NEUTRAL FAULT MANAGEMENT IN LV NETWORK OPERATION SUPPORTED BY AMR SYSTEM

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ABSTRACT

In this paper, examples of existing AMR systems and IT integration solutions are described. Use cases for LV neutral fault management is specially covered. In order to illustrate the capabilities of the current AMR meters for neutral fault indication some laboratory test results are presented.

INTRODUCTION

The primary role of AMR (Automatic Meter Reading) systems is to provide real time energy consumption data for the utility, but the cost of retrofitting the existing energy metering system may not be justified if the meters are used merely for reading energy consumption data. AMR offers two-way communication to the customer site, which makes it possible to enlarge on-line monitoring also to the low voltage (LV) networks. This enables alarms on exceptional events, e.g. network faults and voltage violations, and here meters can also have some protective functions adding the safety. The use and integration of AMR in network operation can be seen as an extension of SCADA and distribution automation to the low voltage level as shown in Figure 1. Low voltage network management includes functions for example to indicate and locate faults, to provide accurate interruption data, to monitor voltages at customer sites in real-time and provide power quality information for customer service.

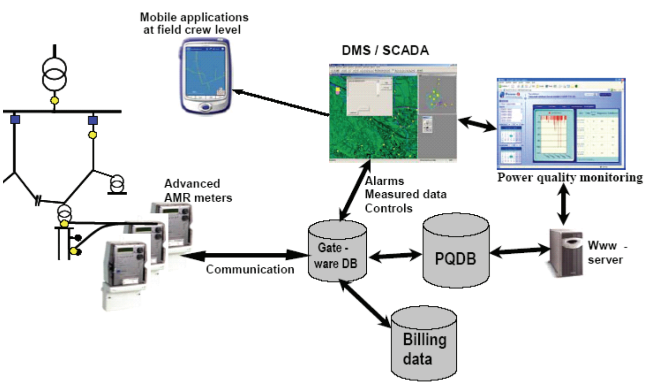


Figure 1. Using AMR system in network management [1]

SMART METERS AND AMR SYSTEMS

LV voltage network management using the integration of AMR and DMS (Distribution Management System) offers quite new possibilities also LV network operation, asset management, customer service and other functions [1,2,3]. Fault management processes are here of great interest.

Smart energy meters measure U_{rms} voltage values in every three phases. Alarms based on abnormal changes in voltages are generally in use. In neutral faults, for instance, voltage asymmetry can be monitored by comparing measured voltage levels and their differences. If some values exceed limit values, the meter can send alarms.

In Elenia Oy (earlier Vattenfall Distribution Nordic Finland) one major step utilizing AMR has been to integrate AMR data collection system with Distribution Management System (DMS). This is called AMR-DMS integration. The main functionality of the network fault management process can be divided into the next two parts, automatic alarms and status queries. Integration also enables status queries from DMS to the meters. A query can be sent manually or automatically to one meter or group of meters. After meters have sent spontaneous alarms e.g. about a neutral fault, alarms are shown on the DMS screen. After receiving spontaneous alarms, DMS sends queries to other meters in the same area.

Another example is Koillis-Satakunnan Sähkö Oy where development projects were realised for developing a comprehensive technology solution of the new functions of AMR and related information systems for low voltage network monitoring and management. The aim was to combine new-generation energy meters, data communication solutions and distribution management systems into an entity with an open architecture according to Figure 1. Aidon's AMR system supports communication solutions which enables real time events to be sent spontaneously from AMR meter. Polling all the meters from the reading system would be too slow. [1]

An advanced AMR meter works as an intelligent monitoring device and utilizes the communication infrastructure to provide spontaneous event or alarm information to the control centre with vital information on low voltage network faults and voltage levels. The meter includes algorithms to inference the existence of a fault and the type of the fault. The most interesting events have been blown LV fuses, a broken LV conductor (line or neutral), a wrong phase sequence, a broken MV conductor, power frequency over-voltages and power frequency undervoltages. In certain cases, e.g. when a neutral conductor is broken, the advanced AMR meter could even automatically isolate the customer from the network. This requires a specific switching device which can be integrated into the advanced AMR meter.

With AMR meters faults can be perceived and identified immediately and located automatically which enable to guide field staff directly to the fault site. Based on AMR data control centre have a real time snapshot from faulted area at the field. This is essential for the optimized allocation of needed work for fault isolation, repairing and distribution restoration. With a reliable snapshot, the scope of faults is under control which intensifies remarkably operations at control centre level.

Being able to solve problem situations during a customer call is seen as a huge improvement in customer service. In the best case, the fault has been repaired before the customer has even noticed it. In cases of any emergency, the immediate disconnection of voltages can help in preventing human and material damages.

When, DSO have selected a service concept for the AMR delivery this makes business environment more complicated than in the case of system delivery. All AMR related services require a comprehensive integration of operational work and IT systems of the DSO and service provider. This is a challenging situation not only to the DSO and service provider, as Empower IM Oy, but also to their subcontractors. After the identification of neutral faults, for instance, meters send alarms to the Empower IM's IT-service environment, which delivers it immediately to the DSO's Distribution Management System (DMS). DSO delivers a SMS message to inform the customer about the fault and related repair time. DSO can also activate meter inquiries to study the status of the customer sites and to carry out fault location in more detail. After the fault repair customer sites are connected to the LV network. Also customers are informed about the connection and fault related other information. DMS stores all disturbances to its database to be utilized, for example, compiling network disturbance statistics or in constant compensation.

Needs of new functions of AMI based systems

In the assessment of the profitability and of the benefits of AMR pure energy reading will be only one component. Benefits are sought out from the development of network operation and planning, demand side management (e.g. load control and dynamic tariffs), and customer service. [2]

New functionality for AMI (Advanced Metering Infrastructure) systems can be roughly divided into two time periods. They are short term and long term development. Short term development includes possibilities what can be realised with today's AMI generations where, for example, meter hardware set limitations for more advanced applications. Long term development includes also meter hardware evolution. Even if the willingness is to increase the intelligence of meters also better conclusions in the upper level IT systems are possible. This is one essential part of short term development and long term investigation will focus more in the metering equipment to specify needed hardware features for the next generation AMI.

At the moment network operation process can benefit especially from more efficient LV network fault management, as the detecting, locating, isolating and reporting of LV faults can be done much more effectively than in traditional manners.

NEUTRAL FAULT MANAGEMENT

During a neutral fault situation, the impedance of the neutral circuit is increased by a conductor break or by a bad connection. Such neutral fault will cause voltages to float as higher or lower depending on the unbalance of the loads in the system. This is illustrated in Figure 2 where the shifting of the neutral point is seen. This type of fault condition causing any too high overvoltage may damage equipment connected to the supply and problems with safety protection occur. Risks both to humans and properties exist.

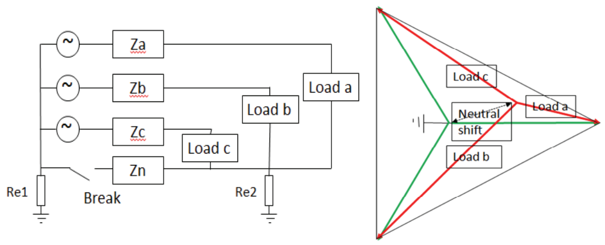


Figure 2. Neutral voltage shift during a neutral fault

While current AMR systems make possible to detect neutral faults there is a need for further development. Present meters can usually detect neutral faults if a phase voltage rises up enough or voltage asymmetry raise abnormally high as is simulated in Figure 3. Also such neutral faults appear where phase voltages remain in between normal limits but can cause danger later on. Such faults should likely be recognized, too. Also in normal state unbalanced loads cause voltage asymmetries as is shown in Figure 3 and these should be taken into account as a limiting factor so that too strict set limits do not cause too many unwanted alarms. Reasonable rapidity of alarms is of course essential.

One need is automatic switch off after a meter observes a dangerous situation. A general description of a neutral fault detection process is presented in Figure 4.

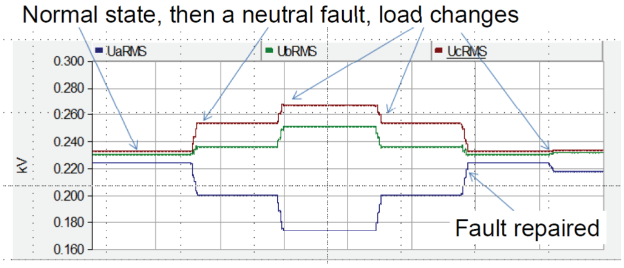


Figure 3. An example of voltage asymmetries caused by neutral fault and load changes

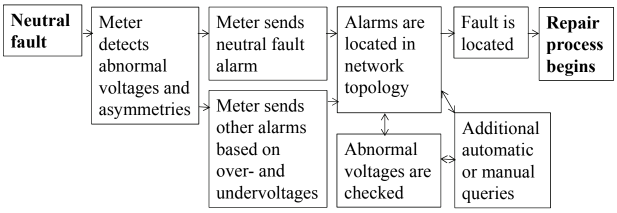


Figure 4. A general description of a neutral fault detection process

In case of a neutral fault, customers are advised to turn main switch open to avoid even lethal risks. When any phase voltage increase high enough happens often damages to customer's property which must be compensated by utilities.

An important research question is that how neutral fault situation should be managed in more advanced way. There an ideal use case for neutral fault management utilizing testing environment in the laboratory based on experience from formerly projects is essential. After "ideal" methods are determined it can be compared to present AMR systems to find out what is possible to do utilizing already installed meters and IT systems.

Application development with present metering equipment

Ideal use case for neutral fault management might be independent of any equipment or manufacturer. For several utilities it is also beneficial to complete use case study focused on the equipment used in a utility. Current generations of AMR meters have limitations to handle e.g. neutral faults and therefore it has been interesting to study what is possible to do with different AMR meter types.

One of the most important features of present AMR meters is that their software is remotely programmable which enables adding new functionality or changes to the meter behaviour in different situations. For example in Elenia Oy one full scale meter software upgrade has been completed. The upgrade was done to implement new features to handle in a more advanced way especially voltage asymmetry situations. Anyway installed firmware limit possibilities and new features must be possible to realise with current meter hardware.

However, essential is to find out both how neutral fault management can be further developed using current meter hardware and what is possible to do in IT system based on metered data analysis. Purpose is to determine how neutral fault management could be utilized more effectively before installation of the next AMR generation meters which should have lot more advanced metering features for different fault situation including neutral fault detection and protection functions.

METER TESTS AND ANALYSES

In order to evaluate the capabilities of the AMR meters some laboratory tests have been carried out by using Real Time Digital Simulator (RTDS) environment at the Tampere University of Technology. During simulations the AMR meter behaves here as it would be in a real distribution system. Network voltages are simulated by the RTDS and are forwarded through amplifiers. Amplifiers can be used to raise the voltages and currents to the levels of the normal operating levels of the AMR meter. If any fault or exceptional event is simulated, then the AMR meter can sense voltage changes in real-time. All the three tested meter types are used by Finnish companies.

Essential settings during the neutral fault tests are shown in Table 1. Tested fault cases and some results are presented in Figures 5 - 9.

Meter A	
Neutral fault	Highest voltage > 253 V and lowest voltage < 218 V 30 s
Overvoltage set limit	Voltage > 248 V 30 s or > 240 V 600 s
Undervoltage set limit	Voltage < 170 V 30 s Or < 207 V 600 s
Meter B	
Neutral fault or asymmetrical voltage	Highest voltage > 112% of the average of the voltages or lowest voltage < 75% of the average of the voltages 600 s
Overvoltage	Voltage > 253 V 600 s
Undervoltage	Voltage < 184 V 600 s
Meter C	
Neutral fault	Two voltages > 253 V and one voltage < 190 V 10 s
Overvoltage	Voltage > 253 V 10 s
Undervoltage	Voltage < 207 V 10 s

Table 1. Set values during the neutral fault tests

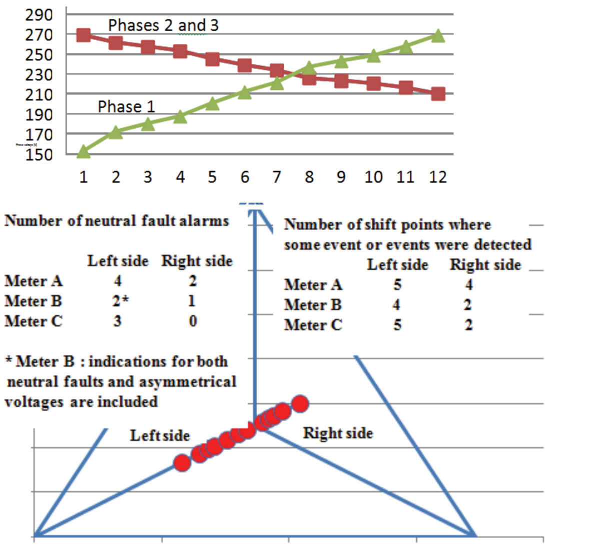


Figure 5. Phase voltages,neutral shifting points and alarms during a neutral fault test

Meter A
Green circle:
Neutral fault alarm generated
Yellow area:
Neutral fault alarms will be generated
Black area:
Neutral fault alarms will not be generated

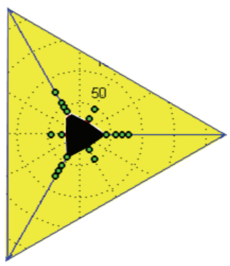
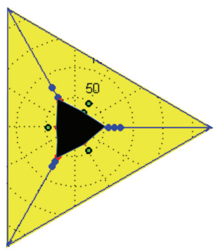


Figure 6. Locations of neutral shifts and alarms

Meter B
Green or blue circle:
Alarm generated
Yellow area:
Alarms will be generated
Black area:
Alarms will not be generated



Alarms based on neutral fault or asymmetrical voltages are included.
If overvoltage alarms are added, black area is as in Figure 6.

Figure 7. Locations of neutral shifts and alarms

Meter C
Green circle:
Neutral fault alarm generated
Yellow area:
Neutral fault alarms will be generated
Black area:
Neutral fault alarms will not be generated

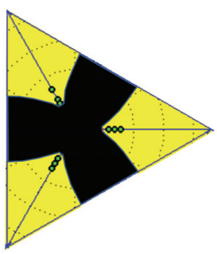


Figure 8. Locations of neutral shifts and alarms

Meter C
Green circle:
Some alarm(s) generated
Yellow are:
Some alarm(s) will be generated
Black area:
Alarm(s) will not be generated

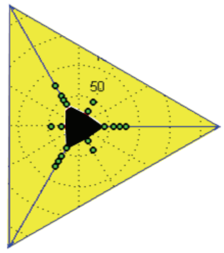


Figure 9. Locations of neutral shifts and alarms

Based on Figures 5 - 9, by using present smart energy meters neutral faults can be detected rather comprehensively. Here results in Figures 5, 8 and 9 show also that voltage level alarms can indicate further possible faults than only the actual neutral fault alarms when set limits are adequate.

Thus it is essential to understand that exceptional low or high voltages can be caused also by neutral faults in spite that neutral fault alarm limits are not exceeded. Therefore at least the overvoltage and undervoltage alarms should be analysed rather carefully with sufficient expertise and methods. In the alarm analyses, also exact numerical voltage values can be quite useful. These can be sent already with alarms or can be acquired by some additional queries.

REFERENCES

[1] P. Järventausta, A. Mäkinen, K. Kivikko, P. Verho,, M. Kärenlampi, T. Chrons, S. Vehviläinen, P. Trygg, P. & A. Rinta-Opas, 1997, *Using advanced AMR system in low voltage distribution network management.* CIRED, 19th International Conference and Exhibition on Electricity Distribution, 21-24 May, 2007, Vienna, Austria 4 p.

[2] N. Löf, M. Pikkarainen, S. Repo, P. Järventausta, 2011, *Utilizing Smart Meters in LV Network Management*. CIRED 21th International Conference on Electricity Distribution, June 2011, Frankfurt, Germany

[3] S. Antila, J. Kuru, V. Maksimainen, 2011, *Integration of AMM Functionality into Operating Systems of Electricity Distribution Company for LV Network Fault Management,* CIRED 21th International Conference on Electricity Distribution, June 2011, Frankfurt, Germany