Safety Analysis of a MicroGrid

N Jayawarna, N Jenkins, M Barnes, M Lorentzou, S Papthanassiou and N Hatziagyriou

***Abstract*—MicroGrids are attracting substantial interest because they have the potential to increase the use of renewable generation and micro-CHP. They can also defer investment in distribution capital plant and can improve local power quality. However the primary operational requirement of power systems is that they must operate safely from a user point of view, even during contingencies. Yet electrical safety of MicroGrids has received little attention to date.**

This paper addresses this important area. The fault current distribution in a generic MicroGrid is investigated for different fault contingencies during grid-connected and islanded operation. Based on an extensive investigation of earthing systems, a grounding electrode system is then developed for the MicroGrid study case so that safe step and touch potentials are obtained.

I. Introduction

INTEREST in development of distributed generation has shown significant increase recently. Formation of MicroGrids is proposed as an evolutionary step of promoting the widespread use of distributed generation. A MicroGrid consists of a cluster of power electronic based micro-sources connected at distribution level, providing both heat and power to its local loads [1]. Some form of energy storage is usually required.

A MicroGrid aims to bring value to both the utility and the customer [1-3]. A MicroGrid appears as a single controlled system to the wider power system without any negative electrical impact on the distribution grid. Deferment of network investment, offsetting the need for new generation, reduction of congestion in the transmission system, and local voltage support are some of the MicroGrid benefits offered to the power system. From the customer point of view, improved power quality, enhanced local reliability and reduction in Customer Minutes Lost (CML) makes the MicroGrid a very attractive option. MicroGrids could also help governments achieve their environmental targets due to integration of renewable sources and heavy emphasis on the use of small-scale Combined Heat and Power (µCHP).

The National Technical University of Athens (ICCS/NTUA) have defined a benchmark model for a MicroGrid as shown in Fig. 1. The MicroGrid is connected to the main distribution network through a transformer rated at 400kVA and a single feeder with micro-sources (micro-turbine, wind turbine, PV, fuel cell) and loads (3-phase and 1–phase) is shown. A flywheel is connected as the energy storage of the system.

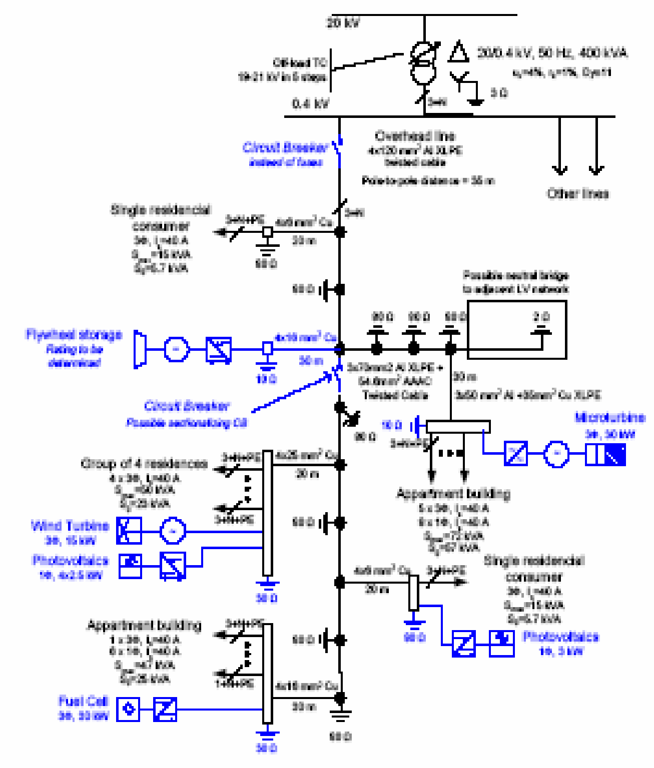

Fig. 1. NTUA benchmark model of a MicroGrid

Electrical safety of a MicroGrid is an overriding operational requirement and its earthing and protection are critical. A MicroGrid is subject to the same safety requirements as a conventional utility power system. Therefore the neutral earthing of the MicroGrid is discussed and its safety is analysed by calculating step and touch potentials.

II. Earthing of a MicroGrid

A fault in a MicroGrid may generate substantial ground potential rise, even if the energy sources operate at low voltage. Thus grounding of the distributed energy sources and the transformer connecting the MicroGrid to the utility network must be carefully analyzed and appropriate rules need to be developed. Also the earthing system of a MicroGrid must be able to deal with both interconnected and islanded operation.

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Low voltage (LV) earthing systems are defined according to the earthing techniques of the secondary of the MV/LV transformer (supply source) and the installation frames. LV neutral earthing is broadly categorized in to three types: TT, IT and TN [4]. In a TT system both the transformer neutral and the frame are earthed. An IT system has an unearthed transformer neutral and an earthed frame. The transformer neutral is earthed and the frame is connected to the neutral in a TN system. TN-C, TN-S and TN-C-S are three sub-systems within TN. In TN-C systems, neutral and protective functions are combined in a single conductor (PEN- Protective Earthed Neutral) throughout the system. A TN-S system has separate neutral and protective conductors all over the system. In a TN-C-S system, the supply has TN-C configuration while the arrangement in the installation is TN-S.

The LV neutral methods differ globally. TT is the most common system while TN is used mainly in Anglo-Saxon countries. IT is mainly used when continuity of service is essential (hospitals) or due to geographical reasons (Norway). The primary factors to be considered when selecting the MicroGrid earthing are: the existing practice in the country, the legislations to be adhered to and the MicroGrid customer requirements.

A TT system is the most common and simplest to implement. The utility companies made use of the underground metallic gas and water pipe network to earth the customer installations. Since these metal pipes are increasingly being replaced by plastic, individual earthing conductors have to be provided at each customer. This has led many countries to switch over from TT to TN system recently. A TN system provides a low impedance return path for fault currents (PEN conductor) and could be operated with simple overcurrent protection. However due to the fact that the source ground and the customer installation grounds are interconnected, faults at a higher voltage level may transfer to the LV gird and also a LV network fault could cause touch voltages at other customers. Based on these considerations, TN-C-S is determined to be the first choice for MicroGrid earthing and the second choice would be TT, Fig 2.

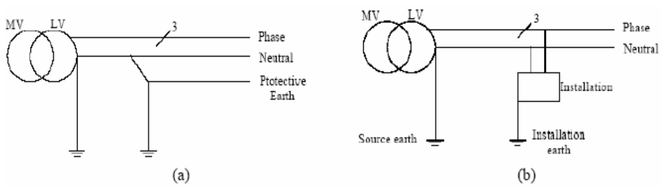

Fig. 2. Proposed earthing systems for a MicroGrid.
(a) TN-C-S system, (b) TT system

The IT system was eliminated as a probable candidate for the MicroGrid earthing as it is so rarely used in practice. Therefore further investigation is carried out only on TN-C-S and TT systems.

III. FAULT CURRENT DISTRIBUTION

Step and touch potentials determine the safety of personnel. These voltages are directly proportional to the magnitude of the fault current component discharged into the soil by the grounding network. It is therefore important to study the fault current distribution in the system. Fault current distribution between the neutral and the ground and their magnitudes depend on the earthing system, the fault location and the operating mode of the MicroGrid (grid-connected or islanded).

A. Study system

A simple MicroGrid system derived from the NTUA benchmark model in Fig. 1 is used for the simulation study. This consists of a single aggregate micro-source and a single load, Fig. 3.

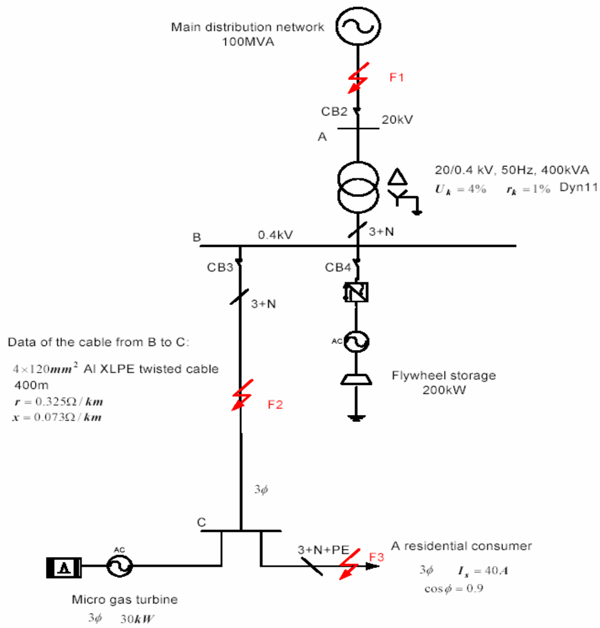

Fig. 3. Reduced model of a MicroGrid used in the study

Three levels of faults could occur in a MicroGrid network: a fault on the main distribution network (F1), a fault on the MicroGrid network (F2) and a fault at a load (F3). If a fault occurs on the main distribution network (F1), the MicroGrid will continue to operate in an island. The 20/0.4 kV distribution transformer secondary is earthed and this earth resistance is equal to a typical value of 3Ω. It is assumed that the MicroGrid would be disconnected from the main grid by opening the circuit breaker upstream of the main distribution transformer (CB2 in Fig. 3), thus retaining the transformer neutral earth in islanded operation. The flywheel is connected to the 0.4kV bus bar and it is considered as the main fault current source in the event of a fault in an islanded MicroGrid. It is presumed that the flywheel provides either 3 per unit or 5 per unit of its rated current under fault conditions in islanded operation only.

A single phase to ground fault is simulated at these three locations in grid-connected operation and islanded operation. The specialist grounding software, CDEGS (subsystem SPLITS) is used for the computer modeling.

B. Simulation results

The fault current magnitude simulation results are given in Table 1. The fault current magnitudes have also been manually calculated using sequence networks.

TABLE I
FAULT CURRENTS IN A MICROGRID

Operating mode	Earthing system	Fault type	Total Fault current (A)		CDEGS results	
			CDEGS simulation result	Manually calculated value	Total earth current	Neutral current
Grid connected	TN	F1	3,073	3,073	-	-
	TN-C-S	F2	14,828	14,778	0	14,828
		F3	858	864	8.7	850
	TT	F2	17.8	17.7	17.8	0
		F3	17.6	17.5	17.6	0
Islanded (3 pu flywheel current)	TN-C-S	F2	889	887	0	889
		F3	452	452	4.6	452
	TT	F2	17.4	17.6	17.4	0
		F3	17.3	17.2	17.3	0
Islanded (5 pu flywheel current)	TN-C-S	F2	1462	1458	0	1462
		F3	558	557	5.7	552.8
	TT	F2	17.5	17.5	17.5	0
		F3	17.4	17.3	17.4	0

As expected fault currents in the TN system are high due to the low impedance of the fault loop impedance (the fault return path being the neutral conductor) and only a small fraction of the current is directed in to the earth. The fault current values in a TT system are very low compared to TN systems, due to the high earthing impedance in the fault loop and the total fault current flows into the earth.

IV. STEP AND TOUCH POTENTIALS AND GROUNDING SYSTEM DESIGN

Potential gradients will be produced within and around a substation due to the flow of current into the earth during ground fault conditions. Touch voltage and step voltage could be used to evaluate the safety and adequacy of the design. ANSI/IEEE Standard 80-2000 [5] defines the touch voltage as “the potential difference between the GPR and the surface potential at the point where a person is standing while at the same time having a hand in contact with a grounded structure”. Step Voltage is defined as “the difference in surface potential experienced by a person bridging a distance of 1m with the feet without contacting any grounded object”.

A. Grounding system design

After reviewing a few designs, the following ground system shown in Fig. 4 is proposed for a MicroGrid.

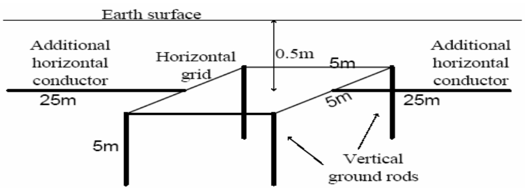

Fig. 4. Proposed grounding system for the MicroGrid

B. Performance analysis of the Grounding system

The MALZ sub-system of CDEGS is used for this study. A uniform soil model with a soil resistivity of 100 Ωm is assumed. A methodology of determining maximum acceptable values for touch voltage and step voltage is provided in [5]. The actual step and touch voltages in and around the substation (for prospective earth fault currents) are evaluated using MALZ in order to ensure that they are within safe limits. The safety limits for touch and step voltages are 160.3 V and 225.3 V respectively. The actual touch and step voltages around the grounding system are shown in Fig. 5 and Fig. 6.

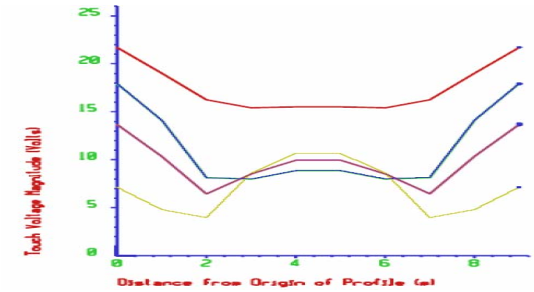

Fig. 5. Touch voltages around the ground system

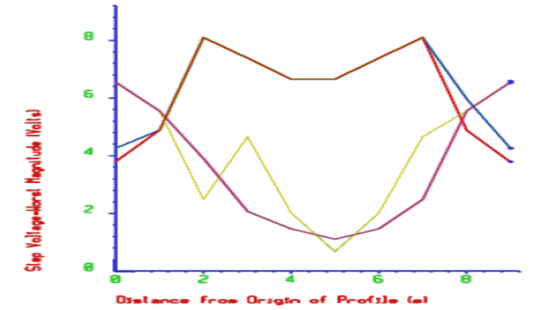

Fig. 6. Touch voltages around the ground system

The maximum touch voltage within the substation is approximately 11V while the maximum step voltage is around 8V at the corners of the grid. The touch and step voltages are considerably higher outside the substation, but still well below the maximum allowable voltages. Therefore the proposed ground system complies with the safety requirements.

V. CONCLUSION

The paper will provide an overview of the earthing system requirements of a MicroGrid. The final paper will include further discussion of the design and system requirements as well as further results.

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