HIGH FREQUENCY MODELLING OF LV & MV DISTRIBUTION NETWORKS CONCERNING POWER QUALITY AND DATA TRANSMISSION

Steen M. Munk, PhD
NESA A/S
Strandvejen 102, DK-2900 Hellerup
Phone: +45 3948 1010, Fax: +45 3938 1011, E-mail: smu@nesa.dk, URL: http://www.nesa.dk

SUMMARY

This paper describes research activities in Denmark concerning high frequencies in the electrical distribution network.

In recent years an increasing awareness of power quality has arisen. This is connected to the growing use of electronic equipment.

With the liberalisation of telecommunication it is of great interest to electric utilities to gain knowledge that will enable them to use the network as basis for (data) communication.

Both for power quality and for power line carrier communication better high frequency models of the network are needed.

INTRODUCTION

The influence of high frequencies on the electrical network increases as more and more electronic loads are connected.

In order to ensure a satisfactory power quality it is necessary to have a thorough understanding of the characteristics of the network as a means for transmitting frequencies higher than 50 Hz.

Monitoring branched, radial networks may be done on the basis of the transients arising when an event occurs in the network. Transients arisen in connection with a fault may be analysed and information about the location of the fault extracted.

It is expected that the network owner/operator in the “deregulated” electricity market will be requested to guarantee that the deviations from the ideal 50 Hz sinusoidal voltage curve will remain under specified limits. If these limits are exceeded customers may be entitled to economic compensation.

Lately focus has been on utilisation of the network as basis for data communication. Products, and claims about products, for power line carrier communication have been seen. It seems that all these products were developed without sufficient understanding of the media used as communication channel. The result has been low communication speed and/or bad reliability.

Both for the analysis of the network with respect to high frequency noise and with respect to the analysis regarding power line carrier communication better models are needed than the ones available today.

This paper describes results of the work in Denmark on a description of the medium voltage network in the frequency range DC to 2 MHz.

HIGH FREQUENCIES ARE TRANSIENTS AND HARMONICS!

The above statement covers how many thinks about the term *high frequency*. This understanding can be found in widespread use of programs like EMTP. This program is designed for the analysis of heavy transients in the network.

Though transients do consist of high frequency components, EMTP, and other similar programs, lack adequate models for high frequency modelling of electrical networks, including transformers, loads, etc.!

NESA has for many years now been involved in research projects concerning the presence of high frequencies in the electrical distribution network; i.e. both 10.4 kV and 0.4 kV. This involvement is the basis of this paper. And it is quite clear that high frequencies are much more than just harmonics and transients.

The paper consists of three main parts:

- Transients arising due to an event in the network may be captured and analysed to give an estimate of what happened and where in the network.
- Electronic devices make noise that is transferred to the medium voltage network, where it may cause disturbances to other customers.
- Communication using the electrical network is a hot issue at the moment. In order to exploit optimally the network, it is necessary to understand the behaviour of the elements of the network at high frequencies.

Why are better models needed?

Both for a better understanding of **P**ower **Q**uality problems and of how the electrical network behaves as a means for data communication, it is necessary to have models that are valid up to the MHz range.

Such models will be an important tool in future standardisation work, as well as for understanding better the possibilities of exploiting the electrical network for communication purposes.

Models valid at or near 50 Hz may only be used at low frequencies compared to frequencies necessary for e.g. communication purposes

Commercial aspects

Until recently customers had to be satisfied with the quality of electricity they had and to the price that was given by the utility. They were not customers, but consumers.

This is changing. Some countries have already gone all the way and liberalised electricity supply to all consumers, making them customers. This indicates the start of a new behaviour. When buying “goods” one normally expects a certain quality. If this expectation is not met, one complains.

It will be of utmost importance for utilities to be able to describe in detail the quality of their product. Otherwise they are bound for trouble.

Customers encountering power quality problems may demand compensation. This demand will most likely be addressed to the utility, which then will have to find the true source of the problem.

The possibility of exploiting the electrical network for (data) communication opens up an enormous potential for the development of new markets, competing with the telecommunication companies.

10 kV TEST FACILITY

In a part of NESA’s 10.4 kV network that is no longer being used, a test facility has been installed. The facility consists of all together about 7.5 km of overhead line and underground cable. It supplies four 10.4 kV/0.4 kV transformers through which loads may be connected[1].

The test facility gives very good opportunities to investigate the impact on the network of specific kinds of loads, without having to consider the influence of other loads, which one does not control.

Since the inauguration in August 1998, NESA has partaken in various experiments. The facility has been used to investigate how electronic loads interact with the medium voltage network, to investigate how electrical noise interferes with power line carrier communication, and to investigate the possibilities of estimating the location of ground faults.

Figure 1 Interior of NESA’s movable low voltage load. In the background is seen the VLT with motor and generator. In the foreground is seen a 35 kVA arc welding unit.

A network without loads is not much of a network. Therefore NESA has built a movable low voltage load, in a container that can be moved by a small van, see Figure 2.

[1]The test facility is owned by DEFU, the Research Institute for Danish Electric Utilities. Further information may be found on DEFU's homepage: `http://www.defu.dk`.

NESA’s movable low voltage load

A central element of this load is a noisy VLT driving an asynchronous motor, seen in the middle of Figure 1.

This motor in turn drives a synchronous generator that may be loaded with up to 45 kW.

Another important element of this load is a 35 kVA arc welder, connected between two phases.

Figure 2 Exterior of movable low voltage load.

All together a load of 150 kVA may be composed.

The current shown in Figure 6 was generated using the load.

MONITORING THE MV NETWORK BASED ON VERY FEW MEASUREMENTS

In most parts of the MV network there is no communication system installed. Therefore, in order to enhance monitoring, it is of interest to investigate if reliable monitoring may be done based on very few measurements.

In Denmark a project has run for six years dealing with monitoring of radial 10.4 kV Petersen Coil grounded distribution networks based on current and voltage measurements taken only at the primary substation.

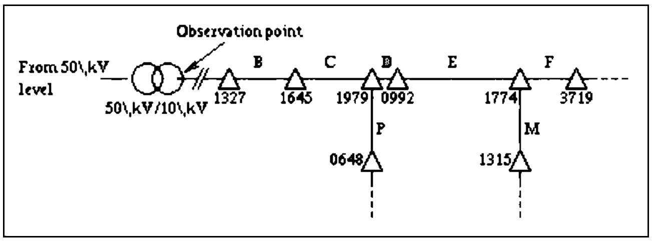

Figure 3 Simulation model of MV feeder, with indication of the Observation Point.

The thesis is that the analysis of transients arising when “something” happens may yield sufficient information to give an estimate of what happened and where in the network.

The project is about to come to a conclusion. The result has been that it is most likely that detection and localisation of ground faults in Petersen Coil grounded networks may be carried out in this manner see [2].

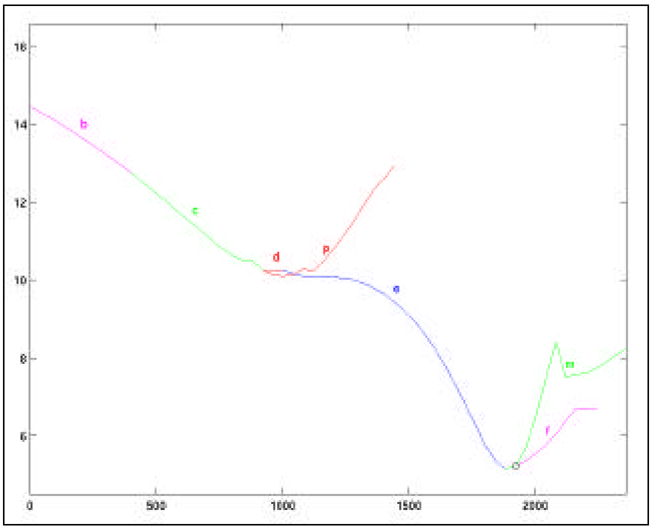

Figure 4 Example of simulated location of error. The x-axis shows the distance from the observation point. The y-axis is the error.

By calculating in advance the impulse response at the so-called observation point from a ground fault being connected to a certain location, it is possible to compare a transient captured to this "bank" of events.

If i denotes a specified point on the feeder, then $\mathbf{h}_i$ is the impulse response at the observation point from an impulse injected at point i.

The entire feeder, shown in Figure 3, may then be represented by the expression in Equation 1.

(1) $$\mathbf{H} = \begin{bmatrix} \mathbf{h}_0 & \mathbf{h}_1 & \dots & \mathbf{h}_{N-1} \end{bmatrix}$$

Where N is the number of points chosen for the description of the feeder.

A transient, $\mathbf{y}_0$, caused by a ground fault in point f of the feeder description, measured at the observation point, may be related to the transient, $\mathbf{x}_f$, at the true location of the ground fault by the convolution in Equation 2,

(2) $$\mathbf{y}_0 = \mathbf{x}_f * \mathbf{h}_f$$

where f is unknown.

An estimate of $\mathbf{x}_f$ is found by the de-convolution;

(3) $$\hat{\mathbf{x}}_f = \mathbf{y}_0 * \mathbf{h}_f^{-1}$$

By de-convoluting a measured transient, $\mathbf{y}_0$, to all points of the feeder description, an error measure is calculated.

(4) $$\mathbf{f} = \left[e_i^2 \right]$$

Where;

(5) $$\hat{e}_i = \left\| \hat{\mathbf{x}}_{i-1} - \hat{\mathbf{x}}_i \right\|_2$$

This measure is shown in Figure 4. The minimum is found near the true location of the fault.

It is obvious that the precision of the method is closely related to the precision of the models used to create the feeder description.

Until now the connection between points in the feeder description are -equivalents.

Today the influence of loads and their variations on the obtainable precision is unclear.

It is therefore expected that the PhD project described in Section ***High frequency modelling of the MV network*** will provide useful models, so that improved precision and reliability of the location estimated may be achieved.

In Figure 4 is seen the true location of the ground fault near the minimum of the error curve. During simulations it is demonstrated how the minimum moves around.

At present (December 1998) these simulations are being verified against measurements taken during experiments in the 10.4 kV test facility. The preliminary results indicate that the measurements match the simulations well.

It seems that much information is available in the voltages, as shown in Figure 5. Much more than expected!

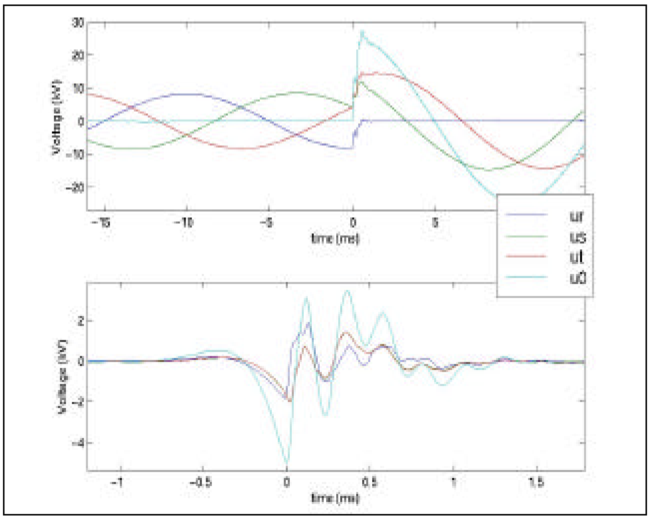

Figure 5 Measured voltages when a ground fault is connected. In the lower part of the figure is seen the high pass filtered voltages. Frequencies under 2 kHz have been removed. 0 on the time axis has been adjusted to compensate for the delay of the filter. Therefore it looks as if the filter responds before the event.

It will be investigated if measurements of the zero system alone, i.e. voltage and current measured at the Petersen Coil, will be sufficient to estimate the location of a ground fault.

DIAGNOSIS OF MV CABLE INSULATION

Being able to estimate the quality of the insulation of a given cable, without having to dig, is of great interest to the network owner.

In many countries there are activities within cable diagnosis based on travelling waves caused by partial discharges in weak points of the insulation.

The objective is to be able to estimate the location of points of the cable insulation susceptible to failure. The quality of the estimate is again connected to the precision of the models used.

CONNECTING ELECTRONIC DEVICES TO THE ELECTRICAL NETWORK

As shown in Figure 6, the impact at 10.4 kV level of a power electronic device may be very significant.

But not only large loads are of concern. The sum of many small loads does actually already today cause problems, e.g. computers and energy saving lamps.

Noise generated by VLT's.

It is of the utmost interest both to the manufacturer of VLT's and to the utility to know how such devices interact with the network.

A PhD project has been defined to investigate this issue in detail.

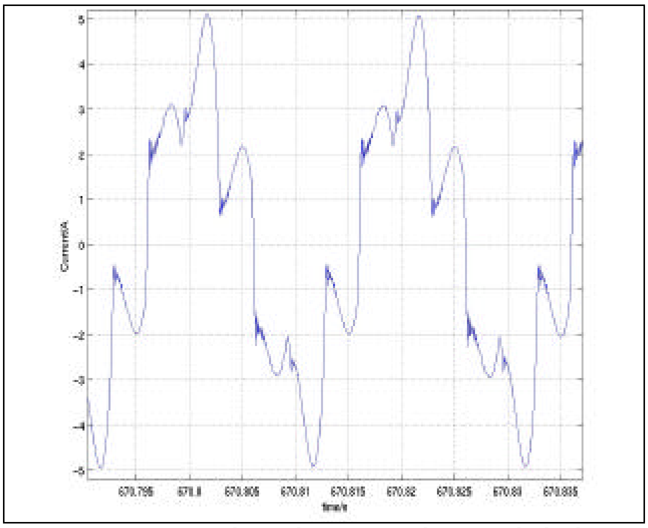

Figure 6 Current measured at 10 kV primary substation. The load is two VLT's. The one driving approximately 50 kW of load and the other approximately 8 kW

Manufacturers experience an increasing awareness from customers on how electronic devices behave. This is both due to demands from utilities but also to the fact that it happens quite frequently that the introduction of an electronic device causes problems to other pieces of equipment in the customers' installations.

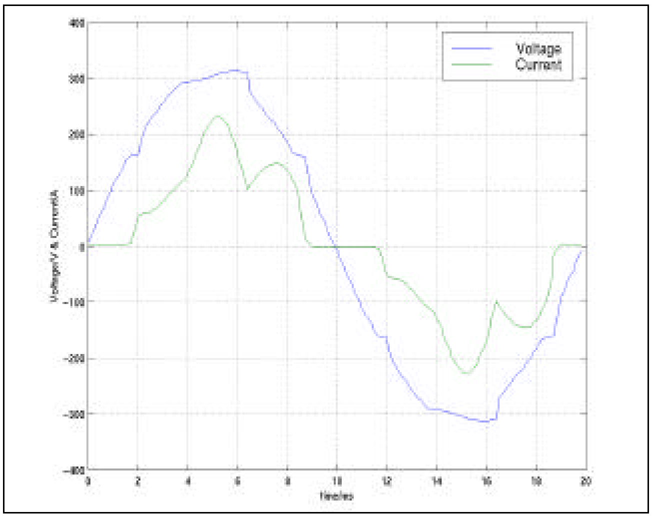

Figure 7 Measurement of current and voltage close to VLTs.

In the 10.4 kV test facility different VLT's were connected through a 200 kVA transformer, which was fed through approximately 1.5 km of overhead line.

The short circuit power at the primary substation is about 150 MVA.

In Figure 6 is shown an example of a current measured at the primary substation. In Figure 7 is shown current and voltage measured at low voltage near the loads. The loads were a three phase load of approximately 50 kW and a one phase load approximately 8 kVA.

In some situations a given combination of VLT's may lead to improved power quality. Understand in detail how VLT's interact with each other and the network may be exploited to create optimal solutions regarding power quality.

POWER LINE CARRIER COMMUNICATION

In the past few years high speed power line carrier communication has been much discussed.

The discussion was initiated by the "liberalisation" of telecommunication, allowing others to enter the telecommunication market.

But to compete with the old, established companies, it is necessary to find alternative means of connecting to the customers, other than buying access to their networks. Therefore the electrical network was immediately in focus. It is already in place and it actually connects even more customers than the telecommunication network does.

However, the electrical network was not designed for transmitting communication signals. Nonetheless many examples of power line carrier communication systems have been seen. They were, apparently, conceived without sufficient understanding of the network as a means of communication.

All existing systems for power line carrier communication give the impression that they are unreliable and unpredictable. It is today not possible prior to installation of a communication system to predict the obtainable quality of communication. This can only be determined after installation. Some providers try, though, through measurements to give an indication of whether communication will succeed in a given part of the network.

It is therefore of the utmost interest to utilities to get reliable models of the electrical network, in order to be able to make better designs of communication systems, and in order to be able to relate measurements made to estimates of the communication quality obtainable in a given part of the network.

This work has been initiated in two PhD projects with the participation of NESA.

One PhD project deals with modelling of the low voltage network, and is carried out at the Technical University at Lund (Sweden), see [3, 4].

The other deals with the medium voltage network and is carried out at the Technical University of Denmark. In [5] is described the basis on which the PhD project has started.

Another issue that makes power line carrier communication interesting is the need for utilities to differentiate themselves against competitors.

Having a two-way communication system, Value Added Services may be offered to the customers.

CENELEC regulations

Today power line carrier communication in the low voltage network is restricted through CENELEC regulations. These regulations assign the frequency band from 3 kHz to 148.5 kHz to communication.

For the medium voltage network no such regulations apply, though there is a growing understanding of the fact that these two voltage levels cannot be separated when discussing higher frequencies, because much will "slip" through the transformers.

Therefore, it must be expected that in the near future regulations will be defined for the higher voltage levels as well. Changes to existing regulations, in order to accommodate high-speed power line carrier communication must also be anticipated.

HIGH FREQUENCY MODELLING OF THE MV NETWORK

In June 1998 a PhD programme was initiated with the objective of creating better models of the MV network in the frequency range DC to 2 MHz.

The project has started at the distribution transformers.

These make up a natural starting point, since they connect the MV and LV networks and thereby play an essential role in the description of loads seen from the MV network.

Next step in the project will be cable models and subsequently the combination of transformers and cables.

It is expected that by the end of the project models will exist that may be used in, for example, the EMTP.

At present this project is concerned with describing the frequency dependency of the parameters of the transformer model. The initial work on this matter is described in [1].

DISCUSSION

This paper has disclosed several questions, which must be answered concerning high frequencies and the electrical distribution network.

It is interesting that different problems may be approached using the same techniques. Monitoring, power quality and power line carrier communication share the need of accurate high frequency models.

Results so far give a clear indication that MV and LV cannot be separated when considering high frequencies. Therefore it is important that modelling of the two voltage levels is treated as one problem.

As for high-speed communication, interference with radio communication systems must be considered. It seems, therefore, that for further development of the technology, work on standardisation must be taken seriously.

The influence of loads has not yet been treated. It is important that this issue is thoroughly investigated, as loads are the cause of PQ problems and play an important role regarding communication.

CONCLUSION

To the electric utilities the possibilities are many. Having realised the true potential of the network through a better understanding of high frequency modelling opens up a wide range of possibilities to the electric utilities.

Results indicate that better power quality may be obtained by having a better monitoring of the medium voltage network. This monitoring may be based on few measurements, so that the establishment of a communication system for this purpose may be avoided.

As more and more power quality related customer problems are reported, utilities must gain a better understanding of the behaviour of higher frequencies in the electrical network.

In this paper Danish initiatives to achieve this better understanding have been described.

It is very clear, though, that there is still a long way to go before a thorough understanding is obtained of both the LV and the MV networks at higher frequencies.

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