POWER QUALITY CUSTOMER FINANCIAL IMPACT/RISK ASSESMENT TOOL

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ABSTRACT

Recent developments in energy policies and prices have directed an increasing amount of interest at exploiting small energy resources. This small-scale power generation obviously needs to be connected to the present power distribution system with simple manners in order to be economically competitive. As the distribution system has initially been built for simple one-way power delivery, interconnecting small generators requires new thinking and new methods for operating the network. Small-scale generators located on the distribution level are generally referred to as distributed generation (DG). There are several clear consequences for locating DG in the distribution network that need to be taken into account. Probably the most critical concern is the operation of network protection. This can be stated as protection malfunctions can result in safety hazards. The presence of DG affects for instance short-circuit current amplitudes, which can further disturb the operation of feeder protection. DG may also result in failing reclosings or situations in which the DG unit maintains the voltage alone in the network. These situations must be avoided. This paper focuses on the network protection impacts of DG. It aims to provide new tools and methods for including the impacts of DG correctly in network planning methods. This can be achieved by bringing the research observations towards the practical level of network planning. The most important observations of this paper relate to the contradictions between protection selectivity and sensitivity; to the problematic nature of differentiating between faults that require rapid actions and other disturbances that should not result in any action.

INTRODUCTION

Local power generation is not a new phenomenon at all. Actually, the initial forms of power systems comprised of local generation units, for instance hydro power, which were feeding local loads. As the amount of installations requiring electricity increased, a need for a more reliable and economical power delivery arose. Further, this led to a need for a wider power delivery system. As entire power networks were constructed, the power generation was concentrated in larger, centralized power plants. This centralized development absolved the customers of maintaining their own generation. Furthermore, larger generating unit sizes improved overall efficiencies.
The present power systems are still mainly based on centralized power generation. This has been considered as the sole settlement, which has led to extending the electrical network in all areas with demand for electrical energy. Practically, this has resulted for instance in long transmission and distribution lines on rural areas with low demand. The typical interest groups of DG are shown in figure 1. The most important player is the power producer, IPP, who has the initial motive to build the DG unit and to connect it to the distribution network.

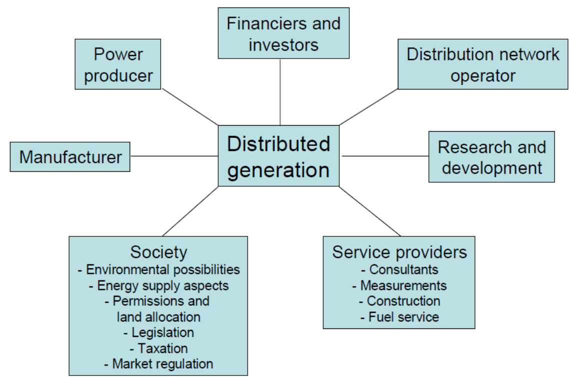

Figure 1. The interest groups of DG.

The purpose of this paper is investigating the network protection impacts of DG and developing methods for assessing them as a part of the practical-level network planning activities. The objectives of the research are focused on usage of advanced network information systems. The point of view applied is clearly on the power system's and distribution network operator (DNO)'s side.

IMPACTS OF DG ON DISTRIBUTION NETWORK PROTECTION

The present-day philosophy of planning and controlling a radial distribution network is based on the assumption of unidirectional power flow. The power is assumed to be fed to the network from higher voltage levels and distributed further to the customers. Short circuit currents are assumed to behave similarly. At the same time, it becomes assumed that the network does not include significant rotating machines, which should otherwise be taken into account. These assumptions enable relatively simple and economical schemes for achieving a selective operation of protection system with suitable gradation settings. [2], [3] According to the principles of selectivity [4], only the protective device closest to the fault must operate to disconnect the fault. Thus the rest of the network can be maintained energized. The propagation of DG on medium voltage and low voltage (LV) levels changes this fundamental basis. The power flows and short circuit currents may even have upstream directions or at least their amplitudes will change due to presence of DG. [5] Thereby the initial schemes applied for instance for feeder protection may become inoperative or less efficient. A typical distribution network has simply not been designed for power generation units with upstream contribution, which may result in problems. [3], [6] The whole distribution system becomes more active as both loading and generation affect the state of the network continuously [7]. One complicating fact is formed by uncertainties related to DG. DG units may remain connected or disconnected depending on different factors. The protection system – as well as the whole network control system – must operate correctly regardless of the state of the DG units. DNO may also be totally unaware of the state of the small DG units. In addition to protection impacts, DG has other influences on the usage and performance of the distribution system. The most important of these is probably the impact on voltage levels. The modified power flows relate closely to voltage levels. DG can also affect the power quality and overall network reliability. The transient stability of the system may also be an issue. These considerations must also be included in the DG interconnection studies, although this thesis is focusing on protection impacts only. When considering a distribution network with installed DG units, the main concern is the correct co-operation of protection devices during all possible faults. Network feeders are typically equipped with dedicated protection relays for managing short-circuits and earth faults. The feeding substation is usually equipped with protection for busbar faults, which also acts as a back-up protection for the feeder protection. The DG connection point is equipped with similar relays with dedicated operation characteristics. The most traditional protection devices of DG connection point are voltage and frequency relays. They are used for detecting abnormalities in the connection point state, which are caused by network faults or other disturbances. Their operation is determined by imbalances of active and reactive power. [8] Their sensitivity and operation times can be adjusted freely. Especially the voltage protection is often set with operation time steps for fast and delayed tripping. The DG connection point is also equipped with overcurrent protection. However, plain overcurrent is not considered a reliable protection factor due to the behaviour of different generator types as explained later. Thus the overcurrent protection often acts as a protection against DG unit's internal faults and short circuit faults near the DG unit. In many cases it is implemented with LV fuses instead of relays. Over-/undervoltage, over-/under frequency and overcurrent functions form the elementary protection of the DG unit. Additionally, the connection point is nowadays usually equipped with loss-of-mains protection, which is often necessary for avoiding situations, in which the DG unit maintains the voltage in the part of the network while the connection to the main system is lost. This is above all a safety issue. A dedicated earth fault relay may also be necessary depending on the network circumstances.Coordinating the operation of DG and feeder protection during different faults is definitely a challenging task. A relatively common practice prefers disconnecting the DG unit during the fault to provide the feeder protection with a normal radial fault situation to be cleared. [3] This is highly required in cases in which DG may actually disturb the operation of feeder protection. Even if the DG unit can not disturb the feeder protection, it will need to disconnect immediately after the feeder breaker operation to avoid islanding situation. Thereby it is a good basic rule to disconnect the DG unit in all cases that require action from the feeder it is connected to. It must be kept in mind, that the protection devices protect also the DG unit against unusual situations.The previous rule leads us to another problem related to the protection coordination. The DG unit has very minor possibilities to differentiate faults requiring action from those that are, for instance, located on other feeders fed by the same substation. If we consider a short-circuit or an earth fault occurring near the substation on the DG feeder and on the adjacent feeder, it is practically impossible to differentiate these situations from the DG unit's point of view. So far, a quite general solution has been to simply adjust the DG unit to trip during all network faults, thus assuring the safety of the network. In other words, unnecessary trippings of DG units have been allowed in the name of safety. As the amount of DG increases, it will also have more significance during disturbances regarding the frequency and voltages of the network.

- **Sensitivity problems**

Sensitivity problems are possible in cases in which the initial feeder relay settings are not checked as DG is installed in the network. Sensitivity problem means a fault that is not detected at all or is tripped slower than in the initial scheme. It is obvious that this may result in severe safety problems. Additionally, relay operation delays may result in exceeding the thermal limits of network components. It is essential to note, that the overall short-circuit currents will increase due to the DG integration, which makes the operation delays more crucial. The sensitivity problem related to the operation of feeder protection is often called *protection blinding*.

Figure 2. shows a typical situation in which the blinding may take place.

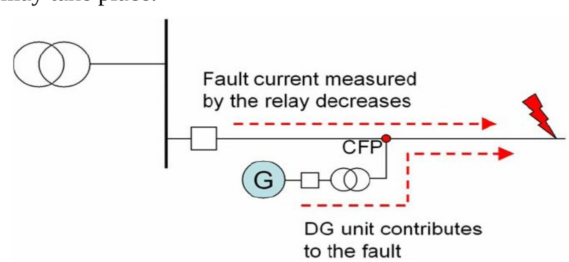

Figure 2. Simplified presentation of a situation in which blinding occurs.

- **Selectivity problems**

DG-related selectivity issues include two typical problems; the possibility of unnecessarily disconnecting the DG feeder (also called *sympathetic tripping*) and the possibility of nuisance tripping of DG units. Neither of these events causes an actual safety hazard, but they are of great harm to both producer and network operator. In both cases, IPP suffers a certain amount of energy not produced due to the missing network connection. In the case of sympathetic tripping, the customers of the whole feeder experience a totally unnecessary interruption, which results in reduced reliability from the DNO's point of view. Also the nuisance tripping of DG results in voltage variations and reduced quality of power supply.

A typical situation during which sympathetic tripping is possible is shown in figure 3.

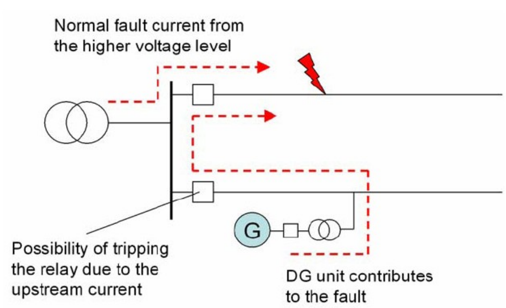

Figure 3. Upstream contribution of DG and the possibility of tripping nondirectional relay.

- Failed reclosing

Automatic reclosing is generally applied in distribution networks for clearing temporary short-circuits or earth faults. Practically it means opening the feeder breaker for a short period, during which the arc at the fault point can decay or the fault may become otherwise cleared. For instance a falling branch of a tree causes a momentary short-circuit fault which may be cleared during the automatic reclosing sequence. According to statistics [8], 90 per cent of all faults were cleared by automatic reclosings on feeders where they were applied. Similar values have also been presented in [7], [2]. If the DG unit is not disconnected properly during the reclosing sequence, it may be able to maintain the voltage in the network and feed a fault current in the case of short circuits. This may further maintain the arc in the fault point. As a result, the fault seems permanent when reconnection is performed. Figure 4. shows a situation during which the reclosing may fail.

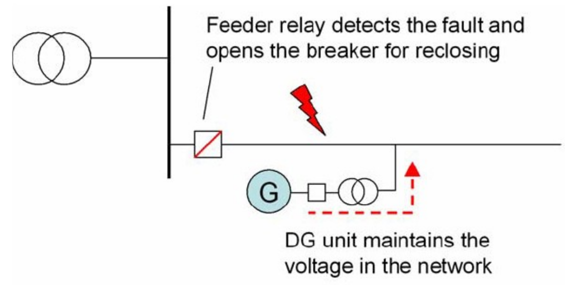

Figure 4. Failing reclosing due to the DG unit.

- Loss-of-mains detection

Loss-of-mains detection – also known as islanding detection – is the subject drawing the most research interest in the area of DG protection at the moment. Increasing amount of DG together with more efficient control system makes unintended islandings more probable. [3], [8], [9] During islanded operation, the DG unit remains feeding a part of the network alone without connection to the public system. It can be seen that islanding detection problems are highly linked to reclosing problems discussed in previous section. An island can be formed through fault or any breaker or switch operation. Basically, unintended islandings must always be prevented. The most important reason for this is assuring the safety of the network. The network must not be energized by the DG unit when it is assumed to be de-energized from the system's side. This could result in severe safety hazards to the network personnel. Another reason relates to the fact that DG units are typically not planned for operating the network in island. Thus the quality of power during the islanded operation can not be guaranteed. Deviations may result in damage to the network equipment as well as to consumer equipment. Asynchronous reconnection during the reconnection to the main grid may result in exactly the same problems as in the case of failed automatic reclosings. [3]

- Earth fault detection

The impact of DG on system earth fault performance is a difficult issue as it depends strongly on the network type and earthing methods applied. Studies performed by the author so far consider the typical Nordic network with isolated neutral. A delta-wye unit generator transformer is used to connect the DG unit to the network. The wye is earthed from the generator side. In such a case, the zero sequence network is cut at the transformer. Thus it is difficult to detect system earth faults from the LV side of the transformer. [5] At the same time, this network configuration means that DG does not contribute to earth faults as actively as it does in the case of short circuits. Thereby no problems related to selectivity or sensitivity of feeder earth fault protection are expected.

Overview of simulation results

In the following, an overview of the simulation results is given. presents simulations in a realistic network with relatively smallscale wind power units. In this study, the network was quite strong and no significant problems were thereby observed. The traditional induction generators that were used in wind power units also influenced the results. On the other hand, all the data used was real and the results were thereby of great interest. The blinding phenomenon was observed, but it can not result in feeder protection problems as the difference in short-circuit current is minor. This can be seen in figure 5.

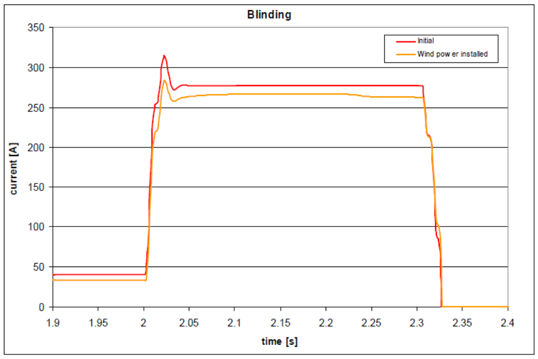

Figure 5. Blinding observations.The impact is not critical although clearly observable.

Similarly, upstream short-circuit contributions were not observed to cause sympathetic trippings. Much more interesting observations were made regarding short-circuits occurring on the adjacent feeder. Short-circuits closest to the substation were observed to trip the wind power units without actual need. Short circuits with a distance of 5 and 15 kilometres from the substation trip the DG unit with the operation time of 0.1 seconds as the voltage decays below the fast tripping limit as shown figure 6. Short-circuits with longer distances result in voltage dips that are not great enough to cause unnecessary trippings. The slow operation time of voltage protection is set at 10 seconds, which does not relate to voltage dips caused by short-circuits.

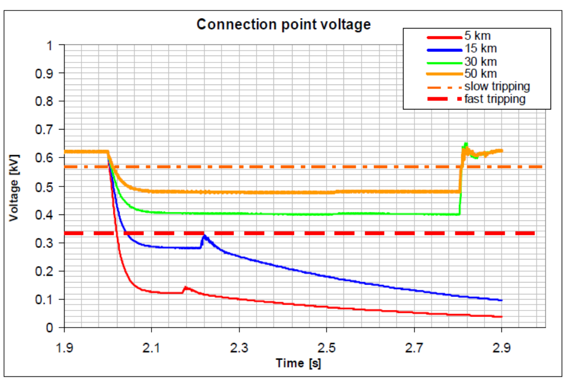

Figure 6. Connection point voltage during short-circuit faults with varying location on adjacent feeder The unnecessary trippings can be seen during closest faults after 0.15 and 0.2 seconds. Fault occurs at 2.0 seconds and is cleared by feeder protection after 0.8 seconds.

Conclusion

The major contributions of this thesis can be condensed as follows:

• The protection impacts related to DG have been covered and analyzed.

• The coordination of protective devices during different situations has been considered.

• Novel methods for assessing the studied impacts on network planning level have been proposed.

• The protection planning procedure presents an approach that can be automated as a function of NIS but can also be used as a manual reference during DG interconnection studies.

• Development needs and possibilities for present network planning systems have been considered and ideated.

REFERENCES

[1] CIGRE Task Force C6.04.01. Connection criteria at the distribution network for distributed generation. IGRE 2007. 195 p.

[2] Salman S.K., Rida M. Investigating the Impact of Embedded Generation on Relay Settings of Utilities' Electrical Feeders. *IEEE Transactions on Power Delivery*, Vol. 16, No.2, April 2001, pp. 246-251

[3] Dugan R.C., McDermott T.E. Distributed Generation: Operation Conflicts of Distributed Generation interconnected with Utility Distribution Systems. *IEEE Industry Applications Magazine*, March/April 2002. pp.19-25

[4] Anderson P.M., Power System Protection. McGraw-Hill, 1999. 1307 p

[5] Girgis A., Brahma S. Effect of Distributed Generation on Protective Device Coordination in Distribution System. *LESCOPE 01 Conference on Large Engineering Systems*, Halifax, USA, July 11-13, 2001. pp. 115-119

[6] Scheepers M., van Werven M., Mutale J., Strbac G., Porter D. Distributed Generation in Electricity Markets, its Impact on Distribution System Operators, and the role of Regulatory and Commercial Arrangements. *International Journal of Distributed Energy Resources*, Vol.2, No.1, January-March 2006, pp. 35-58

[7] Jenkins N., Allan R., Crossley P., Kirschen D., Strbac G. Embedded Generation. IEE Power and Energy series 31, London, UK, 2000. 273 p.

[8] Hartmann W.G. How to Nuisance Trip Distributed Generation. *Rural Electric Power Conference 2003*, Raleigh-Durham, NC, USA, May 2003. pp. C5-1 – C5-11

[9] Gatta F.M., Iliceto F., Lauria S., Masato P. Modelling and Computer Simulation of Dispersed Generation in Distribution Networks. Measures to prevent disconnection during system disturbances. *IEEE PowerTech Conference*, Bologna, Italy, June 23-26, 2003. 10 p.

[10] Chin Koon L. Interconnection of Embedded Generation: The Malaysian Experience. *CIRED 18th International Conference on Electricity Distribution*, Turin, Italy, June 6-9, 2005. 5 p.