SHORT CIRCUIT BEHAVIOR OF DISTRIBUTION GRIDS WITH A LARGE SHARE OF DISTRIBUTED GENERATION UNITS

Edward J. COSTER
TU Eindhoven – Netherlands
edward.coster@stedin.net

Panagiotis KARALIOLIOS
TU Eindhoven – Netherlands
p.karaliolios@tue.nl

Ioanna XYNGI
TU Delft – Netherlands
i.xyngi@tudelft.nl

J.G. (Han) SLOOTWEG
TU Eindhoven – Netherlands
j.g.slootweg@tue.nl

Marjan POPOV
TU Delft – Netherlands
m.popov@tudelft.nl

Wil L. KLING
TU Eindhoven – Netherlands
w.l.kling@tue.nl

Lou van der SLUIS
TU Delft – Netherlands
l.vandersluis@tudelft.nl

ABSTRACT

Nowadays the amount of distributed generation (DG) units is increasing rapidly. Most of these units are connected to the distribution grid. With the increasing penetration level the impact of these units on for instance power flows, fault levels and protective systems cannot be neglected anymore. To allow an increasing penetration level of DG without causing protection problems or unacceptable power flows and fault levels the impact of DG has to be studied thoroughly. Therefore in cooperation with Dutch grid operators and two technical universities a research project has started which focuses on protection issues, fault ride-through behaviour and autonomous operation of distribution grids including DG. In this paper an outline of the project is given and some results are presented.

INTRODUCTION

The society's dependency on electrical energy is greater than ever and will keep increasing in the future. Major power system disturbances and outages have a significant economic and social impact and the security of supply becomes a more and more important issue. Furthermore, due to the increased energy consumption there is a need to expand the electricity generating facilities which causes increased CO_2 emissions, if the electricity is generated in conventional power plants. To cope with the environmental impact of conventional power plants and reduce the greenhouse gas emissions the European policy is to generate 20% of the total consumed energy with renewable energy sources by the year 2020. As a result, the number of renewable energy sources, such as wind turbines and solar panels, is growing.

Along with this development there is a trend towards high efficient, low cost Distributed Generation (DG) based on conventional fuels. Driver for this development is the liberalization and deregulation of the electricity market. The liberalization allows parties to install generators coupled to a specific primary process and sell the produced electricity to the market as a by-product. One of the consequences is an increase of small generators which are spread out or distributed over the area.

Problem definition

Integration of DG impacts important distribution grid features such as local power flow, voltage control, grid losses, power quality and fault level [1].

Besides these effects also the performance of the protective system can be affected. Traditional distribution grid protective systems respond fast enough to clear a fault in a passive distribution grid. But, when DG with a synchronous generator is connected the time needed for the protective system to detect and clear the fault can exceed the stability limit of the DG, hence, the DG has to be disconnected before the stability limits are exceeded.

According to some technical standards, for instance in [2] DG must be automatically disconnected when faults or abnormal conditions occur. This prevents damage to the DG and it also prevents interference with the protective system. Because of the increasing importance of DG the unnecessary disconnection of DG is no longer desirable, reduces the expected benefits of DG and should be avoided.

Intelligent power system research program

To guarantee proper distribution grid operation and protection including a large share of distributed generation units, the fault current contribution and dynamic behavior of these units has to be studied. These topics are addressed in the project on “Short-circuit behavior and protective systems in distribution networks with high penetration of DG” that was initiated by the Electrical Power Systems groups of the Delft University of Technology and Eindhoven University of Technology in cooperation with utility partners. The project is divided in three parts:

1. System behavior of distribution grids including DG
2. Protection philosophy of distribution grids including DG
3. Islanding capabilities of various types of DG

In the first part of the project, the impact of FRT criteria on CHP-plants and wind turbines during faults in the transmission and distribution grids are investigated. Furthermore, the impact of FRT-requirements on the stability of CHP-plants and wind turbines are studied. The current distribution grid protection has also an impact on the stability and FRT-behavior of DG. Hence, in this part of the project these impacts are studied as well.

The second part of the project focuses on the impact of DG interconnection on the grid protection and proposes smart protection philosophies in order to overcome the current shortcomings. In order to increase the DG availability, the fault clearing process is speeded up by applying an integrated protection concept. The real time implementation reflects a smart protection scheme, making use of smart hardware sensors, standard communication protocols and multifunctional software algorithms.

High DG penetration also offers possibilities for islanded operation of distribution networks, because both generation and load are connected so it might be possible to achieve a power balance within the distribution network and to operate it in islanded mode. In the third part of the project, various approaches towards controlling active and reactive power of DG, including the capability of an existing MV grid with a high penetration of DG to survive from a disconnection from the high voltage grid are investigated. In this paper the first results of the project are presented.

CONSEQUENCES OF FRT-CRITERIA

To mitigate the impact of DG on power system stability grid operators have defined Fault Ride-Through (FRT) criteria for DG. These criteria were already set for central power plants but now also become operational for DG connected to distribution grids. Fault ride-through criteria define for what voltage dips with certain duration, the DG has to stay connected to the grid. Depending on the size of the DG-unit the FRT-criteria can also require additional grid support, such as voltage and frequency support, during and after a disturbance. FRT-criteria are developed not only for wind turbines but also for other types of DG. An example of different FRT-criteria for different types of DG is given in [3]. There, a distinction is made between type I and type II generators. A type I generator is a synchronous generator and is directly (only through the step-up transformer) connected to the network. All other generating plants are type II generating units. The CHP-plants studied in this paper can be considered as a type I generation plant and in figure 1 for such type I generator the borderline of the voltage profile at the Point of Common Coupling (PCC) is depicted.

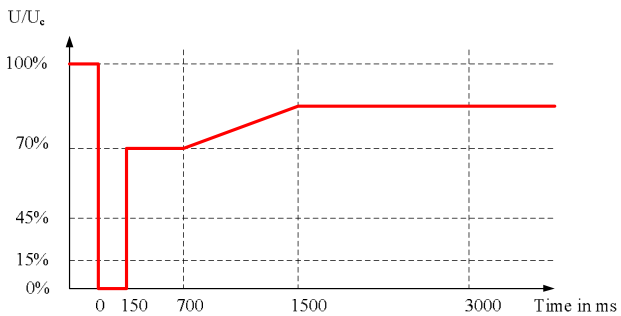

Figure 1: Fault ride-through criteria for a type I generation plant

The borderline given in figure 1 can be interpreted as the maximum voltage dip which can be withstood by the DG-unit without loosing stability.

The rotor dynamics of synchronous generators are initiated and governed by a difference in mechanical and electrical power. For generators running in parallel a sudden drop in electrical power is mainly caused by voltage dips in the grid as a result of short-circuits in the power system. The duration of the voltage dip and thus the fault clearing time of the protective system has a strong relation with the stability of the synchronous generator. This also holds for the depth of the voltage dip. The maximum fault clearing time without causing unstable operation of the synchronous generator is the Critical Clearing Time (CCT).

The depth and duration of a three-phase voltage dip on the generator terminals is used to determine the CCT of a CHP-plant. In figure 2 a two-bus test network consisting of the CHP-plant model and a voltage source is shown.

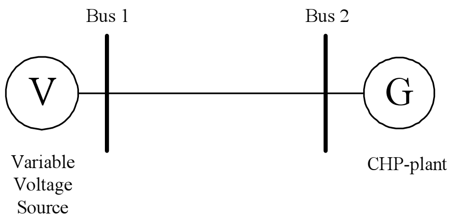

Figure 2: Two-bus test network including variable voltage source

The variable voltage source can create a three-phase voltage dip with a predefined depth and duration. Dynamical simulations are carried out to find the CCT of various CHP-plants for a certain depth and duration of the voltage dip. In these simulations the rotor angle is used to determine if the CHP-plant stays in stable operation after a voltage dip of a certain depth and duration. Instable operation of the CHP-plant occurs when the rotor angle swing exceeds the value of 180° with respect to a common reference source. The results of the simulation are plotted in so-called CCT-curves and are shown in figure 3. In figure 3 U_{dip} is the remaining voltage of the voltage dip.

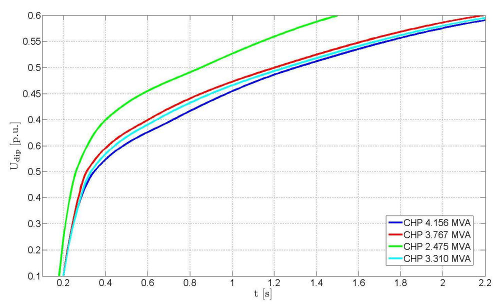

Figure 3: CCT-curve of various CHP-plants

It can be seen that for deep voltage dips the CCT is relatively low while for shallow voltage dips the CCT significantly increases.

In this research project an existing MV-grid including a large number of CHP-plants is modeled in simulation software including the protective system and FRT-criteria of figure 1. The simulation results show that for local short-circuits that all CHP-plants are disconnected due to violation of the FRT-criteria. However, with the FRT-criteria disabled the simulations show that almost all CHP-plants become unstable because the fault clearing time of the grid protection exceeds the critical clearing time of the CHP-plants. In general it can be concluded that the current protective system is too slow to prevent disconnection of CHP-plants and to keep the CHP-plants in stable operation. In order to do so in the near future there is a need for faster protective systems.

PROTECTION PHILOSOPHY OF DISTRIBUTION GRIDS INCLUDING DG

The fault clearing process, in future Dutch distribution grids containing a high amount of DG units, needs to be speeded up in order to solve the aforementioned shortcomings. It is therefore desired to modify the grid protection so that the DG units remain connected to the system even when nearby faults occur. In the second part of the project protection algorithms are improved and combined with state of the art sensor technology in order to keep the fault clearing time as low as possible.

A smart way of achieving this is by introducing communication channels in the distribution networks and by making use of the current numerous communicative abilities of modern microprocessor relays. In this way, future protection schemes can be built up that make local trip decisions based on the information that originates from different locations in the network. This is important to enhance accurate and selective trip decisions in the DG protection system, since current traditional relay protection algorithms do not reflect accurately what is going on in the overall network.

The evolution of contemporary microprocessor relays to communicate digitally with the rest of the power system makes it possible to perform many different functions that facilitate effective power system operation. Examples of these functions are metering, protection, automation, control, digital fault recording and reporting. This gives protection specialists the opportunity to extend today's strictly local-information-based relay protection to innovative communication-based distributed protection applications. Intelligent Electronic devices (IEDs) do prevail in today's substation infrastructure and IEC61850 is at the moment the only standardized effort to address such communication issues inside the substation boundaries. IEC 61850 enhances predominantly distributed protection applications. However, protection of typical Dutch distribution grids gains more advantages with the application of totally integrated protection algorithms. Such an advanced and alternative protection concept for coordinating relays in Dutch MV grids is proposed, described and evaluated in [4].

The fully integrated protection scheme can be implemented with the installation of SASensor (Substation Automation Sensor) systems in strategic branches and busbar points of the network. The system consists of a Central Control Unit (CCU) and three types of process interface modules, one for 3-phase current, one for 3-phase voltage and one for indication and control, as depicted in figure 4. The Current Interface Module (CIM) and the Voltage Interface Module (VIM) are connected to the conventional instrument transformers CTs and VTs. The Breaker Interface Module (BIM) is used for position and alarm indications as well as to open/close the switching devices. The primary information digitized by the process sensors is transferred to the CCU with fibre optic cables. All protection functionality is executed as software in the CCU. A detailed description of the SASensor concept and possible applications can be found in [5].

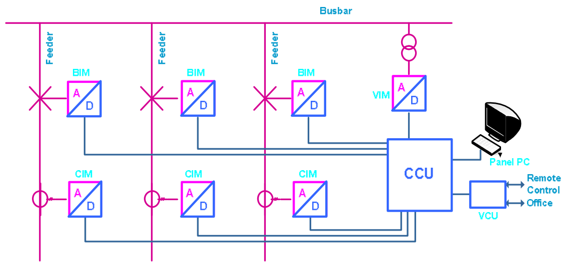

Figure 4: New substation-oriented hardware organization

The relays algorithm is based on upstream zonal blocking and interlocking busbar-based protection concept. Both concepts are founded on directional overcurrent principle but utilize blocking signals to enhance the relay performance. Thus, in this case blocking signals have been used between the different operational zones to enhance the protection reliability. The binary signals generated by each measurement unit were used to block the directional overcurrent function of upstream relays installed in the same feeder [4, 6]. The overall binary status signals of the blocks generated the final trip signals which are transferred back by means of communication to trip the circuit breakers.

The new algorithm efficiently increases the relay speed performance and DG during-fault availability, while simultaneously assures protective device selectivity. The incorporation of the directional element into the protection functionality also eliminates the problem of false tripping. Time coordination is additionally eliminated by utilization of redundant and reliable communication links. Finally, the already tested hardware feasibility of the new system architecture, gives the opportunity of an immediate implementation of the scheme in Dutch MV networks.

ISLANDED OPERATION IN RELATION TO FRT-CRITERIA

In the first part, the application of the FRT criteria in DG installed in MV level has been examined. The proven ability of DG to stay connected during s/c can lead to exploration of alternative ways of operating MV grids, especially in the case of high penetration level, where power demand meets with supply. In the case of a loss of connection with the HV grid due to various outages, the MV grid could operate autonomously, forming a MV island in the logic of a micro grid. This operation mode, with use of load shedding tactics and proper voltage and frequency control could survive for a period that would allow the restoration of the lost HV connection.

In order to investigate this possibility, a test network based on an existing MV grid was modeled in detail.

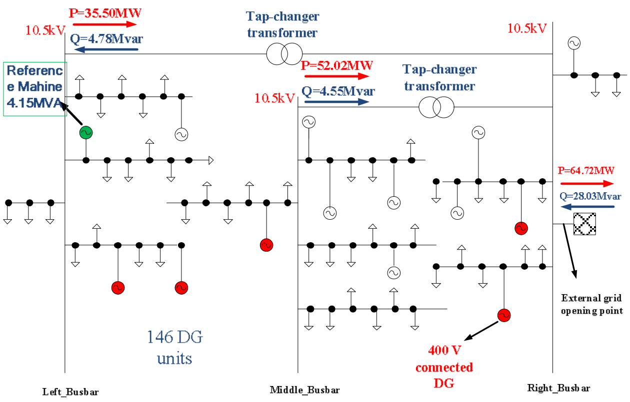

Figure 5: Network scheme

As it can be seen in figure 5, this area has a significant power production coming from CHP plants and in normal conditions it exports power to HV grid. The simulation of various scenarios has proven that the operation of this grid in autonomous mode and the reconnection with the HV grid is possible, with no extended alternations in the infrastructure, under a situation that there is a balanced power demand in the local level.

The network can survive the fault with the HV grid and then run autonomously by applying proper frequency and voltage control in each generator. During the autonomous operation, this control strategy manages to keep frequency and voltage within the limits imposed by the grid code. In figure 6 the disconnection of the network is simulated at 15 sec.

Furthermore, the island has to be able to survive outages which can also occur. Following the CCT curves proposed it can be seen that also during this operation mode, a s/c does not endanger the stability of the island, and voltage recovers within the acceptable limits on time, as it can be seen in figure 7, where a 100ms s/c in the right busbar is shown. Currently the ability to form a stable island has proven to be very depended on pre-disconnection network loading. This limits the flexibility of this scenario, therefore flexible load shedding tactics are being investigated to be able to manage a large power exchange right after disconnection.

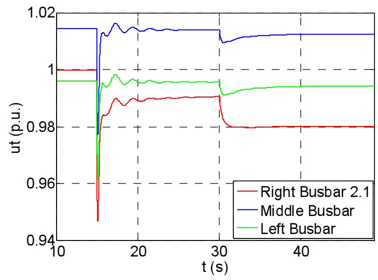

Figure 6: Voltage levels during and after disconnection

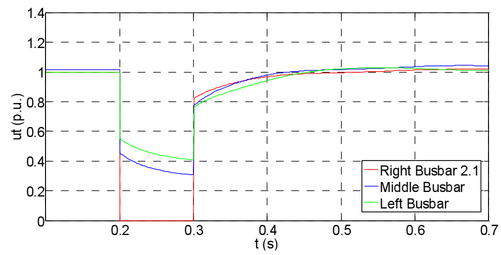

Figure 7: Voltage levels during a s/c in island mode

CONCLUSIONS

In this paper some results of a joint research project are presented. This project has focused on fault ride-through behavior of distribution grids including DG and it can be concluded that FRT-criteria ask for a fast protective system in order to keep DG-units connected to the system. The fault clearing process can be sped up by applying upstream blocking signals and communication channels and it is demonstrated that with these additional measures faults can be cleared fast enough to prevent disconnection of DG. In the project it is also shown that with a sufficient amount of DG connected to the distribution grid this grid can go into autonomous operation. However, load shedding tactics are necessary to make this transition as smoothly as possible.

REFERENCES

[1] T. Ackermann et al, 2002, “Interaction between distributed generation and the distribution network: operation aspects”, *proceedings of IEEE T&D conference, Asia pacific*

[2] IEEE 1547 standard for interconnecting distributed resources with electrical power systems, IEEE 2003

[3] BDEW, “Technical guideline generating plants connected to the medium voltage network”, June 2008 issue

[4] I. Xyngi et al, “Smart protection in Dutch Medium Voltage Distributed Generation systems” IEEE PES *Innovative Smart Grid Technologies Conference Europe*, October 2010, Gothenburg, Sweden.

[5] F. Baldinger et al, 2008, “Advanced Secondary Technology to Evoke the Power of Simplicity”, *IET 9th International Conference on Developments in Power System Protection, DPSP.*

[6] E.J. Coster et al, 2008, “Transient stability of DG in MV-ring networks”, *IEEE T&D Conference and Exposition*