages at the microgrid. For example in paper [7] it is suggested that in islanded microgrid with converter-based production units faults and fault types could be detected in the connection points of production units from d- and q-components of the voltage.

Effect of different converter control methods to their fault behavior

DC voltage is converted with grid side converter to AC voltage by controlling the power devices with certain modulation method. In this paper simulations with PSCAD are made with two different modulation or control methods (Pulse Width Modulation, PWM and hysteresis control) applied on converter of the battery storage/master unit (Fig. 1). On the first simulations the converter of the master unit, which is located at the beginning of the feeder 1_1, is equipped with LCL-filter and hysteresis control. In practice this means that during the faults the converter cannot feed larger current than the rated current of it and average switching frequency is set by the hysteresis band? limits. On the other simulations the converter of the master unit is equipped with L-filter and PWM control, which means that during the faults converter still tries to keep active power fed to the grid on its reference value, so that the current of the converter increases to a certain limit and the switching frequency is fixed and can be freely chosen.

STUDIED SYSTEM AND SIMULATION RESULTS

Studied urban cable LV network based microgrid

The studied urban cable LV network is shown in Fig. 1. The studied system consists of 800 kVA MV/LV-transformer which feeds two LV feeders (1_1 and 1_2) shown also in Fig. 1. The load in the microgrid consists of four passive loads on each feeder and induction motor at the end of feeder 1_1. The passive loads can be adjusted so that the loading of the transformer (which feeds LV feeders 1_1 and 1_2) gets some desired value between 0…150 % of the transformer ratings. Initially loading of the transformer was set to 15 % (123 kW) with power factor 0.985_{ind}. Cable parameters and R/X -ratio of the cable used in the studied LV network (Fig. 1) are shown in Table 1.

In simulations made the microgrid is disconnected from main network with breaker so that the islanded microgrid will consist of feeders 1_1 and 1_2 (Fig. 1). In first simulations (with hysteresis control) front-end of the feeder 1_1 includes a storage unit (battery 120 kW) equipped with hysteresis controlled converter and LCL-filter (L_1 = 0.1 mH, C = 6.9 µF, L_2 = 0.611 mH). In second simulations (with PWM control) this converter of battery storage unit is PWM controlled (5 kHz switching frequency) and equipped with 1.5 mH L-filter. In all simulations there is on the feeder 1_2 also a permanent magnet generator (300 kVA) equipped with frequency converter which is PWM controlled in all simulations (4 mH L-filter and 5 kHz switching frequency).

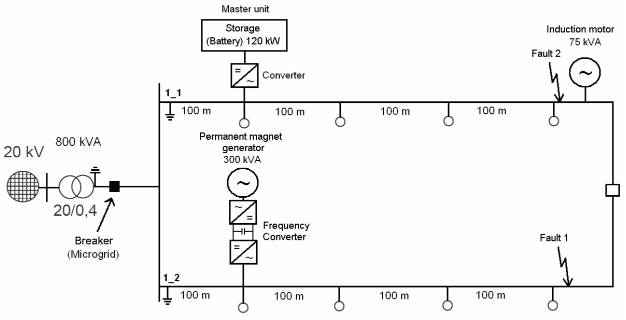


Figure 1. Studied urban LV network based microgrid.

Table 1. Resistance, Reactance and R/X ratio of LV cables in the microgrid.

	R (Ω/km)	X (Ω/km)	R/X
AXMK 4x185S	0.164	0.0817	2.01

Simulations represented in this paper consist of the timed events/changes listed in Table 2. Only the fault type (3- or 2-phase fault or 1- or 2-phase earth fault) and location (Fault 1 or 2 in Fig. 1) will vary in simulations.

Table 2. Essential events/changes in the simulations.

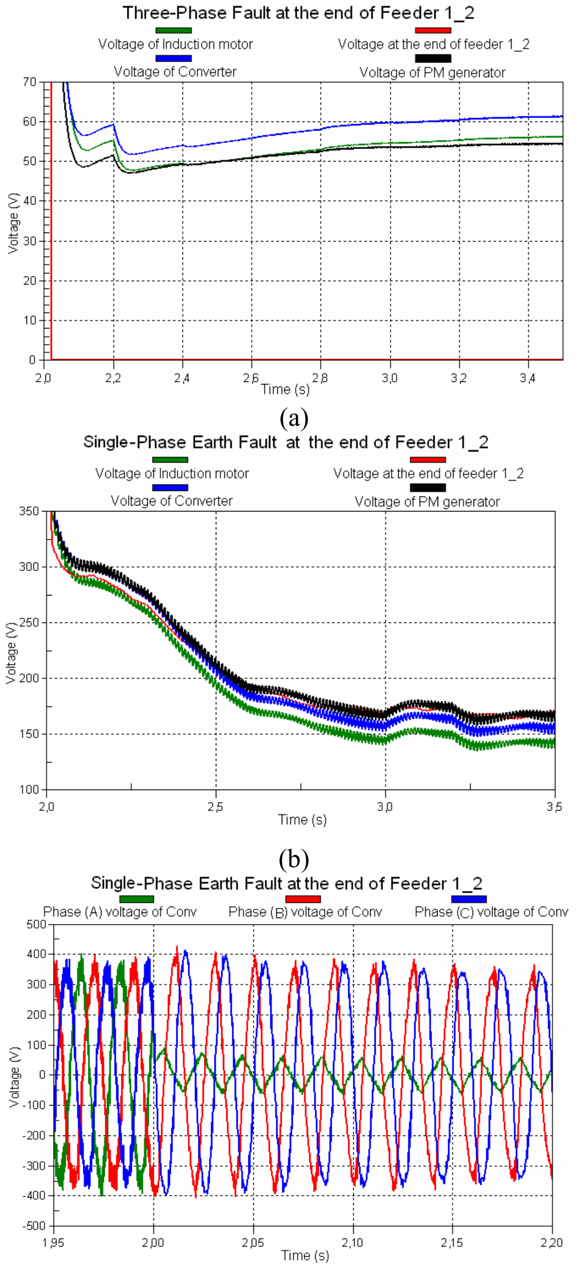
Time (s)	Event/Change
0	Induction motor is connected to network (45 kW and 30 kVAr)
0.1-0.12	Permanent magnet (PM) generator equipped with frequency converter is connected to network (73 kW and 0 kVAr)
0.1-0.4	Battery storage / Master unit converter is connected to network (before fault 90 kW and 37 kVAr)
1.5	A) Islanding of microgrid B) Active power reference value for converter of master unit from PU-droop (500 Hz sampling rate) to keep voltage near 400 V C) Inputs for Phase Locked Loop (PLL) of all converters are changed to the 50 Hz 3-phase reference sine wave generator (instead of microgrid 3-phase voltages) which imitates the voltages of the grid before islanding i.e. converters will now determine the synchronism and frequency of microgrid (multimaster mode)
2.0	3- or 2-phase fault or 1- or 2-phase earth fault in fault location 1 or 2 (Fig. 1)
3.5	End of simulation

Simulation results

In this particular case one should notice that fault current fed from frequency converter of PM generator can increase many times in a fault situation when compared to situation before fault without crossing the limit of twice the rated output current (I_N*2) of it, because before fault this unit produces only 73 kW and 0 kVAr which is far away from the rated power (300 kVA) of it. Because of the page limitation, only the simulation results considering the voltages at the microgrid will be shown in the following sections.

Battery storage converter hysteresis controlled

In Fig. 2a and 2b voltage RMS values in microgrid can be seen after 3-phase fault and 1-phase earth fault at the end of feeder 1_2 in islanded microgrid, when the battery storage converter is hysteresis controlled. Also phase voltage waveforms in the connection point of battery storage converter during 1-phase earth fault at the end of feeder 1_2 are shown in Fig. 2c.



(a)

(b)

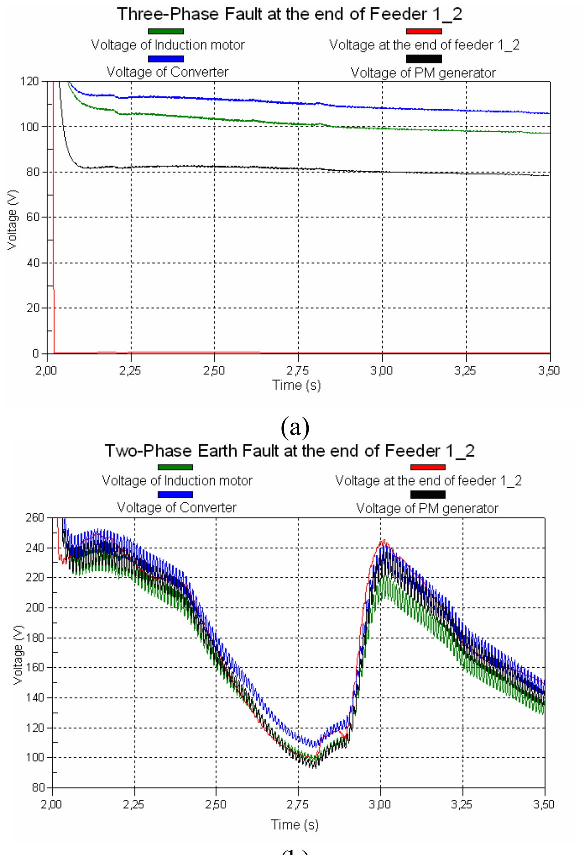
(c)

Figure 2. Voltage RMS values in microgrid after a) 3-phase fault and b) 1-phase earth fault at the end of feeder 1_2 in islanded microgrid ,when the battery storage converter is hysteresis controlled. c) Phase voltages in the connection point of battery storage converter during 1-phase earth fault at the end of feeder 1_2.

Voltage RMS values are usually lower at that feeder where the fault occurs. However, from Fig. 2b we can see that in this case (1-phase earth fault), because of the large fault current fed by PM converter at the faulted feeder when compared to hysteresis controlled converter at the other feeder, the voltage RMS value at the connection point of PM generator was higher than at the connection point of battery storage converter in faults other than 3-phase fault (Fig. 2a) at the feeder 1_2. Fault type (1-phase earth fault shown in Fig. 2c) can be clearly seen from voltage waveforms at connection points of DG units.

Battery storage converter PWM controlled

When the battery storage converter is PWM controlled, the voltage RMS values in microgrid after 3-phase fault and 2-phase earth fault at the end of feeder 1_2 in islanded microgrid are presented in Fig. 3.



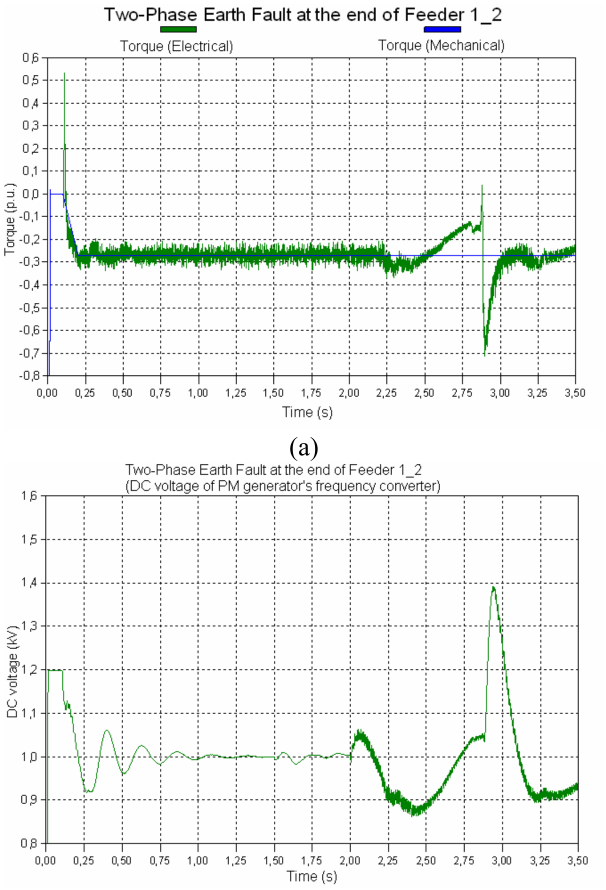
(a)

(b)

Figure 3. Voltage RMS values in microgrid after a) 3-phase fault and b) 2-phase earth fault at the end of feeder 1_2 in islanded microgrid,when the battery storage converter is PWM controlled.

Voltage RMS values are in this case lower, when the battery storage converter is PWM-controlled like the grid converter of the PM generator, at that feeder where the fault occurs regardless of the fault type (Fig. 3). In Fig. 3b one can see the fluctuation in voltages after the 2-phase earth fault in the islanded microgrid.

The reason for this fluctuation is shown in Fig. 4a and 4b drawn from the same simulation as in Fig. 3b (2-phase earth fault at the end of feeder 1_2). The malfunction of the torque control (Fig. 4a) led to fluctuation in dc-link voltage of the frequency converter (Fig. 4b) and through that also the microgrid voltages fluctuated. It delays the fault locating until the control and fluctuation settles down. This is one reason why distortion of voltage and current should be kept in certain limits with proper sizing of converter filters and possibly also with higher converter switching frequencies during islanding of microgrid.



(a)

(b)

Figure 4. a) Torque of PM generator and b) dc-link voltage of the frequency converter during 2-phase earth fault at the end of feeder 1_2.

CONCLUSIONS

Usually voltage RMS values are lower at that feeder where the fault occurs. However, in simulations when fault was at feeder 1_2 and master unit converter was hysteresis controlled the fault location detection was not that straightforward (despite in 3-phase fault). In these simulations the voltage is higher at the faulted feeder which is a result from the fault behavior of different converter control methods. While the hysteresis current controlled converter at the healthy feeder 1_1 fed same amount of current to microgrid before and after fault due to the control method of it, the PWM controlled grid converter of PM generator at the faulted feeder 1_2 tried to fed same amount of power to microgrid before and after fault and so as a result of this control method the current fed by the grid converter of PM generator increased rapidly after the fault. Because of the large fault current fed by PM converter at the faulted feeder when compared to converter at the other feeder, the voltage RMS value at the connection point of PM generator was higher than at the connection point of battery storage converter in faults at the feeder 1_2 (but not in 3-phase fault).

Based on simulations one can conclude that fault location detection based on voltage RMS values at the connection points of DG units within islanded microgrid can be done, if the control principle of all converters is same with each other (e.g constant current or power). Also filters and switching frequencies must be chosen so that voltage waveform of islanded microgrid is good enough to ensure the stable operation of converter controller under sudden changes. From islanded microgrid protection point of view there is urgent need to set standards and other regulations for converters fault behavior.

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