LOW-VOLTAGE DISTRIBUTION NETWORK DESIGN - SAFETY AND COST OPTIMIZATION

P.M. van Oirsouw[1)], F. Provoost[2)]

[1)] Phase to Phase, The Netherlands, [2)] NUON TPC, The Netherlands

SUMARY
This paper describes the technical and economic factors that led to the creation of a new computer program that is able to realize substantial savings in cable investments. Besides the power quality also the customer's safety plays a major role in today's network design and in the program's functionality. The paper describes the practical usability of the program and how it even led to specifications of a new generation of fast over-current protection fuses.

Introduction
NUON (The Netherlands) is a regulated electricity distribution company that faces a continual challenge to reduce system operation and maintenance costs while increasing network availability and reliability. Driven by both technological and economic factors, NUON and the other electricity distribution companies in the Netherlands are forced to examine in more detail the design of new or refurbished low-voltage power distribution networks. The technological factors are:

- grounding system trends from Terra- Terra (TT) to Terra-Neutral (TN)
- dispersed generating systems that can cause voltage problems.

The economic factors are:

- decreasing engineering margins resulting in reduced network investment costs
- a low-investment network should not increase operating costs, introduce poor voltage conditions or create unsafe situations for the connected customers.

The Change in Grounding Practice
One of the technological factors is that many distribution companies are changing their policy from a TT-grounded system (Terra-Terra, where the installation is grounded at the client’s location) to a TN-grounded distribution system (Terra-Neutral, where the electricity company provides the grounding as a service through the network). The electricity companies formerly connected to ground the low-voltage terminals and customer home electric systems to the metallic water conduits system. Since water companies now use plastic instead of metal pipes, this grounding method is becoming obsolete. One solution is to apply grounding electrodes for each customer instead of grounding at the water system. An alternative method would be for the distribution company to provide the grounding together with the electric system. In the latter case, the electricity company is responsible for proper grounding and calculations must be made to ensure safety at all times.

A further technological factor that drives the need for accurate calculation is the growth of dispersed generating systems in the low-voltage system, such as combined heat and power and solar energy. These systems introduce a reverse current path, which affects network operation and safety. In addition to the lower voltage limits, developers need to take into consideration the upper voltage limits (situation B in Fig.1, in contrast to conventional situation A without dispersed generation). In addition, dispersed generation is now connected to the medium-voltage system affecting voltage levels hence, these daily varying voltages have also to be taken into account.

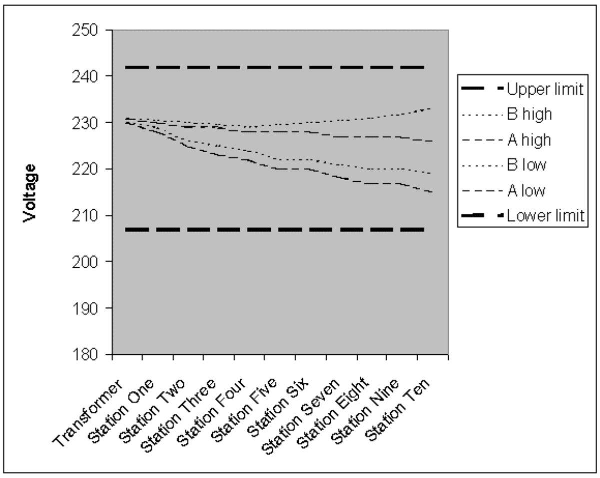

Figure 1 Voltage bandwidths in conventional situation A without and situation B with dispersed generation.

One important economic and political factor is the burden caused by liberalization of the electricity market. The conventional engineering method was based on the use of specified engineering margins, incorporated in well-known rules of thumb. Decreasing these margins results in reduced network investment costs, but existing operating costs, voltage quality and customer safety standards must be maintained. Therefore, the development of new networks becomes increasingly difficult.

In the Netherlands almost 100% of the low-voltage distribution systems consists of underground cables, but the methods of operating the distribution systems are historically based and vary greatly with networks being operated radially and in meshed configurations. Meshed networks are operated as open rings or as closed rings and historically the low voltage network comprises a variety of cables and methods of network grounding. However, it is common to consider long-term practice so that subsequent network adjustments are reduced to a minimum during the cable lifetime.

Software solution

Deregulation leads to new nation-wide constraints imposed by the Regulator and new international standards. Company mergers and changes in the electricity sector initiated the need for a new tool that would be supported collectively. There was a collective desire for a new flexible tool with a low acceptance threshold. The method called Gaia, comprises two major parts:

- calculation of cost-optimal cable diameters regarding the technical constraints and
- correction of the network for contact safety considerations.

Because of the new demands, a new integral engineering method had to be developed and implemented in a computer program. The new program's most important functions are optimization and contact safety and considerable efforts were made to make the resulting computer program user-friendly.

Optimization

The aim of the optimization is to develop a low-voltage distribution network having minimum lifetime costs. The procedure is based on a combined integer and real approach and is based on optimization for economic operational management. In other words, the cheapest solution with respect to investment and electrical losses is sought for the estimated cable life- time. A large cross-section cable requires a higher investment, but gives fewer losses, and vice versa, see Fig. 2.

The method ultimately selects the right cable with respect to load and voltage quality. The main variables in the process are cable diameters and transformer tap positions. The technical constraints are minimum and maximum voltage, maximum cable current and voltage fluctuations. The result strongly depends on the financial parameters, network design, electrical demand, growth rate and dispersed generation.

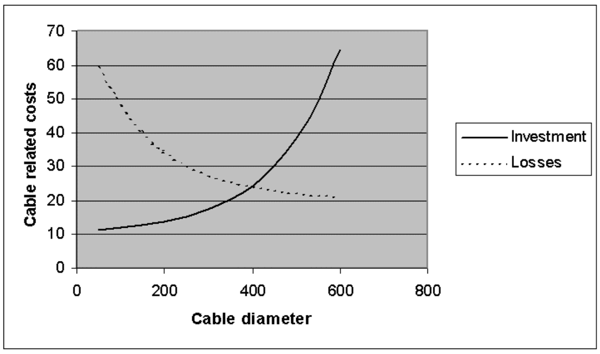

Figure 2 Cable related costs versus cable diameter

Contact safety

By adopting grounding according to the TT system, the customer's safety is almost totally determined by the impedance of the customer's own grounding provisions, but with a TN system, the customer's grounding system is connected to the supplier's grounding system. The neutral and ground in the supplier system are coupled wherever possible. When a phase-to-ground fault in the network cable occurs, the neutral and ground lines will obtain a voltage with respect to the "far-off ground". In this case a person's body does experience a voltage through his grounding conductor, as shown in Fig. 3.

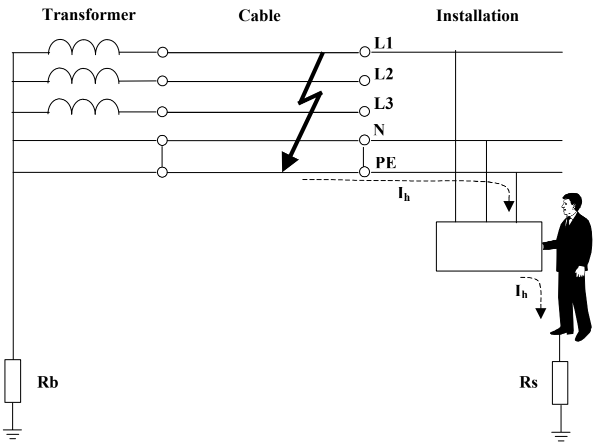

Figure 3 Short circuit in a TN grounded system

In order to avoid serious harm to persons, either this voltage should be low enough or the fault has to be switched off in time, the time taken to isolate the system is dependent on the magnitude of the person's contact voltage and current. The connection between the current passing through the body and the allowable time is stipulated in the Standard IEC 479-1. The voltage depends on the MV/LV transformer and the impedances of the low-voltage cable and the return path. The return path is determined by cable neutral and sheath and by additional grounding electrodes and ground resistance. In this context, the length of the network cable has a major influence on a person's safety, a longer cable extends the cut-off time and hence the length of exposure. For this reason, extra attention is given to the choice of the right network protection devices as the actual cut-off time depends on the fault current magnitude and the fuse characteristic.

For a fast cut-off the total circuit impedance has to be small and this directly limits the maximum cable length. For a low fault voltage the phase/return impedance ratio has to be large. If the network configuration does not meet these contact voltage requirements, additional measures can be taken, such as:

- increasing the cable diameter for an impedance reduction and therefore a quicker cut-off time and
- additional grounding electrodes or connections for a neutral and ground network impedance reduction.

Determining contact safety during short circuits on the low-voltage network with a TN grounding system is very complicated. In the method of calculation the operating resistances and impedances play a role as well as the electromagnetic mutual coupling between the cable conductors.

The voltage at the "touch" point is calculated using normal longitudinal impedances and mutual impedances for all conductive elements: three phases, neutral and sheath. For the calculation of a single-phase fault in the low-voltage system the mutual impedances may not be neglected. Therefore, a complete five-conductive-element system should be necessary, thus yielding a 25-element matrix for a cable. The cable impedances are calculated and stored in a cable database, so that the user is not confronted with these theoretical parameters.

Additionally, two specific technical functions are incorporated into the method for corrections in special cases e.g. voltage dip due to a single phase motor start, and simplified asymmetry calculations.

Usability, Results and Validation

The computer program must have a graphical mouse controlled user interface which enables the low-voltage network designer to calculate their design in a fast and practical way. Therefore much expertise has to be built in as rules and in the components database. The users must be supported by means of a "Wizard", which enable the quick construction of the electro- technical design. The program must be able to contain Company Standard Values for the calculations and must have flexibility for user specific visualization and presentation.

The Gaia computer program provides all the user-friendly requirements and all calculations can be accessed by a graphical user interface. The program has a fast and simple one-line editor that can distinguish between the phase, neutral and grounding networks in layers. The user is supported in the construction and alteration of the network by component databases that contain all the technical data of the components. Consideration is given to the most important technical preconditions, such as the loading capacity of the cables and transformers, voltage limits, motor start and the contact safety in the event of short circuits in the network. The interface and the calculation software run in Windows on a normal PC. All variables can be modified by the user, but a lock is built in for specific company-wide standards, e.g. voltage requirements, financial data and parameters for the safety calculation.

When it comes to human safety, a new network model and new cable data must definitely be validated for correctness by means of measurements in practice. The fault voltages and fault currents were measured by creating short circuits in an existing low-voltage network. The available results of field experiments show that the differences in contact voltages compared with the values determined using Gaia were less than 10% with the results from Gaia always being on the safe side.

Gaia in Practice

The use of Gaia has led to very interesting results when compared with traditional design methods with some companies making considerable savings in the expenditure on new distribution networks. Furthermore, the computer program has effectively used to improve the operation of existing networks, resulting in reduced revenue costs.

The introduction of grounding by means of a TN system as a service to customers initially led to a reduction in the length of the network compared to the TT system where the voltage level is the only constraint. In TN systems the choice of the network fuse protection needs more discipline as the network cable length influences the short circuit cut-off time. In order to satisfy this requirement led to the development of faster standard switching devices designed to fit into the normal switchboard. These devices have a standard characteristic for normal over-currents but have very fast operating times in the event of excessive over-currents due to network faults, see Fig. 4.

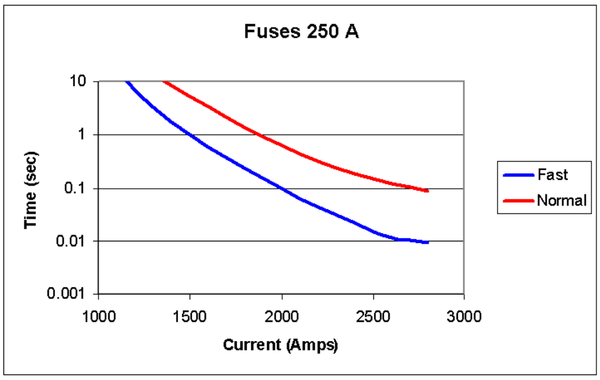

Figure 4 New switching devices cut-off characteristic

Thus, the use of TN grounding systems no longer impose a major constraints in the length of the network. However, care must be exercised in selecting the correct length of the customer connection or service cable, as this is still an important factor in the safety calculations. When introducing TN systems in existing networks, problems can occur when modelling older cables as it is not apparent whether sheaths at joint positions the junctions are connected or not. Also, problems may occur when trying to model non-insulated copper conductors in the ground and older mass-impregnated cables with their sheaths in direct contact with the soil.

The technical network requirements must satisfy the expectations of both power consumers (e.g. standard household loads) and dispersed generation (e.g. PV systems and combined heat and power) and medium-voltage system fluctuations also have to be taken into account. The requirements verification for upper and lower limits to voltage are determined in a single calculation which simplifies the projection in modern network planning.

The presence of a clear and open structure of the database concept ensures that a conversion from and towards the Geographical Information Systems (GIS) is easy. This means that in future systems lines can simply be drawn in the GIS, the network will be calculated in Gaia and the results such as cable types to be used will be stored in the GIS. Using more accurate information from the network may result in improved results. With the current model the calculations are made at two load points only:

- maximum load with minimum generation, and
- minimum load with maximum generation.

Future use of daily load curves and daily generation curves for different loads and different generations, e.g. on an hourly basis, should lead to more accuracy.

The design of networks for lower voltages requires a considerable volume of reliable information but often this information is not always available, hence users of the resulting design should always use experience and be aware of possible inaccuracies in the designed network. Therefore, most of the electricity utilities in the Netherlands have taken considerable care to train their staff in the basics of the program to ensure the designer and project working staff respect the results of the calculation. This implies that the network has to be laid out exactly as it was calculated. Changes in the network, e.g. new connected customers, changes in the power demands of existing customers always have to be included in the model and have and the network subject to re-design before the changes are accepted. By adopting this procedure the existing disciplines planning, construction and operation are maintained.

Conclusion

Distribution companies have been able to realize substantial savings in cable investments and electricity companies in the Netherlands have used this program for some four years. Depending on the engineering method in use before Gaia, savings up to 10% of cable investment costs have been recorded. This computer program proves particularly valuable when required to demonstrate the economic and technical merit of this low-voltage distribution network design tool to utility management or the industry Regulator.

Authors Contact details

Peter van Oirsouw
Phase to Phase
P.O. Box 100
NL 6800 AC Arnhem
The Netherlands
p.m.vanoirsouw@phasetophase.com

Frans Provoost
NUON TPC
P.O. Box 50
NL 6920 AB Duiven
The Netherlands
Frans.Provoost@Nuon.com