# INFLUENCE OF INVERTER-INTERFACED DISTRIBUTED GENERATION AND ITS CONTROL ON POWER SYSTEM PROTECTION IN MICROGRIDS

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## ABSTRACT

*This paper focuses on interaction of inverter interfaced distributed generation (IIDG) into medium voltage and low voltage networks and its effects on power system protection in microgrids. Major focus of this work is to investigate the dependence of short circuit current levels on control schemes applied to inverters in microgrid, and mode of microgrid interconnection. The importance of considering different inverter control modes while developing microgrid protection schemes is proven by using MATLAB/Simulink model of benchmark microgrid test case.*

## INTRODUCTION

Introducing distributed generation into electric power systems is the current trend leading to improvement of reliability in electric power delivery, transmission capacity and reduction of greenhouse gases emission by favorizing renewable sources as distributed generators. Entities called microgrids are believed to be building blocks of the future resilient distribution networks. However, there are certain technical difficulties to overcome, which are not observed in common medium voltage (MV) and low voltage (LV) distribution networks. Traditional distribution network protection schemes were designed to work from the perspective of radial power flow and introduction of power generation into distribution networks will affect the existing schemes. Non-directional overcurrent protection and fuses commonly utilized in these networks are unable to provide required amount of sensitivity and selectivity [1].

## INVERTER INTERFACED DISTRIBUTED GENERATORS

Traditionally, majority of electric power is produced by synchronous generators, which are rotating masses with high inertia. These generators are well analyzed and its behavior during faults is adequately known to providing significant amount of current during faults (approx. 8 times bigger than nominal). However, introduction of microgrids with renewable sources as distributed generation into MV and LV distribution network, changes operating conditions of these networks [5]. Specification of renewable sources usually does not allow these sources to be connected to the main grid directly, since for instance photovoltaics require inverter interface to transform generated current from DC to AC and wind turbines with their stochastic nature need back-to-back converter in order to meet the grid frequency requirement [2]. Moreover, as investigated in [4], contribution to fault current of inverters during faults is much smaller from rotating machines. It means that for networks like microgrids, where the power generation is dominated by inverter-interfaced sources, protection schemes based on assumption of high currents during fault may not be adequate and other criterions for fault detection are required.

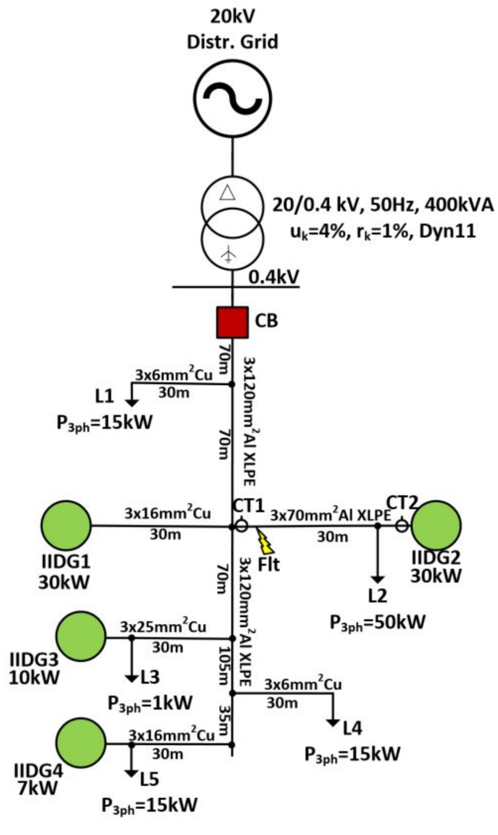


Fig. 1 Benchmark microgrid schematic

Important aspect jeopardizing protection is full controllability of inverters. [6] performs a basic study upon the influence of inverter control method on a level of the current provided by the inverter under specific controls during the fault. It clearly shows significant influence of inverter controls on power system protection schemes in microgrids.

## TEST NETWORK AND MODELING

A study of above said issues is performed based on a representative microgrid presented in Fig. 1 with IIDGs introduced by reference [8]. Line parameters are provided in Tab. 1 in Appendix. Power converter control modes discussed in this paper are presented in [7]. Author introduces there power converters control schemes being the most likely ones utilized in AC microgrids in the future. Two distinctive control modes mentioned is a grid-forming and grid-feeding mode. In the first one converter acts as a voltage source, where nominal voltage magnitude and frequency are references. Second control mode has direct and quadrature currents as a reference, thus in that mode inverter works as a current source. Possible variation of that control method is using as a reference active and reactive power instead of d-q currents.

## PROTECTION SCHEMES FOR LV MICROGRIDS

Issues typical for microgrids addressed in the second section, as well as in [1], [3] and [9] require new methods and schemes providing secure and selective fault detection. Some of the already suggested solutions are briefly discussed below.

[10] first proposed a method based on voltage measurement at the distributed generator terminals. Obtained voltage is then transformed into d-q reference frame and it is used to calculate disturbance signal and to detect faults. The same author in [11] proposes also another method for protection against faults and islanding for microgrids, which is based on THD calculation at the terminals of distributed generator.

In [12], the idea is to handle fault detection separately for earth faults and short circuits. Earth faults detection is done by monitoring zero sequence current of three phases, while short circuits are detected by monitoring negative sequence of the current. One group of methods is formed by methods already known from HV transmission system. Distance protection belongs to this group and its application to microgrids is discussed in [13].

## RESULTS ON PROTECTION SCHEMES APPLIED TO PRESENTED LV MICROGRID

In this section results of MATLAB/Simulink simulations revealing possible problems coming from different inverter control methods are presented and shortly commented.

### Voltage based protection

Fault detection is done by monitoring a quantity called disturbance voltage, which is calculated from voltages measured at the generator terminals and decomposing that signal into decoupled direct and quadrature components. Any fault should cause a sudden rise in a disturbance voltage which is defined as:

$$V_{DIST} = V_{qref} - V_q$$

where $V_{qref}$ is preset reference quadrature voltage component and $V_q$ is measured quadrature voltage component. Upon three phase fault with a fault resistance of 0.5 Ω the voltage dynamics at the terminals of IIDG2 varies significantly as presented in the Fig. 2. At the very first moment after fault inception the voltage drop is the same. However, in voltage control mode inverters act very fast to rebuild voltage (depending on the regulator parameters), thus blinding proposed scheme, if a security delay of tripping signal is applied. In the same situation inverter controlled in a grid-feeding mode with a d-q current reference experiences significant voltage drop, thus working as desired for that method.

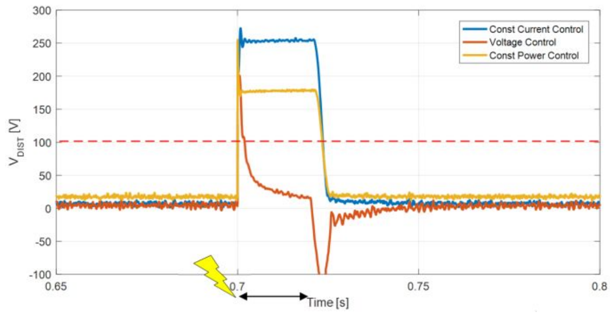


Fig. 2 Voltage dq components based scheme under different control modes of inverters

### Harmonic content

This method is similar to voltage based method, since one of the fault indicators is a voltage drop. Consequently, as presented in the previous subsection inverter control mode significantly influences voltage during fault, so this method also can be blinded when three phase fault occurs in a network fed by voltage controlled inverters.

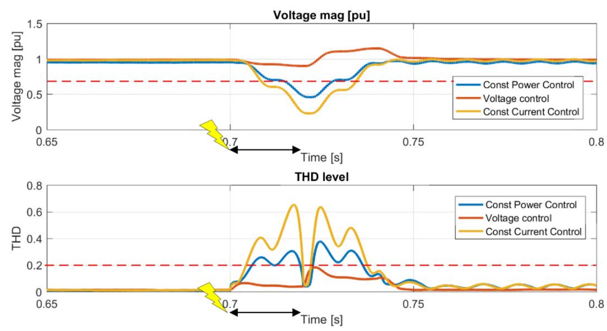


Fig. 3 Harmonic content based scheme under different control modes of inverters

The second criterion is calculated THD of voltage at the generator terminals. As presented in the lower graph of Fig. 3 harmonic content also varies with control method, so for voltage control mode neither voltage magnitude nor THD would exceed tripping threshold in this case. On the other hand, grid-feeding control modes are less harmful for this protection scheme.

## Differential & symmetrical current components

The following fault detection strategy handles the problem separately for earth faults and phase to phase faults. Earth faults detection criterion is based on zero sequence component of measured current. As can be seen in Fig. 4, level of zero sequence component of the current is different when a microgrid is connected to the main grid and when separated. In autonomous operation, the level of zero sequence current during earth faults slightly varies for different control modes. At the beginning of line (CT1) in constant current mode it is almost two times lower than for voltage control mode, so the protection could potentially be blinded if the threshold is set too high. It is also worth noticing that zero sequence current at the terminals of the generator (CT2) is always zero.

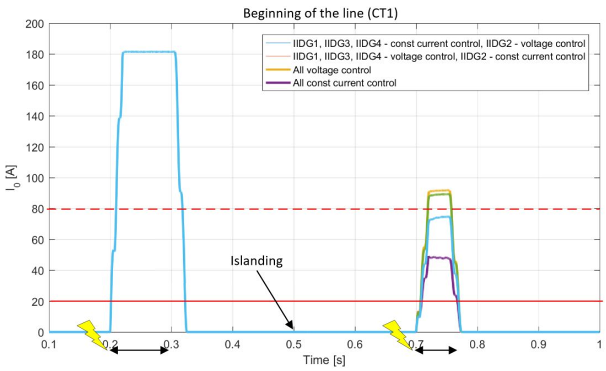


Fig. 4 Zero sequence current measured at the beginning of the faulty line

Phase to phase faults detection method is based on negative sequence component of the current. Fig. 5 shows level of negative sequence current measured at the terminals of IIDG2 for different control modes. It can be seen, that the most critical case for this method is constant current control, where almost none negative sequence current is present.

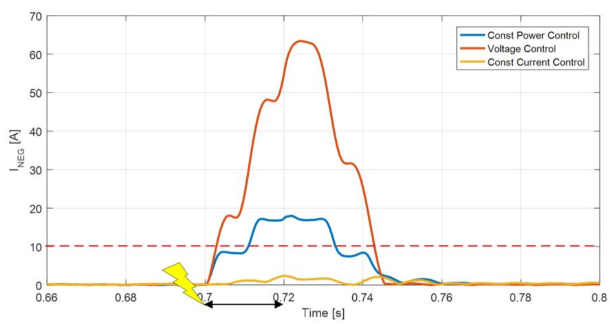


Fig. 5 Negative sequence current during phase to phase fault for different control modes of inverters

## Transmission level protection

General observation is that impedance protection cannot be applied to LV microgrid networks as a standalone scheme. The main reason is the topology of the network itself. Branches are relatively short, thus their impedances are very low and almost purely resistive (on contrary to traditional inductive power system networks). All of that makes impedance relay detect metallic and low-ohmic faults, but low line impedances prevent selectivity.

Fig. 6 presents an effect of controls on impedance measurement during three phase fault with fault resistance of 0.5 ohm. Left hand side graphs show impedance measured at the terminals of IIDG2 when all of the inverters in the microgrid (microgrid runs in islanded mode) are controlled in a constant current mode. Right hand side graphs present impedance measured impedance in the same location, but IIDG1 is controlled as a voltage source. One can observe that a voltage support from IIDG1 is enough to blind the impedance protection, which is not a case when all of the inverters are controlled as current sources.

For constant power control however in order to see the same problem the rest of the inverters (IIDG1, IIDG3, IIDG4) had to be in voltage control mode (not only IIDG1). This can be seen in Fig. 7.

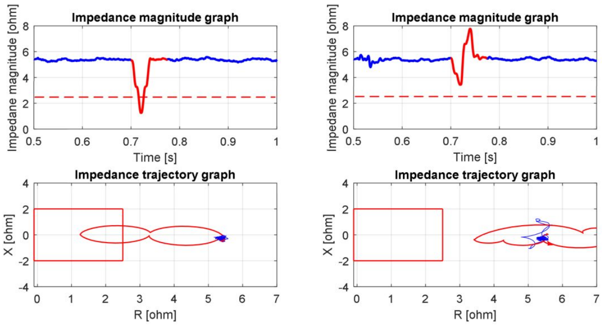


Fig. 6 Impedance magnitude and R/X plane (left) for all inverters in constant current mode and impedance magnitude and R/X plane (right) for only IIDG1 in voltage source mode (red rectangle is an example of a tripping characteristic for an impedance relay)

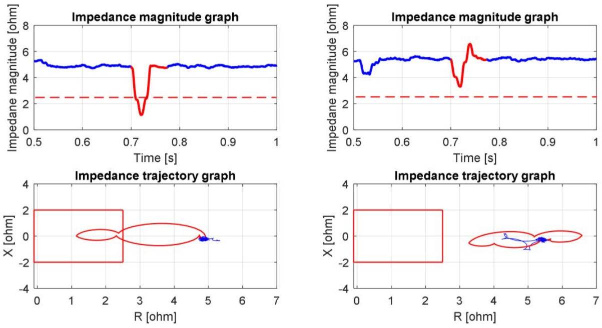


Fig. 7 Impedance magnitude and R/X plane (left) for all inverters in constant power mode and impedance magnitude and R/X plane (right) for IIDG1, IIDG3 and IIDG4 in voltage source mode (red rectangle is an example of a tripping characteristic for an impedance relay)

## Conclusions

Introduction of microgrids with inverter-interfaced distributed generators is a challenge from protection point of view since traditional overcurrent based methods fail due to low current contribution from inverters during faults. Literature presents different fault detection methods for microgrids based, among other things, on voltage, voltage THD, symmetrical components, impedance criterion providing improved performance in case of high contribution of IIDGs. However, control mode of inverters within microgrid, especially in islanded operation may significantly influence validity of these protection schemes. General observations are that voltage control mode of inverter in islanded operation may lead to blinding of methods utilizing voltage measurements, when constant current (or constant power) control modes may jeopardize methods taking current as an input. Possible solutions to these problem might be standardization of the type of controls applied in microgrids. It could help in deciding which protection scheme to apply, or setting threshold values of protection to avoid potential blinding. Another possible solution would be to introduce centralized protection scheme analysing current flows inside the network.

## Appendix

Tab. 1 Parameters of lines

| Element | R+ [Ω/km] | X+ [Ω/km] | R0 [Ω/km] | X0 [Ω/km] |
|---|---|---|---|---|
| 3x120mm$^2$ Al XLPE | 0.284 | 0.083 | 1.136 | 0.417 |
| 3x70mm$^2$ Al XLPE | 0.497 | 0.086 | 2.387 | 0.447 |
| 3x6mm$^2$ Cu | 3.690 | 0.094 | 13.64 | 0.472 |
| 3x16mm$^2$ Cu | 1.380 | 0.082 | 5.52 | 0.418 |
| 3x25mm$^2$ Cu | 0.871 | 0.081 | 3.48 | 0.409 |

## References

[1] S. Conti, 2011, "Protection issues and state of the art for microgrids with inverter-interfaced distributed generators", *Proceedings International Conference on Clean Electrical Power (ICCEP)*, 643-647

[2] A. Darwish, A. S. Abdel-Khalik, A. Elserougi, S. Ahmed and A. Massoud, 2013, "Fault current contribution scenarios for grid-connected voltage source inverter-based distributed generation with an LCL filter", *Electric Power Systems Research*, vol. 104, 93-103

[3] H. J. Laaksonen, 2010, "Protection principles for future microgrids", *IEEE Transactions on Power Electronics*, vol. 25, 2910-2918

[4] N. Nimpitiwan, G. T. Heydt, R. Ayyanar, and S. Suryanarayanan, 2007, "Fault current contribution from synchronous machine and inverter based distributed generators", *IEEE Transactions on Power Delivery*, vol. 22, 634–641.

[5] W. Guo, L. Mu and X. Zhang, 2017, "Fault models of inverter-interfaced distributed generators within a low-voltage microgrid", *IEEE Transactions on Power Delivery*, vol. 32, 453-461

[6] M. A. Haj-ahmed and M. S. Illindala, 2014, "The influence of inverter-based DGs and their controllers on distribution network protection", *IEEE Transactions on Industrial Applications,* vol. 50, 2928–2937

[7] J. Rocabert, A. Luna, F. Blaabjerg, and P. Rodriguez, 2012, "Control of power converters in ac microgrids", *IEEE Transactions on Power Electronics*, vol. 27, 4734–4749

[8] S. Papathanassiou, N. Hatziargyriou and K. Strunz, 2005, "A benchmark low voltage microgrid network", *Proceedings of the CIGRE symposium: power systems with dispersed generation*, 1-8

[9] Consortium for Electricity Reliability Technology Solutions, 2002, White paper on "Protection issues of the microgrid concept"

[10] H. Al-Nasseri, M. A. Redfern and F. Li, 2006, "A voltage based protection for micro-grids containing power electronic converters", *Proceedings Power Engineering Society General Meeting*, 1-7

[11] H. Al-Nasseri and M. A. Redfern, 2008, "Harmonics content based protection scheme for Micro-grids dominated by solid state converters", *Proceedings 12th International MiddleEast Power System Conference MEPCON 2008*, 50-56

[12] H. Nikkhajoei and R. H. Lasseter, 2007, "Microgrid Protection", *Proceedings IEEE Power Engineering Society General Meeting 2007*, 1-6

[13] M. Dewadasa, A. Ghosh, and G. F. Ledwich, 2008, "Distance protection solution for a converter controlled microgrid," Faculty of Built Environment and Eng., School of Eng. Syst., Dec. 18, 2008