RELIABLE PROTECTION SYSTEMS FOR LOCALLY SUPPLIED MV DISTRIBUTION NETWORKS

Fabio BIGNUCOLO
Andrea SAVIO
Massimiliano COPPO
Roberto TURRI
University of Padova – Italy
fabio.bignucolo@unipd.it

Alberto CERRETTI
Roberto CALONE
e-distribuzione – Italy
alberto.cerretti@e-distribuzione.com

ABSTRACT

Under emergency conditions portions of MV networks can be locally supplied for a significantly long time period by moveable generating units connected to the LV side of a standard distribution transformer, which in this case operates as a step-up transformer. It is therefore necessary to ensure a proper operation which must include the detection of any possible faulty condition.

When the MV network portion is operated with isolated neutral (as it is usually the case), a reliability issue arises for earth faults detection by the protection system, due to the negligible capacitive fault current values. In this work, possible detection methods are identified through analytical and numerical simulations and two promising solutions are proposed, i.e., the intentional earthing of one phase conductor and the connection of a suitable neutral forming transformer with earthed neutral terminal, both operated at the MV side of the MV/LV transformer.

INTRODUCTION

Due to Regulator's orders in Italy it is required to contain the duration of long interruptions of power supply, both in case of accidental faults as well as of scheduled interruptions. In the latter case, a portion of the MV network can be supplied by movable Generation Units, usually connected to the LV side of a distribution MV/LV transformer, located either in a substation (rated power up to 630 kVA) or on poles (rated power usually up to 160 kVA). In case of larger Gen-set units a proper LV/MV transformer can be installed in the shelter, whose MV terminals are directly connected to the MV feeder phases. Furthermore, alternative methods based on renewable energy sources and storage systems could be implemented to cope with such emergency conditions [1][2][3][4]. As this emergency supply may last for many hours (or days), a reliable protection system is of paramount importance, in particular against phase-to-earth faults, whose detection may be critical in small and isolated neutral operated networks.

Up to now, as this need was not mandatory and the performance of existing protection system under such emergency conditions was not deeply investigated, maximum residual voltage protection ANSI 59V_0 was usually adopted; alternatively, a maximum residual current protection ANSI 51N was also considered (or their combination, i.e. a directional residual current protection ANSI 67N). Indeed, Italian MV networks are operated with isolated neutral or, even in the most common situation (i.e. compensated neutral) the Petersen coil is not connected to the electric system under consideration (since it is connected to MV busbars in the HV/MV stations, therefore disconnected during the islanded operation). Consequently, the fault current path consists of the earth capacitances, which offer a high impedance value, even in case of a feeder overall length of many km. Considering a circuit sequence representation, the zero sequence network is more or less an open circuit, resulting in a zero sequence voltage very close to phase voltage and negligible zero sequence current, no matter the fault resistance value. As a consequence, a 59V_0 protection is prone to nuisance tripping, since it is not possible to tune it correctly and its sensitivity results always much higher than 100 kΩ, whereas 51N or 67N are unable to detect the faulty condition. In order to ensure single phase-to-earth fault detection under such emergency conditions, two alternative reliable protection systems have been defined, with suitable sensitivity (target not lower than 1 kΩ - value considered acceptable in emergency condition, compared with 3-6 kΩ usually guaranteed by MV protections in HV/MV stations) avoiding nuisance tripping (probability very high with sensitivity not lower than 100 kΩ in case of small extension of the overhead feeder islanded operated). The two proposed protection schemes, described in the paper, differs on the way the system is earthed. A parametric analysis has been performed with an ad hoc analytical model implemented in MATLAB to detail the suitable protection technologies, considering different possible scenarios in terms of fault impedance, intentional earthing impedance, generator size and lines length and type. To validate the analytical method, results have been compared with numerical models implemented in other commercial software, such as Simulink and DIgSILENT Power Factory.

PROPOSALS FOR RELIABLE DETENCTION OF FAULT CONDITIONS

Two possible electric schemes are here described, aimed at increasing the fault currents, in case of single-phase-to-earth faults along a MV feeder supplied by a movable LV connected generating unit, in order to ensure a reliable detection.

The first proposed solution consists in earthing one phase conductor through an impedance Z_e (Phase-To-Ground, PTG), on the MV side of LV/MV step-up transformer at the Secondary Substation (SS). A schematic representation for an overhead line is shown in Fig. 1.a, where the fault current I_f path is represented by the dotted red line. Considering a fault occurring along the line between phase *R* and earth (with a fault impedance Z_f), the current I_f flows through the earth from the faulty section *B* to section *A*, where the intentional earthing of phase *T* is represented through the impedance Z_e.

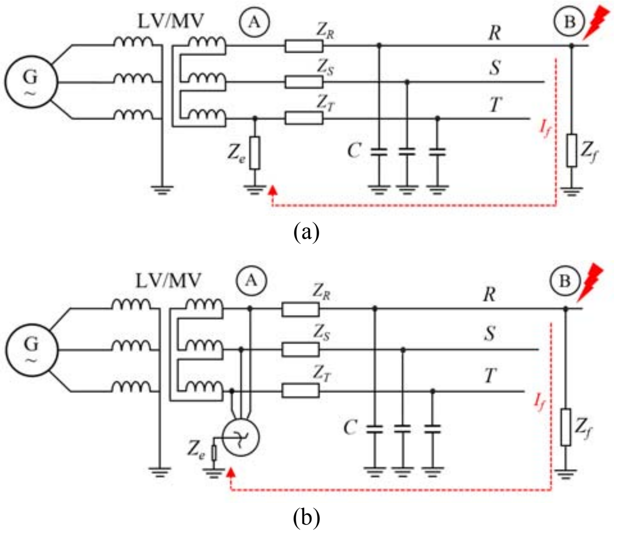
The second proposed solution, depicted in Fig. 1.b, makes use of a Neutral Forming Transformer (NFT) connected to the substation MV busbar, which allows earthing the star point with an impedance Z_e. In this case the earthed NFT is the collecting device for the fault current.

In case MV underground cables are adopted, considering the common solid bonding installation technique and faults occurring between the conductor and the metallic screen, it is possible to assume that the fault current I_f flows along the three screens (one per phase) connected in parallel. In other words, the fault current component flowing through the earth can be neglected since this path is much more resistive than the screens one.

Both solutions are suitable with pros and cons, which need to be assessed on a wide variety of operating conditions, as described in the following.

ANALITICAL MODEL

Discriminant criteria to evaluate and compare the effectiveness of the proposed solutions are: i) the phase currents at the generator terminals and at the NFT neutral connection to earth where protections may be easily installed, to define the protection intervention thresholds; ii) the phase voltages at the fault location (*B*), to verify that no severe over-voltages occurs during the faulty network operation which may results in dangerous insulation damages; iii) the effectiveness of protections in detecting the fault conditions. Depending on the adopted scheme, possible protections are:



(a)

(b)

Fig. 1. Proposed solutions for reliable fault current detection in MV overhead lines with isolated neutral.

- in the PTG case, the ANSI 46 protection (Reverse-phase or Phase-Balance Current Relay) to detect the negative sequence current at the LV generator terminals;
- in the NFT case, the ANSI $59V_0$ (Zero Sequence Overvoltage Relay) and either the ANSI 50 (Instantaneous Overcurrent Relay) or the ANSI 51 (AC Inverse Time Overcurrent Relay) protections, to detect the maximum zero sequence voltage at the transformer MV terminals and the NTF neutral current respectively.

The sub-transient and steady-state regimes (permanent fault) are both investigated. For the scope a suitable analytical model has been implemented in the MATLAB environment, aiming to parametrically study earth fault regimes with varying network parameters.

Symbols meaning is listed below:

• $\underline{I_0}$	is the zero sequence current;
• $\underline{\alpha}$	is the operator $e^{j\cdot 2\pi/3}$;
• $\underline{E}$	is the effective voltage phasor;
• $\underline{Z}_{dA}$	is the positive sequence impedance resulting from the generator and transformer series;
• $\underline{Z}_{iA}$	is the negative sequence impedance resulting from the generator and transformer series;
• $\underline{Z}_{dAB}$	is the line positive sequence impedance;
• $\underline{Z}_{0AB}$	is the line zero sequence impedance;
• U_1	is the transformer LV rated voltage;
• U_2	is the transformer MV rated voltage;
• $\underline{Z}_{0NFT}$	is the zero sequence impedance of the neutral forming transformer.

The model applies to both sub-transient and steady-state regimes, paying attention to consider the relevant generator positive sequence impedance depending on the regime under study, i.e. sub-synchronous and synchronous reactance respectively. Lines and transformer impedances at the negative sequence are considered equal to positive sequence one in all the analysed regimes.

Earthed phase conductor

The double earth fault theory, according to models described in [5][6], results useful to analyse the proposed solution in case of earth faults along the MV line. Since the system is operated with isolated neutral, currents in the earth capacitances and earthing inductors can be generally neglected. In detail, referring to Fig. 1.a, considering a short circuit occurring on phase *R* with a fault impedance Z_f, the analysis under the sequences frame of reference determines the short-circuit current in *B*:

$$\underline{I}_f = 3\underline{I}_0 = \frac{-3\cdot(1-\underline{\alpha}^2)\cdot\underline{E}}{3\underline{Z}_{dA}+3\underline{Z}_{iA}+2\underline{Z}_{dAB}+\underline{Z}_{0AB}+3(\underline{Z}_e+\underline{Z}_f)}\ . \tag{1}$$

Considering the MV/LV transformer as a “Dyn11” transformer (in this case supplied at the LV side), phase currents at the LV side are:

$$\begin{cases} \underline{I}_{LV,R} = -2\dfrac{\underline{I}_f}{3}\left(\sqrt{3}\dfrac{U_2}{U_1}\right) \\ \underline{I}_{LV,S} = \underline{I}_{LV,T} = \dfrac{\underline{I}_f}{3}\left(\sqrt{3}\dfrac{U_2}{U_1}\right) \end{cases} \tag{2}$$

Considering $\underline{Z}_0 = \underline{Z}_{0AB} + 3\cdot(\underline{Z}_e + \underline{Z}_f)$, voltages in B are evaluated as in (3). The analysis may be easily extended to evaluate voltages in A.

$$\begin{cases} \underline{V}_{BR}=\underline{Z}_f\underline{I}_f \\ \underline{V}_{BS}=\underline{Z}_f\underline{I}_f-j\underline{\alpha}\cdot\sqrt{3}E\cdot\left(\underline{\alpha}-\dfrac{3(\underline{\alpha}\cdot\underline{Z}_{dA}+\underline{\alpha}^2\cdot\underline{Z}_{iA})-(\underline{\alpha}^2\cdot\underline{Z}_{dAB}+\underline{\alpha}\cdot\underline{Z}_{dAB}+\underline{Z}_0}{3\underline{Z}_{dA}+3\underline{Z}_{iA}+2\underline{Z}_{dAB}+\underline{Z}_0)}\right) \\ \underline{V}_{BT}=\underline{Z}_f\underline{I}_f-j\underline{\alpha}\cdot\sqrt{3}E\cdot\left(\dfrac{\underline{\alpha}\cdot\underline{Z}_{dAB}+\underline{\alpha}^2\cdot\underline{Z}_{dAB}+\underline{Z}_0}{3\underline{Z}_{dA}+3\underline{Z}_{iA}+2\underline{Z}_{dAB}+\underline{Z}_0}\right) \end{cases} \quad (3)$$

Earthing Transformer

In case of NFT, depicted in Fig. 1.b, the short circuit current can be straightforwardly assessed with (4).

$$\underline{I}_f=\frac{3\underline{E}}{\underline{Z}_{dA}+\underline{Z}_{iA}+2\underline{Z}_{dAB}+\underline{Z}_{0AB}+\underline{Z}_{0NFT}+3(\underline{Z}_e+\underline{Z}_f)} \quad (4)$$

Consequently, phase currents at the LV side are:

$$\begin{cases} \underline{I}_{LV,R}=\dfrac{\underline{I}_f}{3}\left(\sqrt{3}\dfrac{U_2}{U_1}\right) \\ \underline{I}_{LV,S}=-\dfrac{\underline{I}_f}{3}\left(\sqrt{3}\dfrac{U_2}{U_1}\right). \\ \underline{I}_{LV,T}=0 \end{cases} \quad (5)$$

In B, sequence voltages are derived with:

$$\begin{cases} \underline{E}_0=-\dfrac{(\underline{Z}_{0AB}+\underline{Z}_{0NFT}+3\underline{Z}_e)\cdot\underline{E}}{\underline{Z}_{dA}+\underline{Z}_{iA}+2\underline{Z}_{dAB}+\underline{Z}_{0AB}+\underline{Z}_{0NFT}+3(\underline{Z}_e+\underline{Z}_f)} \\ \underline{E}_1=\underline{E}-\dfrac{(\underline{Z}_{dA}+\underline{Z}_{dAB})\cdot\underline{E}}{\underline{Z}_{dA}+\underline{Z}_{iA}+2\underline{Z}_{dAB}+\underline{Z}_{0AB}+\underline{Z}_{0NFT}+3(\underline{Z}_e+\underline{Z}_f)} \\ \underline{E}_2=-\dfrac{(\underline{Z}_{iA}+\underline{Z}_{dAB})\cdot\underline{E}}{\underline{Z}_{dA}+\underline{Z}_{iA}+2\underline{Z}_{dAB}+\underline{Z}_{0AB}+\underline{Z}_{0NFT}+3(\underline{Z}_e+\underline{Z}_f)} \end{cases} \quad (6)$$

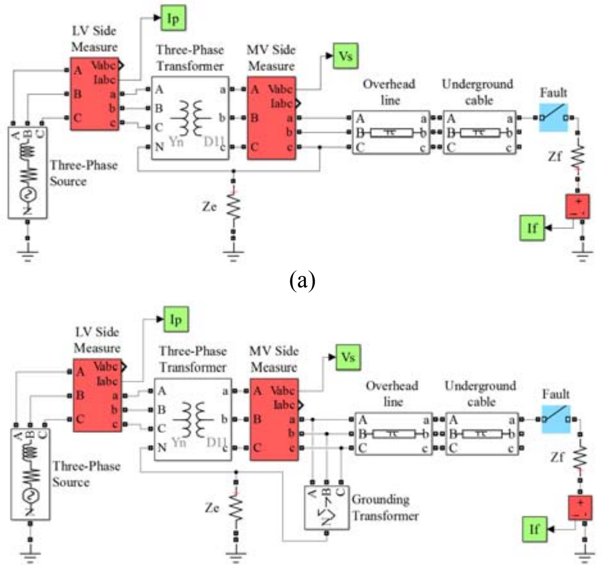
whereas phase voltages are obtained through the Fortescue matrix transformation:

$$\mathbf{V}=\mathbf{F}\cdot\mathbf{E}, \quad \text{where } \mathbf{F}=\begin{bmatrix}1 & 1 & 1\\ 1 & \underline{\alpha} & \underline{\alpha}^2\\ 1 & \underline{\alpha}^2 & \underline{\alpha}\end{bmatrix} \text{ and } \mathbf{E}=\begin{bmatrix}\underline{E}_0\\ \underline{E}_1\\ \underline{E}_2\end{bmatrix}. \quad (7)$$

NUMERICAL MODEL

The steady state model for the first scheme (earthed phase conductor) is simulated according to the Simulink Diagram shown in Fig. 2.a. A *Three-Phase Source* is adopted for the generator model whereas the *Three-Phase Transformer* models the MV/LV transformer. For the simulation of overhead lines and underground cables, two π-section lines are used, each of them implementing a balanced three-phase transmission line model with lumped resistance, inductance and capacitance parameters. In the second model (Fig. 2.b) the phase conductor earthing is substituted by a Neutral Forming Transformer (*Grounding Transformer*) connected to the MV busbar.

The earth fault is applied by the closure of the *Fault* circuit breaker on phase *R*. In the blocks *Ip*, *Vs* and *If* the measures of currents and voltages are stored.



(a)

(b)

Fig. 2. Simulink block diagrams for PTG (a) and NFT (b).

Making use of these two models several earth faults in the range 1-10 kΩ have been analysed aimed at identifying, for each circuit solution, the most suitable protections to be used. In the first scheme a suitable protection consisting in a maximum negative sequence current protection installed at the generator terminals is proposed. Conversely, in the second case, it is possible to protect the network using a maximum current protection (not directional) installed on the neutral connection of the earthing transformer.

CASE STUDY

The effectiveness of the proposed solutions to the fault current detection issue is discussed through a representative study case. Technical specifications of the generator *G*, the transformer *LV/MV* and the lines of the network of Figs. 1 and 2 are reported in Table I. In detail, lines parameters are derived from datasheets, whereas positive, negative and zero sequence impedances are evaluated according to [7] (a solid bonding cable line is considered, i.e. metallic sheaths are earthed at both ends).

Other parameters, such as lines length and fault impedances values vary depending on the considered case. The intentional earthing resistance Z_e is set equal to 10 Ω. Although the parametrical analysis carried out covers a wide range of network operating conditions, for the sake of clarity only a few, yet enlightening, cases are here reported.

Two configurations are compared considering both the PTG and the NFT solutions. In *case a*, a 160 kVA pole transformer with an overhead line is considered and results are reported in Tab. II and Tab. III, for the PTG and NFT solutions respectively. In *case b*, a 400 kVA transformer in a SS supplies an underground cable line (Tab. IV and Tab. V). Results refers to 1 km lines: nevertheless,

Table I. Parameters representing network elements.

G ***(250 kVA)***	Synchronous reactance (x_d)	1.5 [p.u.]
	Sub-transient reactance (x_d'')	0.18 [p.u.]
	Winding resistance (r_G)	$0.15 \cdot x_d''$ [p.u.]
LV/MV TR ***(160 kVA or 400 kVA)***	LV rated voltage (U_1)	0.4 kV
	LV rated voltage (U_2)	20 kV
	Short-circuit voltage ($v_{sc\%}$)	4 %
	No load losses ($p_{0\%}$)	1 %
Overhead lines ***(Al 95/19)***	Direct/inverse impedance (Z_{OH})	$0.385+j \cdot 0.350$ [Ω/km]
	Zero sequence impedance ($Z_{OH,0}$)	$0.456+j \cdot 1.901$ [Ω/km]
Underground cables ***(Al 185 mm²)***	Direct/inverse impedance (Z_{UC})	$0.166+j \cdot 0.115$ [Ω/km]
	Zero sequence impedance ($Z_{UC,0}$)	$1.151+j \cdot 0.477$ [Ω/km]
NFT	Short-circuit impedance ($Z_{SC,NFT}$) per phase	$20+j \cdot 150$ [Ω]

Table II. Aerial OH line (1 km): case of 160 kVA pole transformer (*case a*), with PTG.

	Sub-transient regime					*Steady-state*
	LV generator protections		*MV protections*		*Phase-to-earth voltage*	
Z_f [Ω]	**$I_{max,LV}$ [A]** ANSI 50/51	**$I_{2,LV}$ [A]** ANSI 46	**$V_{0,MV}$ [V]** ANSI 59V_0	**I_f [A]** ANSI 50/51	**$V_{max,MV}$ [V]**	**$V_{max,MV}$ [V]**
1	1,473	736	5,663	25.51	17,210	4,677
10	1,470	735	5,776	25.45	17,323	4,718
100	1,427	713	6,839	24.71	18,380	5,145
500	1,144	572	9,979	19.81	21,249	7,261
1,000	833	416	11,400	14.42	22,088	9,871
5,000	222	111	11,887	3.84	20,989	18,525
10,000	113	57	11,752	1.96	20,539	19,816

Table III. Aerial OH line (1 km): case of 160 kVA pole transformer (*case a*), with NFT.

	Sub-transient regime					*Steady-state*
	LV generator protections		*MV protections*		*Phase-to-earth voltage*	
Z_f [Ω]	**$I_{max,LV}$ [A]** ANSI 50/51	**$I_{2,LV}$ [A]** ANSI 46	**$V_{0,MV}$ [V]** ANSI 59V_0	**$I_{N,NFT}$ =I_f [A]** ANSI 50/51	**$V_{max,MV}$ [V]**	**$V_{max,MV}$ [V]**
1	1,062	613	1,940	36.81	10,742	3,327
10	1,056	610	1,927	36.57	10,823	3,372
100	957	553	1,747	33.15	11,517	3,917
500	518	299	947	17.96	12,231	6,791
1,000	301	174	549	10.42	12,072	9,113
5,000	66	38	120	2.28	11,686	11,481
10,000	33	19	60	1.15	11,619	11,566

simulations demonstrate that no significant differences are appreciable varying lines length within the range 0.3-6 km. Tables report in order: the maximum phase current at the generator terminals ($I_{max,LV}$), the negative sequence current ($I_{2,LV}$), the zero sequence voltage at the transformer MV side ($V_{0,MV}$), the fault current (I_f) and the maximum phase-to-ground voltage ($V_{max,MV}$), both in the sub-transient and steady state regime. These parameter are monitored since allow the fault detection by suitably tuning the protections installed either on the movable generator (PTG) or on the MV busbar (NFT). Maximum phase voltages verify that severe over-voltages do not occur.

Current-based protection systems to detect phase-to-earth faults in a wide range of conditions are demonstrate to be more appropriate than voltage-based protections. In detail, plots of Fig. 3 and Fig. 4 verify the effectiveness of:

- ANSI 50/51 on the negative sequence current magnitude on the transformer LV side for the PTG solution: Fig. 3 shows $I_{2,LV}$ as a function of the fault impedances

Table IV. Underground cable (1 km): case of 400 kVA SS transformer (*case b*), with PTG.

	Sub-transient regime					*Steady-state*
	LV generator protections		*MV protections*		*Phase-to-earth voltage*	
Z_f [Ω]	**$I_{max,LV}$ [A]** ANSI 50/51	**$I_{2,LV}$ [A]** ANSI 46	**$V_{0,MV}$ [V]** ANSI 59V_0	**I_f [A]** ANSI 50/51	**$V_{max,MV}$ [V]**	**$V_{max,MV}$ [V]**
1	1,742	871	5,795	30.18	17,342	4,152
10	1,739	869	5,929	30.11	17,476	4,192
100	1,684	842	7,185	29.17	18,723	4,628
500	1,296	648	10,605	22.44	21,778	6,854
1,000	899	450	11,825	15.57	22,318	9,622
5,000	224	112	11,915	3.89	20,908	18,533
10,000	114	57	11,757	1.98	20,485	19,799

Table V. Overhead cable (1 km): case of 400 kVA pole transformer (*case b*), with NFT.

	Sub-transient regime					*Steady-state*
	LV generator protections		*MV protections*		*Phase-to-earth voltage*	
Z_f [Ω]	**$I_{max,LV}$ [A]** ANSI 50/51	**$I_{2,LV}$ [A]** ANSI 46	**$V_{0,MV}$ [V]** ANSI 59V_0	**$I_{N,NFT}$ =I_f [A]** ANSI 50/51	**$V_{max,MV}$ [V]**	**$V_{max,MV}$ [V]**
1	1,227	708	2,144	42.51	10,560	2,947
10	1,220	704	2,132	42.27	10,538	2,957
100	1,098	634	1,919	38.05	11,278	3,484
500	551	318	963	19.09	12,046	6,545
1,000	310	179	541	10.73	11,930	9,007
5,000	66	38	115	2.29	11,647	11,453
10,000	33	19	58	1.15	11,598	11,549

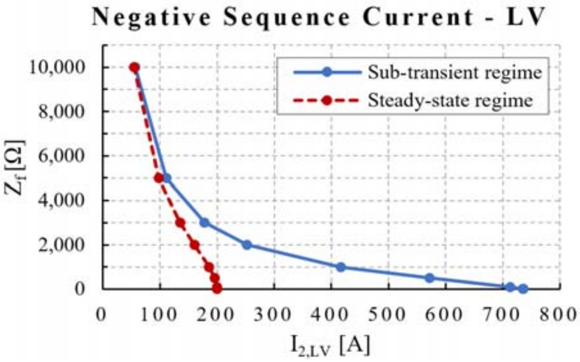


Fig. 3. Correlations between the negative sequence current at the generator terminals and the fault resistance in *case a* with PTG technique.

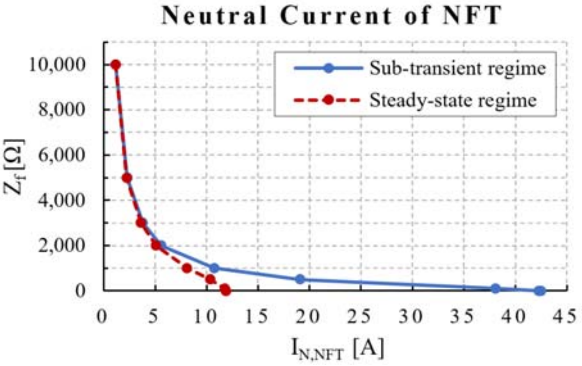


Fig. 4. Correlations between the NFT neutral current and the fault resistance in *case b* with NFT technique.

(considering a Gen-set connected through a 160 kVA pole transformer and a 1 km overhead line);

- ANSI 50/51 on the NFT neutral current for the NFT solution: Fig. 4 shows its magnitude as a function of the fault impedance (considering a Gen-set connected through a 400 kVA distribution transformer and a 1 km underground cable line).

Maximum residual voltage $59V_0$ protection relay, instead, clearly does not appear to be a suitable solution, being its behaviour very close to that referred to insulated neutral operation one.

It should be noted that, even in emergency configurations, distributed generators may entail safety issues [8][9]. To avoid their re-connection to the isolated network portion, a possible solution consists in intentionally operating the network at a frequency lower than the under-frequency threshold of the ANSI 81 relay of interface protection systems.

CONCLUSIONS

Traditionally adopted maximum residual voltage $59V_0$ protection relays are not applicable to small extension MV feeders supplied through a moveable Generator. Indeed, it is also not possible to define a correct regulation in phase-earthed systems, even in case of negligible fault resistance values, over about 500 Ω, considering overall error of the three voltage transducers and of protection relay itself. On the contrary, under the operation condition considered, maximum current protection relays are very effective.

It's worth noting that, although the earthed phase solution gives rise to unbalanced currents distribution and has the inherent criticality of being unable to detect faults occurring on the intentionally earthed phase, it still represents an interesting emergency application for pole transformers, where the connection of a NFT may be an issue (besides being costlier).

However, in case of secondary substations and the local supply is foreseen to last for a significantly long time, the NFT solution, even if more expensive, should be preferred for the higher reliability in detecting faults and for the negligible permanent over-voltages on healthy phase conductors, which may affect negatively, in particular, MV underground cables.

REFERENCES

[1] D. M. Bui, K. Y. Lien and S. L. Chen, "Investigate dynamic and transient characteristics of microgrid operation and develop a fast-scalable-adaptable algorithm for fault protection system," Electric Power Systems Research, vol. 120, 2015, pp. 214-233, DOI: 10.1016/j.epsr.2014.04.003.

[2] F. Bignucolo, A. Raciti and R. Caldon, "A control strategy for the management of islanded networks with renewables and storage systems", *2014 49th International Universities Power Engineering Conference (UPEC)*, Cluj-Napoca, 2014, pp. 1-6, DOI: 10.1109/UPEC.2014.6934752.

[3] F. Bignucolo, A. Raciti and R. Caldon, "Coordinating active and reactive energy balances in islanded networks supported by renewables and BESS", *3rd Renewable Power Generation Conference* (RPG 2014), Naples, 2014, pp. 1-6, DOI: 10.1049/cp.2014.0824.

[4] F. Abusief, R. Caldon and F. Bignucolo, "Remote islanded distribution networks supplied by BESS integrated PV generation units", *2016 IEEE 16th International Conference on Environment and Electrical Engineering* (EEEIC), Florence, 2016, pp. 1-6, DOI: 10.1109/EEEIC.2016.7555634.

[5] International Electrotechnical Commission (IEC), IEC/TR 60909-3 *Short-circuit currents in three-phase a.c systems - Part 3: Currents during two separate simultaneous line-to-earth short-circuits and partial short-circuit currents flowing through earth*, 2003.

[6] R. Roeper, A. Webs, 1985, *Short-Circuit Currents in Three-Phase Systems,* 2nd ed., Siemens Aktiengesellschaft, 77-83.

[7] International Electrotechnical Commission (IEC), IEC/TR 60909-2 *Short-circuit currents in three-phase a.c. systems – Part 2: Data of electrical equipment for short-circuit current calculations*, 2008.

[8] F. Bignucolo, R. Caldon, M. Frigo, A. Morini, A. Pitto and F. Silvestro, "Impact of distributed generation on network security: Effects on loss-of-main protection reliability," *2008 43rd International Universities Power Engineering Conference (UPEC)*, Padova, 2008, pp. 1-5, DOI: 10.1109/UPEC.2008.4651489.

[9] F. Bignucolo, A. Savio, R. Turri and A. Cerretti, "Undesired Islanding of MV Networks sustained by LV Dispersed Generators compliant with present Grid Code Requirements," *2016 51st International Universities Power Engineering Conference (UPEC)*, Coimbra, 2016.