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FEASIBILITY STUDY OF THE AVAILABLE RELAY PROTECTION SOLUTIONS FOR MICROGRIDS

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ABSTRACT

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Feasibility study of the available relay protection solutions for microgrids

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Thesis talks about relay protection for microgrids. Microgrid operation sets more challenges than traditional utility grid protection because of lower fault current levels. Solutions for these challenges are discussed in this paper. Thesis also studies available relay protection solutions and figures out how they would fit for microgrid protection.

TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
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Jukka Ihamäki

Relesuojausratkaisujen käyttökelpoisuus microgridin suojauksessa

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Työ esittelee microgridin suojauksen haasteita ja vaatimuksia sekä pyritään etsimään ratkaisuja haasteisiin. Työssä tutustutaan käytössä olevien relesuojauslaitteiden ominaisuuksiin ja pohditaan niiden soveltuvuutta microgridin suojaukseen.

CONTENTS

ABBREVIATIONS AND SYMBOLS

AMM	Advanced Meter Management
CAIDI	Customer Average Interruption Disturbance Index
CB	Circuit Breaker
CHP	Combined Heat and Power
DER	Distributed Energy Resource
DG	Distributed Generation
DMS	Distribution Management System
EDGE	Enhanced Data rates for GSM Evolution
GPRS	General Packet Radio Service
HIF	High Impedance Fault
HV	High Voltage
I	Current
IED	Intelligent Electronic Device
MMS	Microgrid Management System
MV	Medium Voltage
LCD	Liquid Crystal Display
LON	Local Operating Network
LV	Low Voltage
UPS	Uninterruptable Power Supply
SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
SCADA	Supervisory Control and Data Acquisition
SG	Smart Grid
SPA	SPACOM/PYRAMID–series relay communication standard
δ	Angle

Subscripts

1	Primary
2	Secondary
N	Nominal
u	Voltage

1. INTRODUCTION

Thesis is part of Smart Grids and Energy Markets Research (SGEM) program within Cleen Oy. Thesis discusses about the needs of protection for microgrids. The main focus is on relay protection for microgrids. The aim of this thesis is to figure out how available relay protection devices fit for microgrid protection. There are some differences between microgrid and utility grid which sets some challenges for microgrids. Traditional over current protection might fail because of lower fault current levels. Also the communication between protection devices is needed. Thesis brings out ideas to solve the problems.

Microgrids can be considered as a part of future Smart Grids (SG). Main reason for microgrid operation is better reliability of distribution. Microgrids can offer new opportunities to secure the distribution for important customers. Before implementing microgrids as a part of utility grid, control, protection and communication challenges have to be solved. If microgrids can be protected with existing protection relays, the pilot microgrids could be done without further development in technology. The use of existing technology would ease the implementation of microgrids.

2. RELAY PROTECTION DEVICES

Different fault situations like short circuits, earth faults, over voltages etc. happen in the electricity network. Relays are devices that observe the network and give switching commands when needed. Relay protection is reliable and fast protection method. There are some requirements that are insisted on the relay protection. In Table 2.1 is shown most important requirements and reasons for them. (Mörsky 1993)

Table 2.1. Requirements of relay protection

Requirement	Reasons
Selectivity	Fault affects to minimum amount of customers
Fast operation	Safety, No damages for grid components, stability
Reliable, simple	Protection works when needed and as wanted
Usability	Protection can be modified when the grid changes, easy to use
Testing	Easy to test also onsite
Price	Cost effective, limited investment resources

Selectivity can be achieved by using different release parameters for relays. The primary goal is that the relay sends disconnection signal to the switch only when the fault is on its own protection zone or the next protection device fails. Selective operation can be achieved with time, current, voltage and/or direction parameters. Also interlocking signals can be used to avoid unnecessary switching. In utility grids quick release is needed to prevent devices because fault currents are so high in faults that happen near station. This can also be done in microgrids but it is not always necessary because fault currents are so much lower. (Mörsky 1993)

2.1 Relay technology

First relays were big mechanical devices and included moving parts. Because of moving mechanical parts these relays were slow and needed lots of maintenance. Next step was static relays that already were electronic devices. Static relays enabled the combination of different protection features in one device. Static relays need power to work which means that in case of grid failure backup power is needed. Today relays are microprocessor relays that are capable to measure, control and transfer data. Microprocessor relays are called numerical relays. (Mörsky 1993)

Second generation numerical relays include capability of 2-way data transfer. This means that measured quantities, release values and condition of relay can be red and sent for example to SCADA (Supervisory Control and Data Acquisition). Numerical relays are capable to self control which means that in case of malfunction relay tries to solve the problem and continue working without human interference. All the features of numerical relays are combined to one device that is called feeder terminal. Feeder terminals are widely used in medium voltage networks. (Mörsky 1993)

2.2 Measuring devices

One part of protection terminals are measurement transformers. Measured currents and voltages are galvanic isolated from the relay electronics. Galvanic isolation protects measurement circuit from overloading and breaking. Transformer isn't an ideal device so it has some kind of impedance and permeance. The behavior of transformers is well known and the accuracy of measurement transformers is good. Allowed exceptions are defined in different standards. In Finland 3 % voltage mistake and 120 minutes angle mistake are usually used as limit values for measurement devices. Mistake in voltage can be calculated with

$$f_u = \frac{u_2 - u_1'}{u_1'} 100\% \tag{2.1}$$

where f_u is voltage mistake in percentages, u_2 is secondary voltage and u_1' is primary voltage reduced to secondary circuit. Error in angle can be calculated with

$$\delta_u = \arg(u_2) - \arg(u_1') \tag{2.2}$$

where δ_u is angle error in radians. (Mörsky 1993)

3. MICROGRIDS

Definition of the microgrid varies in different studies. Microgrid can be defined as a part of future smart grids that is capable for island operation. Despite the differences, for example in the size or control of the microgrid, there is something common in all definitions. Microgrid always includes loads and distributed energy resource (DER). Distributed energy resource can be distributed generation (DG), energy storage, electric vehicle or combination of these.

The European Commission has published “Green paper – A European Strategy for Sustainable, Competitive and Secure Energy” (2006). In this paper is discussed that the energy infrastructure needs improving and the need of secure, competitive and sustainable energy is growing. To achieve these needs Smart Grid programs are started. The aim of these programs is to research, develop and demonstrate the future electricity networks. In future the electricity grid must be more flexible, more reliable and economic at the same time. Also the role of distributed and renewable power sources is important in European Commission targets. (European Commission 2006)

3.1 Smart grids

Basis of understanding the reasons for microgrid usage and targets of the technical development can be found from Smart grids (SG). Today the networks are becoming more automated. To equip the distribution network with remote controlled disconnectors and circuit breakers is the biggest step made in last few years in automation. Also new software systems have been implemented to help network controlling and asset management. The next steps are probably taking the network closer to the smart grid.

In future smart grid the communication network is provided all around the grid with no capacity issues. The vision is that the price of the communication is insignificantly small and the grid includes wide distributed intelligence and memory capability. Also the development of controlling systems is needed to handle all the provided information. In smart grids the role of power electronics is rising. With power electronics the quality of distributed electricity can be enhanced. Large scale smart grids aren’t reality yet but research and pilots of smaller smart grid applications will make them closer to reality step by step. (Partanen 2011)

Big question of the smart grid development is energy storage. Visions include cost efficient energy storage which is still waiting for a breakthrough. Development of energy storages also affects to the widespread of electric vehicles. If cost efficient batteries can be developed, the population of electric vehicles can grow extremely fast but if the development cannot be reached, the population will stay limited. The main problems with large scale rechargeable batteries are lifetime of the battery, charge and discharge capability and costs of the battery. (Partanen 2011)

Energy storage and electric vehicles enable many opportunities to change the grid by lowering the peak consumptions. This will also affect to the structure of the grid and make microgrid operation much easier to create and control. Microgrids cannot be based only on cheap energy storages because of the uncertainties related to the development of the energy storage systems. Hence advanced microgrid schemes are needed. These uncertainties set some challenges for the development of microgrid protection. With worst case scenario observation most of the uncertainties in the development can be ignored. (Partanen 2011)

3.2 What is a microgrid?

Microgrid is a part of distribution system that is capable of autonomous island operation. Normally microgrid operates parallel with the utility grid. Island operation as separated microgrid starts when the utility grid fails to feed the microgrid. Microgrid can consist of low voltage (LV) grid or low and medium voltage (MV) networks.

Basic parts of a microgrid are distributed generation (DG) and consumption. The role of distributed generation such as wind turbines, solar panels and micro turbines is growing all the time. That gives new opportunities to improve the reliability of the network. Some customers are more critical for power cut than other. For some customers the two hour annual average shortage, that is usual in Finland, is too much (Antikainen & al. 2011). These kind of critical customers are hospitals, server rooms, stock markets, factories and so on. For them the solution could be found from microgrids.

The idea of island operation is not new and some pilot tests have been made. The biggest problems with the island use are related to switching from parallel operation to islanded operation and vice versa. Protection and control of stability are very challenging especially when the loading or power production varies. Protection parameters for some specific island can be calculated already. The biggest challenge comes when the island or microgrid is set up right after parallel operation. When big changes happen in the electricity network the voltage and the frequency tend to drop or rise because of the unbalance in power. This may lead to instability and collapse of island distribution. Also vary of loads and production makes it difficult to control the island and especially to set the right parameters for protection units. (Antikainen & al. 2009)

It has been shown in Laaksonen & al (2011) that it is not possible to use same protection parameters for parallel operation with utility grid and for microgrid. In microgrid the short circuit current is limited and much smaller than in normal use. Traditionally the power or current flow of the grid is unidirectional but in microgrid it could be multidirectional. These are the reasons why microgrid needs special features from the protection units. (Laaksonen & al 2011)

3.3 Intended island operation

Intended island operation is the first step towards microgrids. The idea of intended island operation is to improve reliability. If the reliability can be improved, the outage costs will be smaller. In intended island operation the grid is carefully determined and calculated. After knowing the parameters of the grid, the island operation can be carefully planned. The opportunities and benefits of intended island operation are highly depended of the network topology, placement of distributed generation and the technology used in power production. (Antikainen & al. 2009)

In Antikainen & al. (2009) the consequences of intended island operation are researched. The conclusion is that with right network topology the intended island operation with reliable distributed generation has positive effect on reliability. If the distributed generation is well placed, the intended island operation can be better choice than traditional solutions like building up new backup connections. Of course this is highly depended of the topology of the grid. In Antikainen & al. (2009) the DG solution reduced SAIDI (System Average Interruption Duration Index) more than automation executed with remote controlled disconnector. This shows that the intended island operation and microgrids can develop the existing networks. (Antikainen & al. 2009)

As discussed before, the society needs more reliable power supply. This leads to bigger reliability indexes used by national surveillance which means bigger costs for distribution system operators. If bigger reliability indexes are considered, the intended island operation can give best results in both economical and reliability points of views. Network investments are very long and that is why intended island operation has a chance to reduce long-term costs. In the Antikainen’s study in question the DG was assumed to operate with 100 % power supply reliability which is not realistic. The reliability of island distribution is highly depended of used DG technology and the source of energy. If only wind and solar power are used, it means that sometimes there is no power production at all. Anyhow the study points out that island operation can compete with traditional solutions when it comes to reliability. In economic point of view the DG solutions are not as advantageous as traditional solutions. (Antikainen & al. 2009)

3.4 Reasons for microgrid operation

The reliability of a network can be described with some reliability indices. These are related to the fault frequency and the outage time. The main indicators are SAIFI (System Average Interruption Frequency Index) and CAIDI (Customer Average Interruption Disturbance Index). Fault in medium voltage network interrupt power supply to large population of customers. By automation and possibility to isolate the fault place, the outage time (CAIDI) can be reduced remarkably. The biggest changes in SAIFI can be achieved by replacing old overhead lines with underground cables and improving the maintenance program. When these basic enhancements are made, new innovations are needed to make the grid better. (Antikainen & al. 2009)

Outage costs are part of present day regulation. The cost parameters that define the harm of outage have grown in past years. The assumption is that the trend will be similar also in future. This means that outage costs of the distribution company are rising if the reliability is not enhanced. Microgrid and self healing smart grids can offer solutions that will reduce outage costs. The rise of outage costs makes new smart grid applications economically more considerable.

3.5 Different microgrids

Laaksonen (2011) has separated microgrids into four cases. These cases are collected into Table 3.1.

Table 3.1. Different microgrids.

Number	Name	Example
1	Separated island microgrid	One village, city or island
2	Low voltage customer microgrid	One household that includes DER
3	Low voltage microgrid	Low voltage network that can include many DER units and customers
4	MV feeder microgrid	Output of one HV/MV substation

The table shows that the microgrids can be very different and the specifications of microgrids can vary a lot. This means that microgrids can be modified according to the customer needs. To clear things out, different microgrids are shown in Figure 3.1.

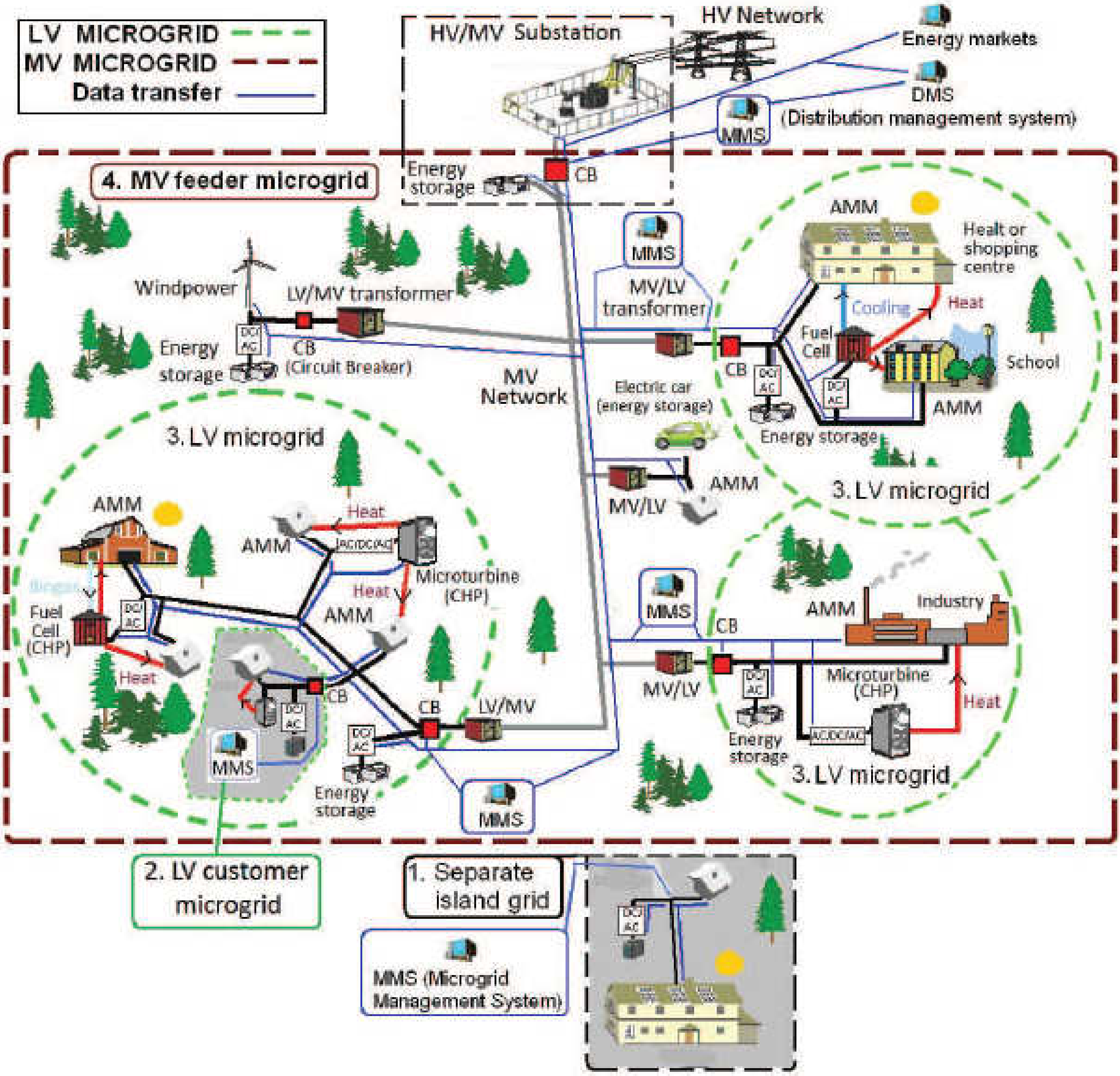

Figure 3.1. Different microgrids (Laaksonen 2011).

First one is separated island grid where DER provides electricity to small community outside of utility grid for example on some distant island. This kind of microgrid or intended island operation can provide electricity outside the utility grid. Second option is to have low voltage (LV) customer microgrid that could consist of one household. For example detached house or a farm can use own solar panel system or wind turbines to make the electricity that they need.

Third case is low voltage microgrid that provides electricity for larger group of low voltage customers. The low voltage microgrid can include to the whole low voltage network of a MV/LV distribution transformer. This kind of microgrid suits well for factories, schools and shopping centers. Fourth option is to have medium voltage microgrid that consists of medium network separated by a feeder. MV microgrid can include one or all MV outputs of one HV/MV substation.

Microgrid management system (MMS) is needed to manage the microgrid. MMS can be similar with present time distribution management system (DMS) upgraded with LV automation. Microgrid also needs supervision and configuration so the use of microgrid SCADA (Supervisory Control And Data Acquisition) software is recommended (Elias-AlceGa & al. 2011). (Laaksonen 2011)

3.6 Low-voltage microgrid

Low-voltage microgrid is similar to medium voltage microgrid. Low-voltage sites are usually considered as UPS (Uninterruptible Power Supply) or backup power usage, not as island operation or as a microgrid. However it is possible to consider them as microgrids. Challenges of microgrids are similar despite the voltage level. Stability, protection and communication are the biggest concerns. When connected to the utility grid the fault currents are much higher than in the microgrid. (Laaksonen 2011)

It is challenging to provide economically considerable LV microgrid alternatives because traditional protection devices, fuses, are so inexpensive. When microgrid operation is considered, the problem is that traditional solutions don’t offer flexibility. Cost difference means that adding more complex devices to the grid raises the costs of the low voltage grid significantly. Low voltage microgrid also needs own management system which means more expenses. These are the reasons why medium voltage microgrids can be considered to be closer to reality in near future. Also low voltage microgrids should be researched because server rooms, hospitals etc. need uninterruptable power supply. LV microgrids could be one good alternative. (Laaksonen 2011)

3.7 Medium voltage microgrid

Electricity grid is traditionally operated as a radial network. In a radial network current flows from HV/MV substation to MV/LV distribution substation. In present day grid there is at least one medium voltage circuit breaker on each substation feeder. The circuit breaker is usually controlled by relays. In microgrid operation the circuit breaker in the substation is opened. In present-day networks the opening action of circuit breaker leads to situation where the DG units are detached if the first reconnection fails. This means that the whole substation feeder is without power. In MV microgrid the loads and distributed generation are expired more closely. With this knowledge the island can be created and the balance with production and consumption achieved. For safe operation, MV microgrid needs own management system that discusses with the protection units. The protection units include intelligence and can detect the faults that happen in the microgrid. The challenges of the MV microgrid protection are examined later in this work.

3.8 Example microgrid

Because of the different versions of microgrids here are some specifications of the microgrid on which this thesis mainly focuses. Observed microgrid is a medium voltage grid which naturally includes also the low voltage side. Grid is assumed to work so that the first fault (N-1) happens in the utility grid which leads to microgrid operation. If some other faults happen in the microgrid, they have to be detected and network components protected. This can lead to blackout in the microgrid but it is acceptable because this fault can be defined as N-2 fault. (Sortomme 2010)

Building a microgrid that can handle N-2 faults is the next step towards self healing networks. Today there are enough practical challenges with N-1 microgrids so those are more closely discussed. Building an N-2 microgrid means that it has to include many distributed generator units and have capability to calculate new protection values any time when the grid varies. The intelligence that self healing microgrids need cannot be achieved easily. This means that more development and more costs are needed. Today this makes competitiveness of the microgrids very challenging.

Control of a microgrid is one of the main challenges. The power supply to the customers has to be safe and protected. Power and frequency have to be measured, controlled and kept in balance. The control is here assumed to be solved with microgrid SCADA. The control cannot always answer to the sudden needs of the grid and voltage changes. This means that the protection has to ignore transients that are part of normal operation and separate them from fault situations.

4. REQUIREMENTS OF MICROGRID PROTECTION

Protection of a microgrid is very challenging because the features of the microgrid are so different from the features of the utility grid. Distributed generation units are usually connected to the grid via power electronics which provide very limited short circuit current. When connected to the utility grid there are higher short circuit current levels in the network than in microgrids. Power flow can be bi- or multidirectional in microgrid. Usual relay protection is based on over current detection so the traditional settings are shown to fail in microgrid mode. Working protection also needs fast and reliable communication between protection units. Especially during changes the fast enough and reliable communication is a challenge.

4.1 Microgrid fault detection

Typical faults in medium voltage network are short circuit and earth faults. In utility grid the short circuit current rises dozen or usually even more times higher than rated current. This is easy to detect. In (Voima & al. 2011) is mentioned that converters have short circuit current producing capability to only 2-3 times their rated current. This means that the over currents cannot be detected in all parts of the microgrid especially when distributed generation units are connected to the microgrid via power electronics. Even if the over currents could be detected the selective protection is hard to achieve.

When we are aiming towards self healing networks and microgrids, new innovations are needed. One answer to the protection problems is to use voltage measurement and compare it to current measurement. Voltage measurement detects voltage dips which result from short circuit. At the same time current flow direction is under scope. This kind of protection schemes can be part of the future grids but now they are still only visions. In Figure 4.1. can be seen the current and voltage phasors of different IEDs (Intelligent Electronic Devices).

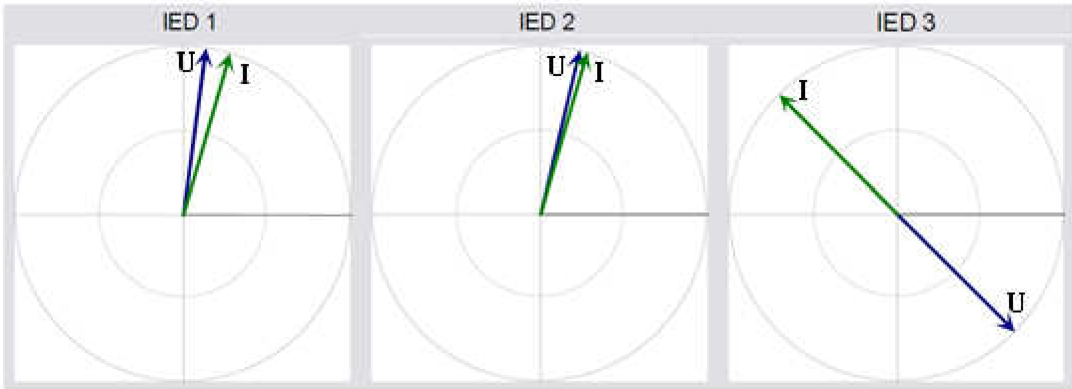

Figure 4.1. Fault direction indication with current I and reference voltage U phasors (Voima & al. 2011).

With the information of short circuit current direction the fault can be located and the faulted part decoupled. In figure the intelligent electronic devices are presumed to be in the network in order of one to three. Figure shows that when fault is in front of the IED (1 & 2) the phasors are close to each other. IED 3 shows situation when the fault is in backward direction. The fault is between IED 2 and IED 3 and this zone can be disconnected. To achieve selective protection the protection devices have to send interlocking signals to relays that shouldn't act. This needs reliable communication where delays are minimal. The system works so that protection units that notice the fault send interlocking signal to devices behind it. If the device itself don't get interlocking signal from the next device, it will act and the fault zone is disconnected. (Voima & al. 2011)

The biggest challenge in microgrid operation is to detect high impedance faults. These faults are also challenging in traditional network because the changes, that fault cause into measured values, are very small. In microgrid the changes in measured values are even smaller. High impedance faults are nonlinear, asymmetry and the duration of peak value can vary a lot. Same kind of features can be seen in the network also without fault. In traditional networks the problem is solved with sensitive current transformer and measurement units. This might not be enough in all microgrids and also other methods should be considered. Although sensitive measurement should be considered as the base of protection in present day pilot microgrids that use available relay protection units. (Sortomme & al. 2010)

4.2 Relay protection of distributed generation

Distributed generation units have own protection units which can disconnect the DG unit when needed. Distributed generation is set up to detach when some limit values are crossed. To prevent the unwanted disconnection of DG the utility grid protection has to be faster than DG protection. This means having tighter protection limits and use of interlocking signals. The fast protection in utility grid is the key to smooth change from utility to microgrid mode. (Voima & al. 2011)

DG protection units protect DG's similarly than traditional network protection units. The idea of own protection and disconnector is to prevent unwanted operation during fault and protect the distributed generation unit from harmful interference. Protection is designed so that the currents and voltages that affect to the generation unit stay in allowed limits. Generation unit is protected from harmful over and under voltages, over currents and also from over and under frequencies. Normally the control system of DG takes care of frequency but frequency relays are used as secondary protection. Secondary protection acts usually when the stability is lost. (Antikainen & al. 2009)

One challenge of DG protection is to find out when the DG unit should be detached. In utility grid mode the unintended operation of DG can be detected from the sudden change of loads. If the load raises a lot it means that the network lost some of its power supply. If the lack of power continues over limits and the stability is lost, the DG will be detached. In microgrid this method is not always possible because the DG can be the only source of power connected to the grid. (Redfern & al. 1993)

4.3 Active and passive protection methods

Protection methods of distributed generation that can be applied to the future microgrids can be separated into passive and active methods. In active methods small changes are made into the network and the consequences are followed. Passive methods are based on measuring and change detecting. There are also some algorithms that detect the speed of change in power supply. In this method the signal is sent to the switch if the supplied power changes faster than the limit value. This leads to disconnection of distributed generation. (Redfern & al. 1993)

Active methods are easiest to execute with generation that include power electronics. Active method can be based on reactive power observation because the amount of transferred reactive power changes when the grid loses supply. This leads to the awake of relay. Other active method is to connect an inductor in parallel with connection point and calculate the impedance. The impedance can be calculated by measuring current and voltage and then the calculated impedance is compared to the base value. The difference can be easily noticed and the release can be made quickly. (Redfern & al. 1993)

Passive methods are usually based on voltage and frequency relays. The protection detects the change in voltage or frequency level because the generator can not supply enough power to the grid. Passive methods work especially for small generators. In microgrids this method can work in grid that includes many small power sources. Voltage relay detects the change in reactive power and frequency relay detects the change in active power. The advance of this method is its simplicity. The biggest drawback is the poor capability to detect small changes. (Redfern & al. 1993)

4.4 Protection of low voltage microgrids

Present day low voltage protection is based on fuses that break when the current is high enough. Protection is very simple and cost effective. The problem of present-day LV protection in smart grid environment is that it has very low degree of flexibility. As in medium voltage microgrid also in low voltage microgrid fault currents are lower. This means that flexibility and different setting groups are needed. Because the conventional LV protection is inexpensive, it is very challenging to achieve economically feasible protection system which can answer to the needs of LV microgrids. (Laaksonen 2011)

The stability is one of the main issues in low voltage microgrids. In Laaksonen & al. (2011) it is mentioned that especially directly connected rotating machines can lose their stability in voltage dips. Losing stability of directly connected rotating load can lead to loss of stability in whole microgrid. In above mentioned paper the protection of low voltage microgrid is done using LV feeders and protective relays. Also microgrid management system is needed. This means that in principle the protection of LV microgrid is very similar to MV microgrid protection. The biggest difference is in the expenses of network protection. In LV network the new protection expenses create remarkable share of the cost of the network. MV networks are already actively monitored and relay protection is used for safe operation. In LV system the changes from conventional fuse protection to MMS driven relay protection are bigger. (Laaksonen 2011)

4.5 Communication standard IEC 61850 in microgrids

The role of communication is bigger in microgrids than in normal utility grid. IEC 61850 is communication standard for substation communication. The target of this standard is to get different equipments to work with each other without separate data modifiers. The standard determinates architecture, protocols for connections, data models etc. IEC 61850 do not define what kind of devices or communication links should be used. It only defines the ambience where things should operate. Data transfer is usually done with Ethernet which is bus based system where connected devices can send and/or receive information. (Siemens 2011) (Liang & Campbell 2008)

Many substation communication protocols and methods used in utility grid that can offer fast and reliable communication usually via Ethernet. In microgrids the distances are longer than at substation but the data transferring has to be almost as fast. In Laaksonen & al. (2011) it is suggested to use IEC 61850 for microgrid communication. Study doesn’t offer any practical solutions for communication. In Elias-AlceGa & al. (2011) communication between microgrid protection devices also known as IEDs (Intelligent Electronic Devices) is done according to IEC 61850. (Laaksonen & al. 2011)

Thus the IEC 61850 can be used for microgrid protection communication there might be some problems in real life solutions because the definition of IEC 61850 is quite unspecific. IEC 61850 standard is complicated and includes some open questions in detail planning. IEC 61850 is a mixture of application and node communication. This means that separated system parts that are based on IEC 61850 have to have similar application logic for successful implementation. Thus only the label of IEC 61850 standard won’t guarantee successful operation. The object oriented approach on which the standard is based requires intelligence from implemented devices. Manufacturers have adopted IEC 61850 standard well and new protection devices are IEC 61850 compatible. Because the intelligence is software based, new applications can be downloaded for protection devices. Software can also be updated which means that suitability issues can be solved. (Liang & Campbell 2008) (Siemens 2011)

4.6 Communication of protection devices

A great deal of studies doesn't give specific details about communications. Most of the studies on rely only the assumption that fast and reliable communication can be achieved with IEC 61850 standard devices. Many protection devices like ABB REF 541 support several protocols like LON, SPA, Modbus and IEC 61850. Protocols don't define what kind of communication link should be used so one open question is how the communication between protection devices is built? In some cases also wireless options are needed.

As mentioned before the communication is needed also for other smart grid applications and it could be possible that optical fiber network is available all around the microgrid. When it is possible to use optical fiber network, it should be done because optical fiber is the most reasonable available communication link. Optical fiber is good for long distances because the data travels fast and only few repeaters are needed. Signal travels in optical fiber 1000 km in 5 milliseconds. If this is compared to the limit value for time-selective operation of relays which is about 150 ms it can be concluded that optical fiber is fast enough under any circumstances. (ABB 2004)

If physical connections are not available some wireless options are needed. One option for communication link could be GPRS (General Packet Radio Service). GPRS is widely used for mobile communications. GPRS technology enables sending and receiving at the same time which is new compared to older wireless techniques. The problem of traditional GPRS is latency which can be as much as 1 s. This means that the GPRS connection isn't always fast enough.

Enhanced GPRS also known as EDGE (Enhanced Data rates for GSM Evolution) can provide end to end latency less than 150 ms. Hence EDGE could be fast enough for selective relay protection usage. The problem with EDGE is that latency is not always this good and it can sometimes be as high as 600 ms which is not fast enough. In HSDPA (High-Speed Downlink Packet Access) latency is less than 150 ms so it is fast enough for protection usage. The conclusion is that the most developed wireless communications can offer data transfer speeds high enough for protection usage. Problem with these wireless communications might be how they work in practice under every circumstance? Some reliability analysis should be considered before applying EDGE or HSDPA as the base of communication. (Vrolijk & Bouwman 2008)

The development of communication is needed in almost all of the smart grid applications. In Partanen (2011) it is suggested that in future every device have own IP (Internet Protocol) address. With IP address data finds the right device. Domain specific protocol will probably be the base of smart grid communication. If the costs of fast and effective communication network are targeted to only one of the smart grid applications, it is difficult to get that application competitive with existing solutions. But if the cost of communication is divided to all smart grid innovations the significance of the communication costs will be negligible small. (Partanen 2011)

5. RELAY PROTECTION SOLUTIONS FOR MICROGRIDS

It has been shown in Sortomme & al (2010) that the available relay technology can satisfy the needs of microgrid protection. The problems in the microgrid protection are not in the relay technology but in configuration and communication between protection units. Relays can detect well usual single line-to-line and line-to-ground faults but the challenge comes with high impedance faults. In High impedance faults the fault current is hard to separate from load current. (Sortomme &al. 2010)

5.1 Different protection schemes

Feeder terminals have capability to measure and observe currents and voltages from phase and neutral lines. With combination of these features all possible fault schemes can be detected. Even though the faults can be detected relay settings are not easily determined. Relay setting need specific knowledge about the protected network. Relays offer many choices to protect the grid and the best one is selected case by case. Different measurements can used to get safe and reliable protection. (Sortomme & al. 2010)

Several relay based protection methods have been shown for microgrids. Sortomme & al. (2010) have studied plusses and cons of different methods. These are gathered into Table 5.1.

Table 5.1. Different relay protection schemes for microgrids

Scheme	Description	Plusses	Cons
A	DG current protection	No need for communications	Fails to detect high impedance faults (HIF)
B	DG Voltage protection	Can be implemented to the existing relays	Need for calculations and fails to detect HIF
C	Combination of A and B	Standard over current differential protection and voltage and frequency relays as backup	Probably fails to detect high impedance faults (HIF)
D	Synchronised phasor measurements	May be able to detect HIF's	Still under development
E	Microprocessor relays with phasor measurements	Can detect all fault types	Costs and still under development

Schemes A, B and C are already available but they might have problems to detect high impedance faults. Schemes D and E can detect high impedance faults but they are still under development which means that they cannot be implemented into microgrids yet.

5.2 Available microgrid protection schemes

In scheme A every distributed generation unit has own relay that measures currents. The protection is based on sum of phase and neural currents and zero sequence currents. Same relays could also measure voltages with different measurement units. The protection scheme B observes the variation of voltage synchronous frame and compares it to some reference value. This means that when the voltage drops the switch is released. Both methods will fail to detect high impedance faults (HIF) in worst case scenario. HIF detection fails especially when the DGs are connected to the grid via converters. (Sortomme & al. 2010)

Scheme C is combination of current and voltage protection. In this scheme each line is protected with standard over current differential protection. Protection also includes voltage and frequency protection as backup at each DG unit. Even though two methods are added together the reliable protection for high impedance faults might be difficult to achieve. If right placement of distributed generation and protection units is added to sensitive measurement devices, the working protection can be achieved. (Sortomme & al. 2010)

5.3 Future protection methods for microgrids

There have been ideas to have a scheme (D) in which synchronized phasor measurements determine the appropriate islanding and restoration strategy. This kind of protection schemes are still under development. Sortomme & al. 2010 state a scheme (E) in which synchronized phasor measurements and microprocessor relays are used to detect all kinds of faults. The study in question shows that this proposed scheme enables cost-effective protection. Protection scheme E is based on digital distribution feeder relays that include phasor measurements. (Sortomme & al. 2010)

In Sortomme & al. (2010) is mentioned also the case of communication failure which is ignored in many other references. If the communication link fails the relays start to use comparative voltage protection. In scheme E voltage protection takes care of other faults than high impedance faults. The proposed protection scheme E can detect HIF's in two ways. First one is to have very sensitive current transformers that can detect fault currents where magnitude is at least 10 % of the nominal current. Detection is based on differential protection. Other method for HIF detection is the program relays to detect certain HIF characteristics mentioned in chapter 4.1. The second method needs more development from the protection devices. These schemes can not yet be installed into microgrids but they can be achieved with small development in the technology. (Sortomme & al. 2010)

5.4 Available feeder relays

Today feeder terminals can offer the properties that are needed from the microgrid protection. In Finland VAMP and ABB are the most famous feeder relay manufacturers. They both offer feeder relays that supports IEC61850 standard. VAMP 40 and ABB REF 541 are shown in Figure 5.1.

Figure 5.1. VAMP 40 feeder and motor protection relay (VAMP 2011) and ABB REF541 feeder terminal (ABB 2004).

VAMP is a manufacturer of protection and control devices. VAMP manufactures different feeder relays for different purposes. In the front panel of VAMP 49 that is shown in the figure is LCD display, keypad buttons, indicator lights and RS 232 serial port. Keypad buttons are made for navigation in the menu and to set parameters for protection. With serial communication port relay settings can be done with a computer. Similar features can be seen in the REF541 front panel: display, buttons, indicator lights and communication connection (ABB 2004). (VAMP 2011)

VAMP 40 offers most of the features that are needed from microgrid protection unit. Most of the protection functions have two sets of parameters. This is needed for utility and microgrid mode operation. The active setting group can be selected from the device or trough remote communication. Thus the Microgrid Management System (MMS) is needed. This also means that MMS has to detect when the islanding happens and send signal to VAMP. With two setting groups own microgrid mode settings can be used. In Sortomme & al. (2010) is mentioned that the differential protection scheme can detect High Impedance Faults (HIF's) with the high sensitivity of current transformers. VAMP 40 over current protection has pick up current capability 0.10-5.00 x I_N. Thus at least theoretically all of the HIF's could be detected. Case specific calculations are needed to get certainly reliable protection because the placement of distributed generation and relays affect significantly. (VAMP 2011)

ABB manufactures REF family that includes many feeder terminals. REF feeder terminals offer several options for protection settings. Different setting groups are separated and can work independently. The structure of panel is same as in VAMP (display, buttons, indicator lights and communication connection). Capability to pick up current is also same in REF 541 as in VAMP 40. This means that also REF should detect all fault types if the configuration is correct. REF has capability to change setting group with remote signal. Hence REF can be considered as a protection unit for microgrids. To work as microgrid protection units there is need for system planning, configuration and on site testing before applying feeder relays into the microgrid, though configuration and testing are also done before initialization of utility grid. (ABB 2004)

6. CONCLUSION

Thesis points out the main challenges of microgrid protection. These challenges are detection of high impedance faults and communication between protection units. Development of technology will offer more sophisticated and more secure protection schemes. New schemes can offer synchronized phasor measurements which can be used to detect the faults. These new schemes are not reality yet.

In this thesis the protection of microgrid is concluded to be possible with existing relay protection devices. Feeder terminals can communicate with control system which is the base of the operation. In microgrids the fault current levels are much lower than in utility grid. In utility grid the fault currents are dozen or more times higher than load current but in microgrid the maximum short circuit current might be only two or three times the load current. Sensitivity of current transformers is the key for detecting low fault current levels during microgrid operation.

The main contribution of this study is that microgrid protection can be done without major development in the technology. Thus the protection is not a barrier for testing and implementation of a pilot microgrid. Although the problems with protection can be solved, there are some subjects that need further study. Role of central control system that works together with protection is the backbone of the distribution system. Microgrids need own software that takes care of the operation. Use of existing SCA-

DA and DMS with microgrid settings should be considered as one solution for microgrid control.

To guarantee secure and selective operation microgrids need measurements that provide information for SCADA and DMS. Optimum numbers of measurement points and protection units have to be defined case by case based on the network topology. This means that case specific calculations are needed. Microgrids need batteries or other energy storages to achieve stabile control. Hence case specific economical calculations are recommended before implementation of microgrid.

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