NETWORK INFORMATION SYSTEM BASED LOSS OF MAINS RISK MANAGEMENT

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ABSTRACT

A large variety of different loss of mains (LOM) protection schemes is nowadays available. Network utilities are facing a difficult task when trying to decide which of the available schemes is the most appropriate choice for each DG installation. This paper presents a novel network information system based concept for aiding in this task and in managing the LOM risk.

INTRODUCTION

The amount of DG is growing strongly. This brings potential benefits, but a number of challenges related to the integration of DG are also present. Unintentional islanding is one of the most troublesome of these challenges. This is due to the associated safety problems such as failed reclosings, damage caused by out of phase reclosings, safety hazard for utility field personnel and risk of customer loads being damaged due to poor power quality. Because of these concerns, it is mandatory to equip all DG units with some kind of loss of mains (LOM) scheme which disconnects the protected DG whenever it becomes islanded.

There are a large number of different LOM protection methods. Generally the methods can be divided into four categories which are passive, active, hybrid and communication based methods. Passive methods are affordable, simple and applicable to all types of DG units but commonly suffer from relatively large non-detection zone (NDZ). Many active methods have a very small sized NDZ, but these methods generally have a degrading effect on power quality. Hybrid methods create less power quality problems compared to active methods but their operation times also tend to be slower as several methods are used in sequence. Communication based methods can usually eliminate the unintentional islanding problem completely, but the high cost of implementing these methods makes it unreasonable to utilize these kinds of methods for the protection of small DG installations. Moreover, a local LOM detection scheme is always needed for backup protection in case if the communication medium fails.

All four classes of LOM protection methods thus have their pros and cons, and consequently potential utilization cases. For instance, for converter connected DG units it is often favorable to utilize active or hybrid LOM detection schemes, whereas, for directly coupled DG units they are rarely an option. Sometimes the network utility may also forbid the use of active methods due to power quality issues. Because of the large variety of LOM protection schemes, there should be a simple way by which one can assess which method is the best choice for each DG installation. This paper proposes a network information system based LOM risk assessment procedure as a solution to this need.

THE RISK OF NON-DETECTED ISLANDING

The performance of most LOM detection schemes is highly dependent on the power imbalance in the islanded circuit. Large imbalances between production and consumption lead to large deviations in voltage magnitude and frequency in a circuit separated from the main grid. Such a situation is easy to detect for LOM protection. However, LOM protection may become completely non-operational in situations where the power imbalance before the transition to islanding is of minor scale. The set of active- and reactive power imbalance combinations where LOM protection fails to detect islanding rapidly enough is referred to as the NDZ.

The imbalance between the production of a local DG unit and the consumption of local loads varies throughout the day and throughout the year. Consequently, the risk of unintended islanding also varies most of the time. The size of the NDZ depends on the utilized LOM protection scheme. It can be reduced by applying stricter LOM protection settings but this is usually restricted by the fault ride through requirements and protection security issues. There is, however, yet another factor that affects the risk of non-detected islanding. This is the fact that a DG unit can become isolated from the main grid with various amounts of local loads [1].

LOM RISK ASSESSMENT

The risk of non-detected islanding can be evaluated by comparing the load and the local DG generation on the studied network section. Obviously there is no non-detected LOM risk if the minimum local demand is clearly larger than the local DG generation capacity. However, certain theoretically possible combinations may never occur in practice. For instance, in the north maximum demand occurs during winter season when electric heating is needed, whereas, the production of photovoltaic is lower during winter period than during summer season.

Estimation of imbalances

Network information system (NIS) has become an essential planning tool for almost every distribution network operator.

In Nordic thinking, a typical NIS includes network component data and plenty of calculation functionalities combined to a graphical interface. NIS's usually show the geographical image of the network area on the background in order to help the user to visualize the work better. NIS can be used for many purposes such as network documentation, asset management, network configuration planning, investment planning and construction planning.

Modern NIS provides an excellent platform for the LOM risk assessment. Data from medium and low voltage networks and DG units are already embedded in modern NIS. Data needed to model customers is taken from customer information system. Loads are typically modeled with the help of customer class specific hourly load curves. Maximum and minimum consumption values for all network sections could be calculated with the help of these load curves and nominal data of the studied DG units. This concept is illustrated in Fig. 1.

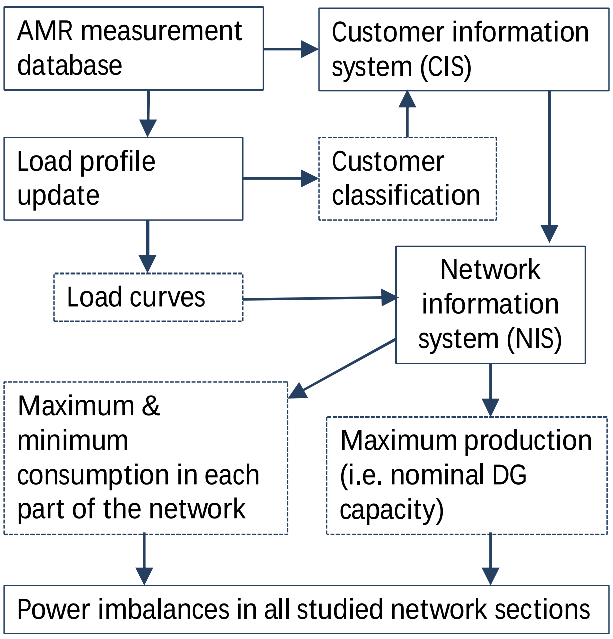

Fig. 1. Estimation of imbalances

The load curves, which are typically divided from 20 to 50 customer classes, contain mean and standard deviation values (normal distribution is nearly always assumed) for electrical energy consumption for every hour of the year. The load curve of each customer is scaled based on the customer's annual energy consumption. If the load is assumed to be normally distributed, the value of load in a calculation which is carried out with a certain confidence level is quantified using the cumulative probability density function of normal distribution. Typical confidence levels used for maximum capacity calculations are 99% and 95% and 1 and 5% for minimum consumption. The possible inaccuracies in the load curves or customer classification could be corrected by utilizing hourly consumption data provided by Automatic meter reading (AMR) system as proposed in [2]. Special customer can be modelled with individual customer specific load curves using real AMR data [2].

All in all, with this approach NIS could be harnessed to calculate the active- and reactive power imbalances for every hour of the year based on statistical load curves and nominal DG capacity. The analysis of imbalances can be realized for all network sections which can theoretically become islanded, i.e. which can be divided by switches.

NDZ risk probability assessment

Evaluating the non-detected LOM risk based on the imbalance between consumption and DG nominal capacity leads to conservative results. The actual probability of the non-detected LOM risk could be determined by extending the load curve based NIS calculation with production curves and then analysing the results of combined load and production curve calculations. Due to the stochastic nature of DG units, production curves are based on long-term statistics of wind speed, water flow, solar radiation or temperature etc. Reference [3] has proposed a method for creating production curves based on very simple initial data of production units and a calculation method for analysing distribution networks for planning purposes. If multiple production curves are utilized in the evaluation, the user would be given a probability of the actual non-detected LOM risk in the form of power imbalance probability distribution.

Determination of the NDZs

NDZ risk margins of optional LOM protection schemes would have to be added to a database. Conservative NDZ estimates should be utilized since the NDZ region not only depends on the protection scheme and protection settings, but also on the DG unit type, utilized control mode of the DG units and characteristics of the loads. For instance, synchronous generators are considerably more challenging from LOM detection point of view than induction generators. Moreover, a converter coupled DG unit behaves very differently than a directly coupled generating unit. [4] – [6]

The estimation of the NDZ regions is a laborious task but it is, nonetheless, doable. This task could be done within a reasonable time frame by using a real time simulator as presented in [4]. The difficult task in such estimation is choosing an appropriate simulation model. A simulation model for testing the performance of LOM protection of a photovoltaic converter is defined in standards [7] and [8]. Although this model is not originally meant for studying the performance of LOM protection in the presence of directly coupled generators, it could also be utilized for this purpose. The parallel RLC load utilized in the model is appropriate for obtaining a conservative NDZ estimate of a LOM protection of a directly coupled synchronous generator as the load equals to a constant impedance load from the synchronous generator point of view. According to [5], constant impedance type load is appropriate for obtaining a conservative NDZ estimate. A suitable quality factor value for the parallel RLC load could be 2.5. This leads to very conservative NDZ estimates since a quality factor value 2.5 is considerably higher than what would be expected from a real load [1].

The modeling of the DG unit(s) is naturally an essential issue for obtaining realistic NDZ estimates. The simulation model should probably include a converter coupled DG and a directly coupled synchronous generator in parallel since the relationship between active- and reactive power with voltage magnitude and frequency is different for directly connected and converter connected DG units [4]. The exciter of the synchronous generator should be set to control the terminal voltage [5]. Another aspect which requires consideration is the inertia constant of synchronous generators. The larger the inertia constant of the machine, the more stable the machine is and thus consequently, the more challenging the situation is to LOM protection. What comes to the control of converter coupled DG units, constant power controlled DG units lead to the largest NDZ [6].

One challenge in the NDZ estimation of different schemes is that the utilized LOM protection settings often vary to some extent from utility to utility. This could be overcome by having NDZs with several protection settings in the database. Another option would be to have the NDZs defined with one relatively loose protection settings. However, this could lead to excessively conservative results in certain cases. Another disadvantage is that it would not be straightforward to add new optional LOM detection schemes since their NDZs need to be defined by simulation studies.

THE LOM RISK ASSESSMENT PROCEDURE

Fig. 2 illustrates the principle of the proposed NIS based LOM risk assessment procedure. At first, the nominal DG capacity, consumption data and conservative NDZ estimates of the optional LOM protection schemes are fed to the procedure. The procedure then examines with the help of NIS if there are any parts of the network where a NDZ risk exists. First, a simple comparison between the nominal power ratings of studied DG units and the annual minimum load on the studied network area is realized. From local LOM protection point of view, the situation is only acceptable in case if minimum demand is sufficiently larger than maximum DG generation capacity. A certain margin which takes into account the expected DG capacity- and load growth in the following years is highly advisable. This comparison then gives the minimum possible active and reactive power imbalances. These imbalances are then compared to the NDZ regions of the optional LOM protection schemes. It is evident that if the minimum annual power imbalance is very large, then the performance requirements for LOM protection are low. In such case, it would be unwise to invest in costly communication based LOM detection schemes. Moreover, active LOM protection schemes could be set to inject less/lower perturbations if simple passive schemes were sufficient for reliable islanding detection.

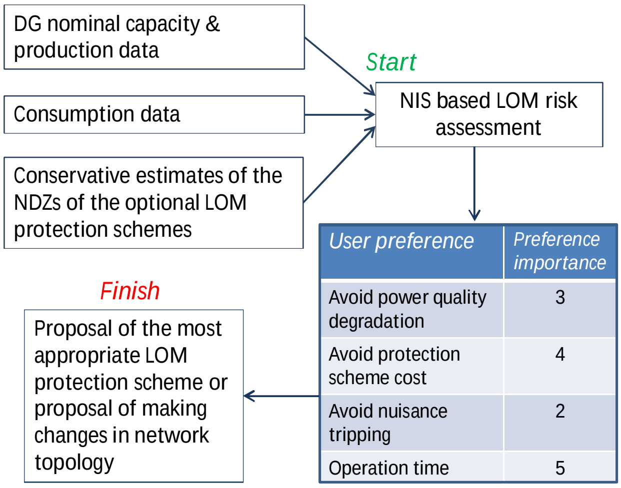

Fig. 2. The NIS based LOM risk assessment procedure

The procedure could also take into account certain user definable preferences as for instance operation time or avoidance of power quality problems. These preference factors would naturally be predefined so that the user was to simply give an importance value to each feature. Finally, the procedure would list few of the most appropriate LOM detection schemes. Optionally, the procedure could also be configured to propose changes in network topology. The idea behind this is that it may sometimes be possible to eliminate the non-detected LOM risk simply by opening and closing certain switches and thereby altering the possible power imbalances in the studied circuit.

As already discussed, certain theoretically possible combinations of production and consumption may never occur in practice. This can be taken into account by performing more detailed hourly analysis of power imbalance based on probability distributions for the potential NDZ risk areas. These network areas can be found out by the simple comparison, i.e., by comparing annual minimum load with the nominal capacity of DG. However, from protection planning point of view it may be more troublesome and risky to take into account the stochastic behaviour of production side since production curves are not accurate in the same way as load curves are and power imbalance probability should therefore be considered as a qualitative supportive guidance for decision making of LOM protection [3].

APPLICATION IN NETWORK OPERATION

The LOM risk assessment could also be extended to aid in network operation. This extension should be integrated to distribution management (DMS) system rather than NIS since the purpose of this extension is to aid in the continuous network operation rather than long term planning. However, the idea of this "real time" application is very similar to that of NIS based procedure. Moreover, network modelling and calculation applications in DMS are mostly based on the same modules as in NIS.

This DMS application is started by using the NIS based LOM risk assessment procedure for assessing appropriate risk margins for demand in each of the studied network sections. This is done by assessing how much larger the demand in each of the studied network section should be in comparison to the nominal capacity of the local DG. Naturally the different performance characteristics of each LOM protection scheme has to be taken into account in this phase. The real time application could then assess the NDZ risk based on the hourly consumption estimates which were scaled based on AMR measurement data and the calculated risk margin. Whenever the imbalance between demand and DG nominal data is large enough, no risk exists. However, if the imbalance was smaller than the calculated margin, the procedure could suggest disabling reclosing functionality of feeder protection relay in the problematic parts of the networks and warn the field crews about the LOM risk. The procedure could also suggest changes in network topology. In a rare and very dire long lasting LOM risk situation, the DG in the problematic network section could be ordered not to operate at their full output power.

DISCUSSION

Running the proposed NIS based procedure for the whole network with large amount of possible switching configurations would require a fairly large amount of computation. However, this is not a major problem since it would be sufficient to run the procedure for the whole network only on an annual basis. Naturally the procedure should additionally be run always when new DG is installed but only for analysing the network sections that are affected by the addition of the new DG units. Another potential use case for the procedure would be to assess the LOM risk whenever network topology changes are planned.

The proposed procedure is applicable only to medium voltage (MV) networks and very large low voltage networks. This is because it is not reliable to assume a certain minimum demand from a small number of customers. The procedure should thus always check that the network section under study contains enough customers for making such an assumption. The main benefits of this procedure are thus in MV-level reclosing coordination planning and in assessing the LOM risk caused by changes made in network topology.

CONCLUSIONS

This paper presented a novel NIS based concept for managing LOM risk. The concept takes advantage of existing calculation features embedded in modern NISs. However, certain additional data is required for the functioning of the proposed procedure. For instance, the NDZs of the optional LOM protection schemes need to be mapped to a database so that the procedure can evaluate the suitability of different schemes for each case. The procedure could help network utilities greatly in choosing appropriate LOM protection schemes for each case and avoid unnecessary investments in communication based LOM protection methods in cases where a local LOM protection scheme is sufficient. The LOM risk assessment could also be extended aid in network operation.

REFERENCES

[1] W. Xu, K. Mauch and S. Martel, 2004, *an Assessment of Distributed Generation Islanding Detection Methods and Issues for Canada*, CETC-Varennes 2004-074 (TR) 411-INVERT, Canada

[2] A. Mutanen, M. Ruska, S. Repo and P. Järventausta, 2011, "Customer Classification and Load Profiling Method for Distribution Systems", *IEEE Trans. on Power Delivery*, Vol. 26, 1755-1763

[3] S. Repo, H. Laaksonen and P. Järventausta, 2005, "Statistical Models of Distributed Generation for Distribution Network Planning", *Proceedings CIRED Conference and Exhibition 2005*

[4] O. Raipala, A. Mäkinen, S. Repo and P. Järventausta, 2012, "The Effect of Different Control Modes and Mixed Types of DG on the Non-Detection Zones of Islanding Detection", *Proceedings CIRED Workshop 2012*, paper 237

[5] J. C. M. Vieira, W. Freitas, W. Xu and A. Morelato, 2008, "An Investigation on the Nondetction Zones of Synchronous Distributed Generation Anti-Islanding Protection", *IEEE Trans. on Power Delivery*, Vol. 23, 593-600

[6] Z. Ye, A. Kolwalkar, Y. Zhang, P. Du and R. Walling, 2004, "Evaluation of Anti-Islanding Schemes based on Nondetection Zone Concept", *IEEE Trans. on Power Electronics*, Vol. 19, 1171-1176

[7] 929WG – Photovoltaic Working Group, 2000, *IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems*, IEEE Std. 929-2000

[8] Underwriters Laboratories Inc., 2001, *Inverters, Converters, and Controllers for Use in Independent Power Systems*, UL Std. 1741