ABSTRACT

This paper addresses the problem of probabilistic assessment of large scale low voltage distribution networks. The focus is on network safety, security and efficiency. The paper shows how with today’s technology one can satisfy such a requirement. Perhaps an even more relevant issue, also addressed in this paper, is due to the leading role of LV distribution networks as a receiver of distributed microgeneration. This role comes together with an emergent availability of massive telemetered data and more demanding performance requirements for efficiency, safety and security.

1. INTRODUCTION

Traditionally, low voltage (LV) network analysis has mostly been made in the context of investment planning. The analysis consists of studying a feeder at a time, using estimated peak values for loads and empirically defined simultaneity factors. Load information comes from the number of clients, their requested capacity and some empirical rules. As one moves upstream, from the loads to the transformer station, at every load junction a predefined simultaneity factor applies (Note that nodal Kirchhoff’s law for power applies only if powers are multiplied by the corresponding simultaneity factors). That empirical approach has been an effective, computationally simple approach that served our industry well. It is an approach adequate for a simple computer program, an equivalent to today’s spreadsheets. As the perception that the LV planning problem grew to be an economically important problem and that the LV networks need to be analysed together and more often, so did grow the demand for a more adequate technical solution. Clearly new loads and load growth can be accommodated in many possible ways and not simply by providing for a new feeder or extending an existing feeder. Neighboring feeders, from the same transformer station or from a neighboring transformer station can be considered at the same time, as one problem, thus enlarging the decision space of the problem, allowing for a more integrated, better solution. This naturally comes with an increased effort to deal with the increased computational complexity.

Other important technical issues should also be addressed: (1) to use load diagrams instead of single peak values; (2) to substitute the traditional simultaneity factors by a scientific approach based on probability distributions; (3) to consistently set the network configuration for maximum efficiency and the protections for maximum system security and safety. These issues are addressed and dealt with in this paper.
largely unknown, except for the number of clients behind a certain point of the network and the assumption that the loads did not occur simultaneously, i.e. a low simultaneity factor. Today’s high resolution information, even at the level of the individual residential customer, may soon comprise a high-resolution chronological demand for each customer. There are already such high resolution data corresponding to quite a few residential loads and many commercial and industrial loads. Long and numerous data logs can be analyzed to extract considerable statistical information. That information can in turn be used to support adequate probabilistic hypotheses as needed for an adequate analysis and planning of LV distribution networks.

Those probabilistic hypotheses concern mostly the load diagrams for each customer or class of customers as obtained from the statistical analysis and should include information regarding mean values, variances, probabilistic distributions and stochastic correlations. This paper assumes that that probabilistic information is available and presents technological contributions for a probabilistic assessment of the safety, security and efficiency of LV networks.

It should be recognized that utilities have been making a considerable effort towards improving availability of LV network data and will have in the near future massive customer information from new metering systems, including customer load diagrams. This creates an opportunity for thoroughly analysing large-scale LV networks with probabilistic methods based on large amounts of data. EDP has been involved in the development of such methods to support analysis and decision making for large-scale LV networks. Safety, security and efficiency assessment procedures have been developed to (1) evaluate assets’ adequacy based on maximum currents and minimum voltages with confidence up to 95% for unbalanced non-synchronous customer load diagrams, as well as a comprehensive reliability and investment analysis, (2) evaluate system’s protection adequacy based on maximum and minimum short-circuit phase currents and propose adequate protection device installation; and (3) evaluate persons’ protection security based on maximum short-circuit neutral voltages, earthing system and installed protection devices. The paper describes the methods developed, the corresponding probabilistic framework, and the results obtained. Perhaps more importantly, it illustrates how the results are displayed and used for large scale networks so as to improve safety, security and efficiency of LV networks [1-2].

3. PROBABILISTIC ASSESSMENT

For real-time network analysis, the network loads are continuously measured or estimated and the corresponding values enter the network analysis as instantaneous loads. In this case, Kirchhoff’s power law is applied for every node of the network. On the other hand, for a study regarding the planning of a network, the loads do not correspond to a specific time. In that case, the load profile should represent a peak situation, i.e. a situation in which the currents reach the highest values and voltages drop to the lowest values. An inaccurate knowledge of load behavior in peak situations can lead to overloads of the network equipment, which can result in shortening of the equipment lifetime or even permanent damage. In addition, energy losses can be very significant, excessive voltage drops can lead to voltage delivered outside the admissible limits, a degradation of the quality of service and customers satisfaction, and can also lead to customer’s equipment damage. The opposite situation can also occur, i.e., the network can be over-dimensioned for the peak load, resulting in useless investment costs and an erroneous assessment of voltage and current profiles and efficiency patterns.

For the probabilistic representation of network loads, the load at any hour is represented by a random variable [3]. At that hour, the load of any set of customers is also a random variable, which is the sum of the random variables of each customer in the set. The probabilistic method does not exhibit any of the disadvantages described for the empiric method. In particular, Kirchhoff’s law for power still applies, even though not for real quantities but rather for random variables, including random variables for power losses. With an adequate probabilistic characterization of the customers’ loads, this method produces the most accurate results possible. Peak values are then determined to within a certain probability. In this paper all results are for a choice of a 95% probability of the peak value not to be exceeded.

Of course, this analysis for peak values requires the use of probabilistic load diagrams, not probabilistic load peak values. Indeed, loads do not peak at the same time of the day. Thus, individual 24-hour load diagrams are used, not individual load peak variables.

[An additional explanatory note for those who may have got confused here: at any given hour, the probabilistic power at any given point in the network corresponds to the probabilistic sum of the probabilistic powers at the points downstream at that particular hour. Also, because peaks for each load do not occur at the same hour, a peak upstream will likely occur at a different hour than that at which another particular load peaks. Thus, it is necessary to use a probabilistic load diagram for each individual load.] Those load diagrams are also necessary in order to assess the network efficiency accurately, and also for an accurate assessment of the reliability values.

A practical note: the analysis, as explained above, has to be thorough, detailed and rigorous. It should also be very fast and presented in a graphical manner. We make extensive use of color filters and query filters to efficiently present the computed results. For anything that the user wants to see in more detail, she/he can then make use of many readily available analytical tools and numerical dialogs.

Consider now Fig. 1, which shows a small portion of a network. In the major window, one sees the results displayed corresponding to two filters: the nodes are
colored according to voltages (min values); the branches are colored according to overload protection (max values)—as those were the filters selected. For example, if a load (a small circle) is green, its voltage is OK. For example, if a branch is yellow, overload protection for that branch is barely OK. Thus, through filters the numerical results of the system analysis can be viewed in an efficient manner. By switching between different filters, the engineer can make a rapid assessment of the system efficiency, security and safety.

Consider now Figs. 2 and 3. They show results as seen from a particular node and branch, respectively. For the node, it includes voltages at peak (probability 95%) for phases A, B and C, and for the neutral. It also shows phase peak loads, customers represented at various power levels, outage duration and frequency, service cable, short circuit values. As an option, it shows a diagram with the 95% voltage minima together with some useful reference lines. As for the branch, Fig. 3 includes currents at peak for phases A, B and C, and for the neutral; and values for losses, fault current, ENS, and optionally a diagram with the 95% current maxima together with some useful reference lines such as cable ampacity and transformer loading.
4. SYSTEM SECURITY

The assessment of system security is also made in a very efficient manner through the use of filters. The network is colored according to the security achieved as provided by the protection devices in the transformer station and in the various protection boxes along the network. The computation of the network security includes analyzing the effects of all protection devices, namely protections against overloads and against short circuits. As for short circuits, it is often necessary to consider maximum and minimum values for short circuits. The corresponding display of the results are like before (recall that Fig 1 already shows the filter for the protection against overloads, and in the smaller window, against short circuits. Fig. 4 shows a view of branch results for a branch colored green by the filter. The corresponding protection diagram shows that indeed it should be green: the characteristic curve (time vs current) for the protection, in black, lies below the thermal characteristic for the line, in red. It also shows two blue lines: one for the minimum short circuit current in the line and the other for the corresponding acting time for the protection.

Fig. 4. Info for quantities of a particular branch, with a view of the corresponding line protection diagram

5. SYSTEM SAFETY

The system safety assessment uses filters as well. Safety is calculated for every short circuit by computing the effect that the corresponding fault could have on human beings. Once the conditions for the computation of the current flow through the human body have been input, then, in accordance with the person protection norm IEC 60479, the safety measures can be computed.

Consider now Fig. 5. The main window shows a filter assessment, where green means safety is OK, without physiological effects beyond current perception and involuntary muscle contractions; yellow corresponds to a stronger reaction, with reversible effects for heart response, without body damage. The smaller window shows a view for a branch colored yellow. It shows the characteristic for human current perception and muscle contraction (in green) and the characteristic for ventricular fibrillation (in red). The intersection of the two blue lines defines the corresponding safety point: one blue line defines the protection acting time, the other line defines the current through the heart.

Fig. 5. A general view with filters for person protection and short circuit protection and a corresponding view for a particular branch colored yellow.

6. CONCLUSION

LV networks are playing an increasingly important role. They require a frequent, thorough assessment for safety, security and efficiency. Such an assessment can be made by today’s technologies: advanced probabilistic models, intensive computing, efficient display of results and an adequate interaction technology. A correct assessment prepares the LV network for better performance and to serve its new role in today’s business environment and in tomorrow’s distributed microgeneration.

REFERENCES