Reliability evaluation of mini-grids considering protection issues

M. Riou[1,2,3]
F. Dupriez-Robin[2], D. Grondin[3], C. Le Loup[1], M. Benne[3], Q. T. Tran[2],
Entech Smart Energies[1] / CEA Tech[2] / LE2P Energy Lab[3]
69 avenue des sports, 29000, Quimper, France
Phone: +33 7 80 51 65 06
E-mail: mael.riou@entech-se.com
Website: https://entech-se.com/
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Mini-grids are in considerable expansion in rural areas of developing countries. They have the potential to provide electricity to millions of people and the use of renewable energy resources provide valuable benefits in terms of cost and environmental impact [1]. However, without a possible connection to the national grid, these power systems are fragile and can encounter frequent interruptions if not designed properly.

Protection schemes of rural mini-grids are usually based on conventional overcurrent devices. An important criterion to take into consideration when designing protection is the level of short-circuit current available from generating sources. The ability of renewable resources, such as PV and wind generators, to feed short-circuit currents is very limited since they are interfaced through power electronic converters with current limiters. A large integration of these power electronics interfaced sources will lead to protection issues. For mini-grids, reliability analysis is often restricted to evaluating generation adequacy. Few researchers have attempted to consider protection schemes when evaluating reliability of power systems [2].

This research paper presents a method developed as part of a PhD collaboration between the company Entech Smart Energies and the research laboratories LE2P Energy Lab and CEA Tech. The method is based on a dynamic simulation of the mini-grid to predict operational conditions (cf. Table 1) and evaluate the reliability of the protection scheme. Two causes of protection failure are investigated:

- Protection insensitivity in case of insufficient short-circuit level to trip protection devices
- False tripping

The first failure mode occurs when short-circuit current is lower than the protection trigger and will lead to a selectivity issue as a total blackout may be encountered when only part of the mini-grid is meant to be disconnected. The second failure mode occurs when normal operation current is higher than the protection trigger and consumers are disconnected, although the network is in a healthy condition. A simple test system including photovoltaic arrays (PV), diesel generators (DG), and electrical storage (ESS) is presented in Figure 1. **Figure 15** shows how the two failure probabilities are evaluated. The protection trigger current is modelled with a normal distribution around the mean setting value to consider tripping error, line currents during normal operation are obtained through load flow simulation and short circuit currents are calculated according to IEC 60909.

Operating conditions 1 & 2 where the mini-grid is solely fed by power converters are critical in terms of short-circuit current level and have a high risk of insensitivity as shown in Figure 2. False tripping also represents an important risk if insufficient margin is taken in setting protections.

When integrated in the design phase, this method can help developers size generation and conversion for a secure operation of the mini-grid.

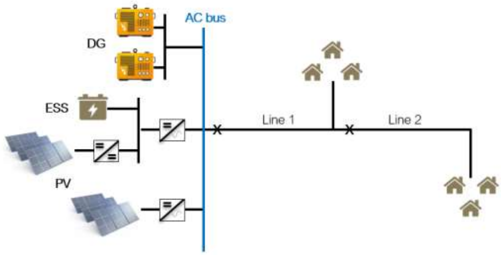

Figure 14: Mini-grid test system

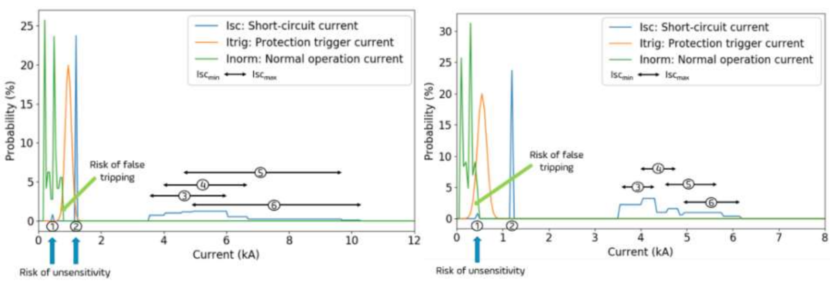

Figure 15: Illustration of protection failure probabilities for distribution line 1 (left-hand graph) & distribution line 2 (right-hand graph)

Table 1: Explanation of operating conditions numbered in Figure 2

Operating condition	Percentage of occurrence (%)	GE1	GE2	Battery inverter	PV inverter
1	0.8	-	-	√	-
2	23.7	-	-	√	√
3	35.8	√	-	√	-
4	15.9	√	-	√	√
5	14.4	√	√	√	-
6	9.4	√	√	√	√

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