NOVEL PROTECTION APPROACH FOR MV MICROGRID

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ABSTRACT

The amount of distributed generation (DG) connected to medium voltage (MV) networks is expected to increase continuously. This trend creates a good opportunity to use MV feeders as microgrids. Normally microgrids will be operated parallel with the utility grid. However, for example during outages in utility grid they are capable of operating in an island mode. Nevertheless, island operation produces challenges for protection. Traditionally MV network has been protected against short-circuit faults with overcurrent relays. In island operation these relays may fail to detect fault conditions due to drastically changed network parameters and lack of short-circuit power. Above-mentioned issues create need to develop new protection concept for MV microgrids. The aim of this paper is to address these issues and to present an adaptive protection approach for MV microgrids based on telecommunication.

INTRODUCTION

Microgrids can be described as part of distribution system capable of autonomous island operation [1]. Microgrid contains DG, energy storages and controllable loads [2, 3] and it can be considered as an integral part of the future Smart Grids. This is indicated also in the definition given by The European Technology Platform SmartGrids [4]: *"A SmartGrid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies"*. The amount of DG connected to MV networks is expected to increase continuously. This trend creates a good opportunity to use MV feeders as microgrids. Normally microgrids will be operated parallel with the utility grid. However, for example during outages in the utility grid they are capable of operating in an island mode. This characteristic allows increased reliability and security of supply and contributes directly one of the important features of Smart Grids, the self-healing capability. Nevertheless, island operation produces challenges for protection [3]. Traditionally MV network has been protected with overcurrent sensing devices. In island operation these devices may fail to detect fault conditions due to drastically changed network parameters and lack of short-circuit power. Most of the DGs and energy storages in the future are converter interfaced and thus are not capable of producing high fault currents [2, 5]. Above-mentioned issues create need to develop new protection concept for MV microgrids. The novel protection approach presented in this paper applies modern protection relays, usually referred to as IEDs (Intelligent Electronic Devices). An important aspect of the proposed approach is that it relies on telecommunication links between all IEDs in the system. Furthermore, the consideration of the various system states requires that the protection system is also adaptive. For a microgrid there are two basic states or modes: grid connected and island operated.

Contrary to typical use of the term microgrid which refers to low voltage (LV) network [6] this paper addresses microgrid as MV feeder as shown as one possible configuration in Figure 1. Here the connected low voltage networks are treated only as passive or active resources.

The scope of this paper is to analyse and classify protection challenges of MV microgrid and suggest a solution to selected problems by presenting an adaptive protection approach for MV microgrids based on telecommunication that meets the challenges of Smart Grids. In this paper the focus is especially in island mode of operation while grid connected mode and islanding situation are only briefly discussed. In the second chapter of this paper the protection challenges are classified. In the third chapter the studied system and studied case are presented. The fourth chapter introduces the proposed novel approach using illustrative results from the simulation example made with PSCAD simulation software. At the end also an alternative approach is presented.

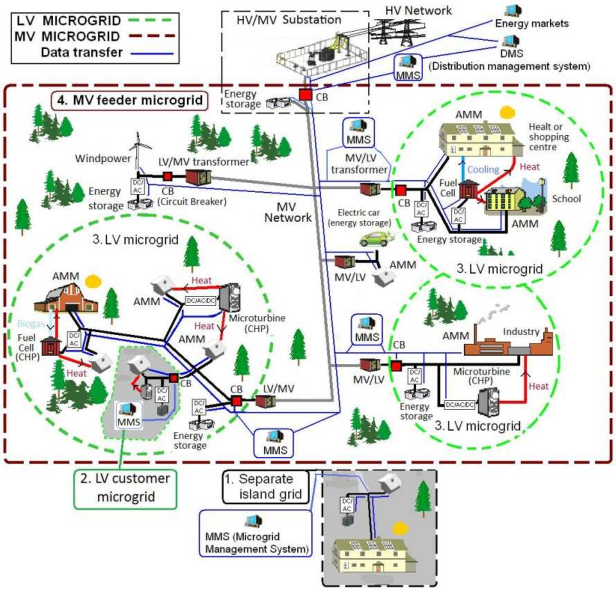

Figure 1. Different possible microgrid configurations [6].

PROTECTION CHALLENGES

Some of the protection challenges needed to achieve fast and selective protection within an islanded microgrid are discussed in [2, 3].

The overall protection scheme must cover both grid connected and islanded modes. For grid connected mode the traditional overcurrent protection scheme may be sufficient but the problems arising from DG, as identified for example in [7], must be properly handled.

Increasing number of distributed generating units are expected to be connected to the network via converter interfaces. It is mentioned in [2, 5] that converters have limited short-circuit current producing capability to approximately 2-3 times their rated current. Thus protecting microgrids with converter interfaced production units with traditional overcurrent protection scheme is infeasible. In [5] it is suggested that to overcome this problem oversizing the converters in order to get larger fault currents is one possible solution, but in practice this is quite expensive. Increasing fault current levels by other means is proposed in [8] which promotes the use of fault current source while [3] suggests using a flywheel or super-capacitor as energy storages for reserve short-circuit power.

After all it is possible to connect multiple generating units to a microgrid which leads to multidirectional power flow and because of this fault detection cannot be based on the assumption of fault current from single source only.

To allow time for the protection to work generation units must have some fault ride-through (FRT) capability. This is the case for both interconnected and islanded modes of operation. FRT requirements must be taken into account when designing the loss-of-mains (LOM, anti-islanding) protection. With FRT requirements it must be ensured that faults external to the microgrid do not cause any unnecessary disconnection of the DGs. On the other hand LOM protection should not trip from, e.g., voltage drop caused by an external fault. During islanding and in islanded mode the LOM protection should be disabled to avoid tripping of the DGs. However, DGs should still have FRT capabilities to cope with the islanding and voltage and frequency transients caused by it. The FRT capability during islanding is recommended in [1] to ensure that the DGs don't trip unnecessarily. With telecommunication the protection could be made adaptable so that it can automatically change protection settings, enable or disable certain protection functions and adjust the interlocking setup.

STUDIED SYSTEM

The studied system is presented in Figure 2. The system is modelled with PSCAD transient simulation software. The network is energized with two identical sized (2.3 MVA) DG units with their maximum output current limited to 1.2 p.u. They represent typical converter interfaced DG units which operate in current control mode to output a desired power. For protecting the electronics there is a set upper limit (in this case 1.2 p.u.) for the current to avoid damages when the voltage drops due to a grid fault.

The DG units are connected to the microgrid to both ends of the feeder via YNyn transformers. The microgrid is disconnected from the secondary side of the feeding HV/MV transformer. The earthing method is chosen to be isolated and thus the disconnection of the microgrid from the secondary side does not affect the earthing method. Loads or in this case distribution substations feeding the LV networks are evenly distributed along the feeder, with total load of 2.4 MW and 0.85 MVAr. LV networks can be considered as passive or active resources, but in this case they are all passive loads.

The system comprises of one 20 kV overhead line feeder with a total length of 50 km. The feeder is divided into four protection zones with respective lengths from the start 5 km, 15 km, 15 km and 15 km. Between protection zones there is a circuit breaker controlled by an IED. Furthermore, both DG units are protected with an IED. The IEDs are equipped with voltage and current measurements and with directional overcurrent protection function. Arrows in Figure 2 indicate forward current direction of the IEDs. The forward direction of DG IEDs is towards the feeder in both cases. In addition, the IEDs are connected to each other with a high speed telecommunications links.

Distance protection function has also been implemented in DG1 IED to test out the usefulness of distance protection in island operation.

There are four fault locations which are marked from 1 to 4 in Figure 2. Only three phase short-circuit faults are studied here.

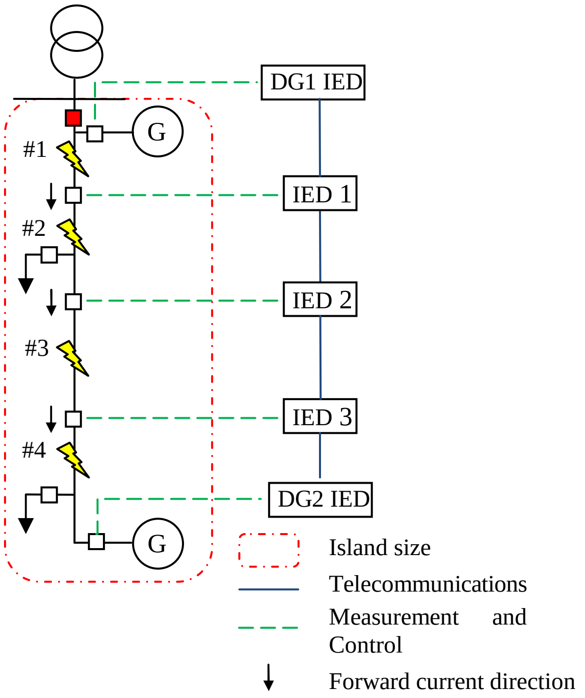

Figure 2. The studied example Microgrid system.

PROPOSED APPROACH

Firstly the suitability of the traditional (non-directional) overcurrent scheme to protect islanded microgrid is examined. A short series of simulations was done with the example network and regardless of the fault location all of the IEDs measured a current of 1.2 p.u. in magnitude. With conventional overcurrent limits based on short-circuit ratings none of the IEDs detect the fault and lowering the overcurrent setting below 1.2 p.u. risks all of them tripping from a temporary overload condition. On the other hand all the IEDs will always be tripped in the fault situation and this makes it impossible to achieve selective protection. As a conclusion the traditional overcurrent scheme proves to be inadequate to protect islanded MV microgrid.

The proposed approach for islanded mode is a method based on two different pieces of information available through measurement of current and voltage from multiple measurement locations. The pieces are voltage measurement and current flow direction. Combining these makes it possible to detect faults accurately to the faulty protection zone.

The method has two phases, in the first phase the fault condition is detected and in the second phase the faulted zone is located. Fault detection is based on the undervoltage. With three phase short-circuit faults the voltage dip is considerable. The depth of the voltage dip depends on fault resistance and distance to the fault. Figure 3 shows a simulated voltage dip across the feeder when nominal voltage is 20 kV with three phase short-circuit at fault location #3 in Figure 2.

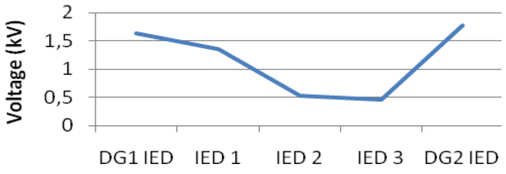

Figure 3. Simulated voltage dip (remaining voltage) across the feeder for a fault at the fault location #3.

Second phase of the method is fault locating. It is based on current flow information from the IEDs. Current flow information gives relative direction of the fault from any particular IED. In other words an IED is able to detect if the fault is in forward or backward direction. Figure 4 shows the current phasors together with the reference voltage phasors applied by the directional functions of the IEDs. With multiple IEDs along the feeder it is possible to pinpoint the fault between two of the IEDs. Figure 4 has simulation results from fault #3 and shows the direction indications of IED 1, 2 and 3. Both IEDs 1 and 2 indicate that the fault is in forward direction while the IED 3 indicates the fault as backward direction.

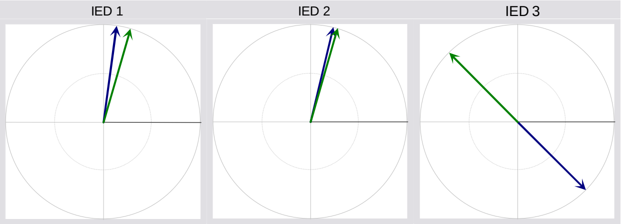

Figure 4. Simulated fault direction indication (blue = reference voltage phasor, green = current phasor).

It is assumed here that all the IEDs are able to communicate with each other without any significant delays. Total system selectivity and speed is achieved from using telecommunication to transfer fault direction and interlocking information between the IEDs.

If an IED has detected fault in its forward direction it automatically interlocks the IED in its backwards direction. Likewise for faults detected in backwards direction the IED in forward direction is interlocked. Fault direction information is also sent only either forward or backward direction of an IED depending of the case. In this way when a fault occurs only two IEDs do not receive any interlocking signal and they can operate. Interlocking is used to avoid unnecessary interruptions by making the protection selective and to cope with the FRT requirements by enabling fast fault isolation. One example was simulated with fault location chosen as #3 in Figure 2. The IEDs 1 and 2 detect the fault as forward direction faults. DG1 IED and IED 1 are interlocked by IED 2. IED 3 detects the fault as a backward direction fault and interlocks DG2 IED. Now only IEDs 2 and 3 are not interlocked and therefore it can be deducted from current flow information that the fault must be in the zone between them and that zone is disconnected.

Furthermore, the proposed method is adaptable with grid connection status. In interconnected mode the microgrid protection can be switched to traditional overcurrent protection by sending connection information from the PCC of the microgrid. Likewise during islanding the protection settings can be instantly changed to match the new connection status.

In reality the described approach requires fast communication links between the IEDs and it should be based on the IEC 61850 standard.

ALTERNATIVE APPROACH

In [9] it is said that load flow changes could adversely affect the performance of the distance protection by altering the measured impedance from actual positive sequence impedance. So a DG between the measurement point and the fault location could have negative impact on the protection.

The suitability of distance protection implemented at DG1 IED with this kind of network topology was simulated. Figure 5 shows the R-X trajectory at the simulated fault in location #3. In the simulations the relay measures the impedance to the fault so that the resistance is 7.03 Ω and the reactance is 9.12 Ω. Calculating from the line input data of the simulation model we get a resistance value of 7.03 Ω and reactance of 9.68 Ω. For other fault locations as well the accuracy was within similar range. Overall the accuracy is rather good with this kind of network topology but further studies are required with different network topologies and with more fault types.

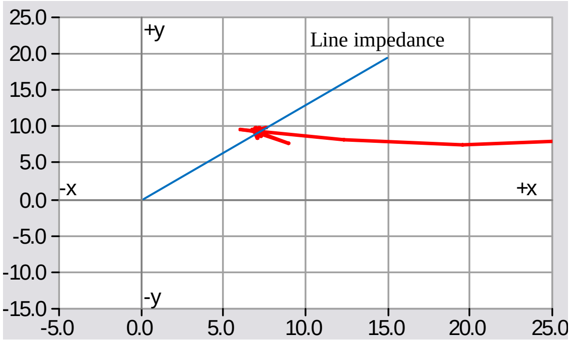

Figure 5. Simulated distance protection R-X trajectory.

CONCLUSIONS

Island operation contributes to an important Smart Grid feature, the self-healing. One way to achieve self-healing functionality is to switch over to island operation in case of a fault in some part of the utility grid. This paper presented a novel protection approach for MV microgrids and in this regard contributes towards tomorrow's Smart Grids.

The results of the analysis showed that with traditional protection devices it is not possible to achieve adequate level of protection sensitivity and selectivity. These findings were supported with short set of simulations.

Therefore a telecommunication based adaptive protection approach was suggested. The proposed solution has two phases with separate fault detection and location tasks. For final application there are still several issues that require further studies but in overall it can be stated that telecommunication based protection approach suits well for the requirements of MV microgrids since it will achieve selective and fast protection in all operating states.

In addition, an alternative approach with distance relay added to the network was studied. The distance protection seems to have some potential but additional studies are needed to verify the applicability of it in various situations. In future studies more fault types and network topologies will also be covered.

Acknowledgments

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REFERENCES

[1] H. Laaksonen, K. Kauhaniemi, S. Voima, 2010, "DG Unit Fault Behavior and Protection of LV Microgrid", *International Review on Modelling and Simulations (IREMOS)*, vol. 3, no. 3, 353-367.

[2] S. Chowdury, S.P. Chowdury, P. Crossley, 2009, *Micrograds and Active Distribution Networks*, The Institution of Engineering and Technology, London, United Kingdom, 4-5, 70-95.

[3] A. Oudalov et. al. 2009, "Novel protection systems for microgrids" MORE MICROGRIDS project report, 11 November 2009.

[4] European Technology Platform SmartGrids, 2010, "Strategic Deployment Document for Europe's Electricity Networks of the Future", Final Report, 20 April 2010.

[5] T. Loix, T. Wijnhoven, G. Deconinck, 2009, "Protection of Microgrids with a High Penetration of Inverter-Coupled Energy Sources", *CIGRE/IEEE PES Joint Symposium on Integration of Wide-Scale Renewable Resources Into the Power Delivery System*, 2009.

[6] H. Laaksonen, K. Kauhaniemi, 2010, "Smart Protection Concept for LV Microgrid", *International Review of Electrical Engineering (IREE)*, vol. 5, no. 2, 578-592.

[7] K. Kauhaniemi, L. Kumpulainen 2004, "Impact of Distributed Generation on the Protection of Distribution Networks", *Developments in Power System Protection*, Amsterdam 5-8 April, 2004.

[8] F. Van Overbreeke, 2009, "Fault Current Source to Ensure the Fault Level in Inverter-Dominated Networks", *20th International Conference on Electricity Distribution*, Prague, 8-11 June, 2009.

[9] V.P. Mahadanaarachchi, R. Ramakumar, 2008, "Impacts of Distributed Generation on Distance Protection Performance - A Review", *Power and energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century*, Pittsburgh, 20-24 July, 2008.