



A short communication to define the overcurrent protection system of the CIGRE European benchmark distribution networks for RES penetration studies

J. M. Maza-Ortega¹ · F. J. Zarco-Soto¹ · S. Gkavanoudis² · D. Tampakis² · C. Demoulias²

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Abstract

The use of clean energies in distribution networks is an unstoppable trend which has a significant positive impact on the progressive power system decarbonization. However, it has to be considered that conventional distribution systems have been designed to operate as passive networks. Therefore, a massive penetration of distributed generation may create several operational problems, such as malfunction of the protection systems, which may limit the deployment of this technology. The analysis of these limitations by means of representative benchmark networks is of utmost importance. Most of the proposed benchmark networks proposed so far, however, lack of information about their protection system. To overcome this shortcoming, this letter specifies the protection system of the benchmark European distribution networks proposed by the CIGRE Task Force C06.04.02 for this purpose. In this way, this letter facilitates the analysis of the possible impact that renewable energy sources may have in the distribution system protections.

Keywords Distribution networks · Protection systems · Renewable generation

1 Introduction

Traditional low voltage (LV) and medium voltage (MV) distribution systems are planned and operated in a radial manner to provide the energy to passive customers. Taken into account this operation, the power flows from the primary substations to the end users in an unidirectional manner [1]. The protection philosophy of this distribution system is extremely simple, being required just overcurrent protections to detect and isolate short-circuit faults. Circuit breakers, located at the primary substation, and fuses are used for MV and LV grids, respectively, most of the cases. However, this distri-

bution paradigm is evolving with the advent of distributed renewable energy sources (DRES) which is key for achieving a progressive decarbonization of the power system generation mix. The impact that a massive DRES penetration may have is usually analyzed by suitable benchmark networks representing real-world cases. Some institutions and working groups have shed light on this issue proposing different distribution benchmark networks. The Test Feeder Working Group of the IEEE PES Distribution System Analysis Subcommittee made publicly available a wide range of distribution test feeders which are summarized and reviewed in [2,3]. In addition, EPRI developed two sets of distribution feeder models that are representative of actual small- to large-scale distribution networks [4,5]. The Pacific Northwest National Laboratory introduced a taxonomy of prototypical radial distribution feeder models [6,7] to facilitate the analysis of the upcoming smart grid technologies [8]; the Pacific Gas and Electric Company and the California Energy Commission provided 12 prototypical feeders developed through a cluster analysis [3,9]. The Joint Research Center of the European Commission published a technical report with the most comprehensive data collection of the European distribution systems so far [10]. Similarly, the CIGRE Task Force C6.04.02 [11] presented a comprehensive set of test systems

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✉ J. M. Maza-Ortega
jmmaza@us.es

¹ Department of Electrical Engineering, Universidad de Sevilla, Camino de los Descubrimientos s/n, 41092 Seville, Spain

² Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Building D, University Campus, 54124 Thessaloniki, Greece

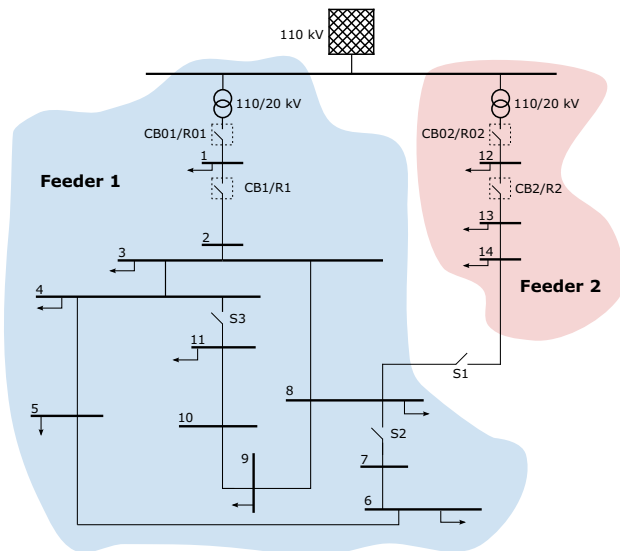


Fig. 1 CIGRE MV distribution network

Table 1 Parameters used for defining the protection settings of the MV distribution system

Circuit breaker	I_{lth}, I_{tr} (A)	I_{sc-3P}^{max} (kA)	I_{sc-3P}^{min} (kA)	I_{sc-1P}^{min} (kA)
R1, R01	285, 722	2.730 (N1)	1.089 (N7)	839 (N7)
R2, R02	276, 722	2.553 (N12)	1.818 (N14)	1.244 (N14)

in an attempt to facilitate the analysis and validation of novel techniques and methods, aiming at the DRES integration in an efficient and economic way.

All these benchmark networks allow performing a wide spectrum of studies including major areas such as operation and control [12], planning and design [13], power quality [14], stability issues [15] and short-circuit fault analysis [16]. Most of them, however, lack of any information of their protection system being, therefore, impossible to analyze the impact of DRES penetration on this essential grid component. Note that system protection with a massive DRES integration is a conspicuous issue because these generation units must possess fault ride-through capability. This behavior may interfere the adequate performance of the protection system, usually designed assuming a passive network hypothesis [1], which might pose limits to the DRES hosting capacity of distribution grids.

The aim of this letter is to fill this gap, similarly than [17], by proposing an off-the-shelf overcurrent protection system for the CIGRE Task Force C06.04.02 MV and LV benchmark distribution networks extensively used for the analysis of DRES penetration. In this way, it should be possible to analyze the impact that a massive DRES penetration may have on the actual protection systems of the distribution grid.

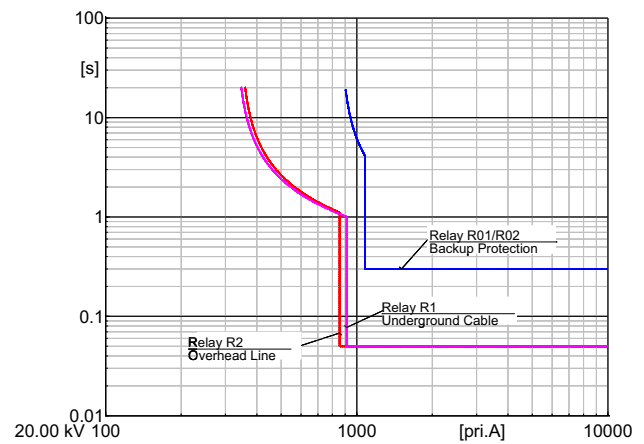


Fig. 2 CIGRE MV network: feeder protection curves

2 CIGRE TF C06.04.02 MV benchmark network

2.1 Network description

This benchmark system is the reduced version of a MV network in southern Germany and is representative of the typical European MV distribution. As depicted in Fig. 1, it is composed of 14 nodes divided into two 20-kV feeders, where residential, industrial and commercial loads are connected. Three isolation switches (S1, S2 and S3) allow to reconfigure the network topology. All the network details are included in [11].

2.2 Protection system design

The MV system is protected through a circuit breaker at each feeder header (R1 and R2) and the corresponding back-up circuit breakers (R01 and R02) in the MV side of the HV/MV transformers as depicted in Fig. 1. The protection system is designed according to the guidelines provided in [18,19] and considering a passive network behavior. For this purpose, the relevant short-circuit currents are calculated using DIgSI-LENT PowerFactory 2020 SP3 according to the standard IEC60909. Table 1 summarizes the obtained results including in brackets the corresponding node where the short-circuit fault is computed.

The relay settings are summarized in Table 2 according to:

$$I_{FSC} = \max[1.5I_{lth}, \min(0.9I_{sc,min-3P}, 3.0I_{lth})] \quad (1)$$

$$I_{BSC} = \max[1.5I_{tr}, \min(0.9I_{sc,min-3P(all)}, 3.0I_{tr})] \quad (2)$$

where I_{FSC} and I_{BSC} are the short-circuit settings (ANSI 50) of the main feeder and back-up protection relays, respectively, I_{lth} is the feeder rated thermal current, $I_{sc,min-3P}$ is the

Table 2 Definition of the protecting devices for the MV distribution system

Circuit breaker	I_{cs} (kA)	ANSI 51	ANSI 50	ANSI 50N	
		I_{OC} (A)	I_{SC} (A)	Delay (ms)	Delay (ms)
R1	12.5	342	855	50	85
R2	12.5	331	828	50	85
R01, R02	12.5	866	1083	300	215

Fig. 3 LV CIGRE benchmark distribution network

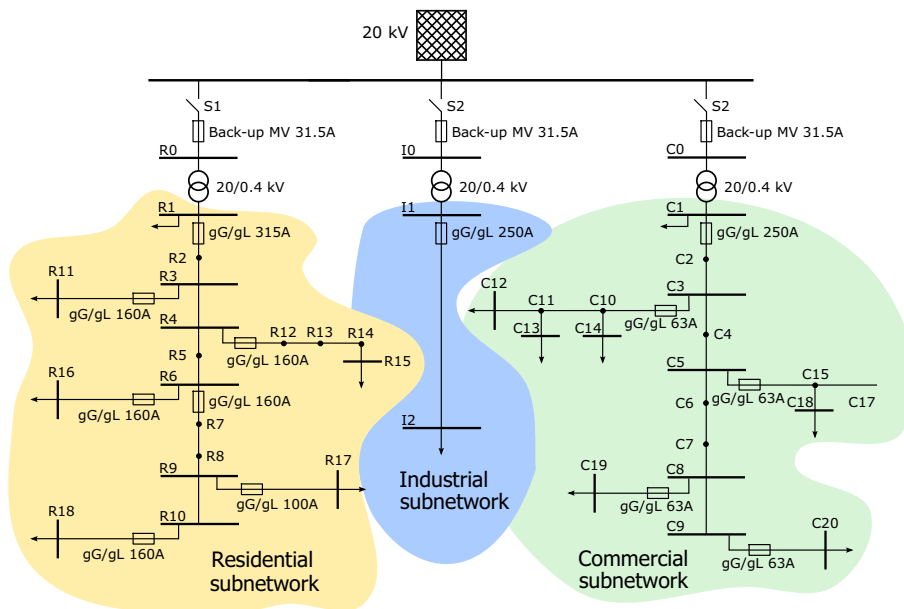


Table 3 Fuses used for protecting the feeders, short-circuit currents and fusing times

Branch	I_z (A)	I_n (A)	I_{sc}^{max} (kA)	t_c^{max} (s)	t_f^{max} (s)	I_{sc}^{min} (kA)	t_c^{min} (s)	t_f^{min} (s)
<i>Residential subsystem</i>								
R1–R6	435	315	16.85	1.74	< 0.01	3.48	40.05	0.66
R6–R10	435	160	5.64	15.29	< 0.01	2.08	111.47	0.06
R3–R11	180	160	9.72	0.22	< 0.01	3.44	1.77	< 0.01
R4–R15	180	160	7.86	0.10	< 0.01	1.15	17.71	0.56
R6–R16	180	160	5.64	0.10	< 0.01	2.29	3.98	0.04
R9–R17	180	100	3.93	0.10	< 0.01	1.72	7.07	0.02
R10–R18	180	100	3.57	0.10	< 0.01	1.59	8.29	0.02
<i>Industrial subsystem</i>								
I1–I2	330	250	5.47	6.58	0.02	1.90	56.94	0.84
<i>Commercial subsystem</i>								
C1–C9	275	224	10.57	0.32	< 0.01	1.11	29.00	3.80
C3–C12	88	63	4.56	0.08	< 0.01	1.06	1.64	0.01
C5–C17	88	63	2.81	0.23	< 0.01	0.87	2.43	0.02
C8–C19	88	63	1.77	0.57	< 0.01	0.94	2.08	0.02
C9–C20	88	63	1.58	0.75	< 0.01	0.86	2.51	0.02

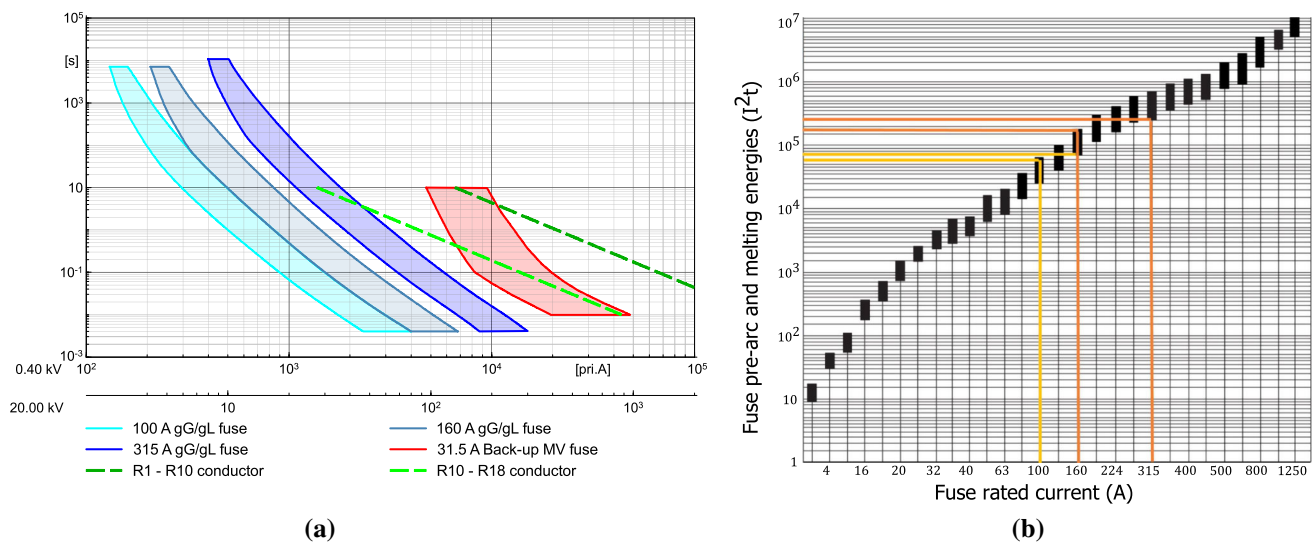


Fig. 4 Residential feeder path R1–R6–R10–R18: **a** fuse and cable damage I - t curves; **b** Pre-arc and melting energy of the selected fuses

feeder minimum short-circuit current, I_{tr} is the transformer rated current and $I_{sc,min-3P(all)}$ is the minimum short-circuit current of all feeders connected to the transformer. Table 2 also includes the rated short-circuit breaking capacity (I_{cs}) which must be higher than the corresponding maximum short-circuit current detailed in Table 1. Time settings of the feeder protection relays are set to 0 (50–60 ms circuit breaker opening time). Conversely, back-up protection is by definition slower than the main feeder protection due to selectivity reasons. Hence, the time settings for the back-up protection are set to 300 ms in order to ensure graduation between main and back-up protections. The over-current protection (ANSI 51) is designed considering that in the case of MV networks the actual loads are unknown. For this reason, the relay pick-up currents are set to 1.1–1.2 times the line rated current and transformer rated current for the main feeder and back-up protections, respectively. Figure 2 represents the I - t curves of these relays, where it can be observed the selectivity of the main and back-up protections.

Finally, regarding the instantaneous ground fault protection (ANSI 50N), it has been set to about 30% of the rated line current and rated transformer current for the main feeder and back-up protections, respectively.

3 CIGRE TF C06.04.02 LV benchmark network

3.1 Network description

The LV system represents a real three-phase four-wire network with three feeders supplying residential, commercial and industrial loads as shown in Fig. 3. The rated voltage is 400 V, and each subsystem is connected to a 20-kV MV

network through different 20/0.4 kV transformers. All the network data are available in [11].

3.2 Protection system design

The protection system is based on fuses as shown in Fig. 3 complying with [20] and dimensioned according to [21]. Note that the network laterals are protected by their own fuses because the corresponding cables have a lower cross section than the main feeder one. Table 3 contains all the data of the selected fuses with indication of the feeder rated current, I_z , rated fuse current, I_n , and the analysis of the protection for the maximum and minimum short-circuit currents. These have been computed using DIGSILENT PowerFactory 2020 SP3 according to the standard IEC60909. Maximum short-circuit currents, I_{sc}^{max} , correspond to a three-phase fault at the node where the fuse is installed. Conversely, minimum short-circuit currents, I_{sc}^{min} , are computed for a single-phase to ground fault at the farthest node of the fuse-protected branch. The melting times for the maximum and minimum short-circuit currents, t_f^{max} and t_f^{min} , as well as the cable damage time for these currents, t_c^{max} and t_c^{min} , are detailed. Note that an adequate protection is achieved as the melting times are always lower than the cable damage times for both maximum and minimum short-circuit currents.

The MV fuses are detailed in Table 4. However, the back-up protection provided by these MV fuses is quite limited because the minimum short-circuit currents within the LV distribution system can be really low. As a matter of fact, the MV fuses are selected to protect the network in case of a three-phase short-circuit fault in the secondary side of the MV/LV transformer.

Table 4 Back-up MV fuses

Transformer	I_n (A)
Residential subsystem	31.5
Industrial subsystem	16
Commercial subsystem	20

Finally, and in order to evidence the selectivity between the selected fuses, Fig. 4a shows the $I-t$ curves of the fuses installed in the residential subsystem to protect the path comprising the branches R1–R6, R6–R10 and R10–R18. In this case, the length of the main feeder is longer than the critical distance, i.e., the distance where the minimum short-circuit melts the fuse in 5 s. Therefore, the feeder is divided into two sections (R1–R6 and R6–R10) protected by a 315 A and a 160 A fuse, respectively, whereas the lateral (R10–R18) is protected by a 100 A fuse. It is important to note that the selectivity is guaranteed if the melting energy (I^2t) of the downstream fuses is lower than the pre-arc energy of the upstream ones. This is represented in Fig. 4b where the I^2t ranges for the normalized gG/gL fuses are shown. The lower and upper values of each bar correspond to the pre-arc energy and melting energy, respectively. Therefore, and according to Fig. 4, the selected fuses in the analyzed path of the residential sub-network verify the selectivity criterion.

4 Conclusions

This letter has defined an off-the-shelf overcurrent protection system for the CIGRE Task Force C06.04.02 European distribution networks which are extensively used for the analysis of DRES penetration. The letter contributes on setting a common base for the researchers dealing with DRES integration to extent their analysis with issues related to the protection systems.

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