THE ELECTRIFICATION OF FAST DEVELOPING AREAS

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SUMMARY

This paper presents an original methodology for planning the electrification of fast developing areas, either urban or rural. The objective is to define economically efficient network reinforcement projects that must comply with predefined planning criteria regarding, e.g., over-current, voltage drop, losses and undelivered energy. A specific computer tool, named GIPSY (Graphical Integrated Planning System), has been developed to tackle the challenge of fast developing areas where hundred of projects need to be technically designed and economically ranked.

INTRODUCTION

The electrification of fast developing areas is a complex task that requires an adapted methodology supported by powerful computerized tools.

The methodology for the study or the follow-up of the electrification of fast developing areas involves several steps:

- Large scale data gathering, aimed at defining precisely the present status of the electrical networks;
- The estimation of the future load demand, with a level of detail suitable for the design of MV networks;
- The design of electrification projects, either in rural or urban areas, including dispersed generation;
- The economic and/or financial appraisal of the projects.

The application of that methodology to a fast developing area is a challenge because of the hundreds of projects that need to be technically designed and economically ranked. Therefore, Tractebel Energy Engineering has developed a specific computer tool, named GIPSY (Graphical Integrated Planning System), to tackle such complex problems. This tool is described hereafter.

THE METHODOLOGY FOR STUDYING THE ELECTRIFICATION OF FAST DEVELOPING AREAS

The data gathering

For each study, Consultant teams have to master a new, different system and therefore, the performance of the data collection is critical to the study performance. The first step of the methodology specifically developed to study fast developing areas involves the acquisition and computerization of many data related to the geographical background, the existing system and the demand.

The geographical background: The geographical background is an important data to be gathered during the first steps of the study. This background has to be digitized or scanned from available maps. Sometimes geographical databases and computerized maps are available. The knowledge of the geographical background is essential for the introduction of the geographical constraints on the demand or on the network development. Adequate scales for rural development studies are included in the 1/25000 – 1/100000 brackets; for urban areas, more detailed maps are necessary: typically between 1/2000 and 1/10000 scale values.

The electrical description of the system: A detailed description of the existing systems must be obtained and carefully checked. Sometimes the detailed description is obtained under the form of a one-line diagram and sometimes under a geographical representation of the networks. Very often, these maps are not up to date and field checks using GPS (Global Positioning System) equipment have to be done. In rural electrification, the dispersed character of the information poses the greatest challenge for the data collection process. In urban schemes, the data quality depends on the ability of the various operating sections of the distribution companies to set up adequate procedures to maintain the correct network representation on a day to day basis.

The demand: The following step of the data gathering consists in the acquisition of a precise image of the present load pattern. Comprehensive metering data constitutes one of the basic information to be obtained. Very often, extensive on the field survey has to be performed for future potential load identification, such as small agro-industries or villages. Digitized meter reading areas boundaries allow the production of thematic maps to view and check the data.

The future demand

The second step of the analysis of fast developing areas consists in determining the future demand. The future demand analysis often includes several steps: a national load forecast, a geographical distribution of the load, an analytical load forecast and finally, a peak power forecast.

The global load forecast: Forecasting the load at the country level is of crucial importance, as it allows to take the national economic development into account and the design of scenarios of development coherent with the national economic and social development. A frame can thus be set up into which the development of fast developing areas can be evaluated and mastered.

The geographical load distribution forecast: To cope with the accuracy required for distribution planning, a geographically detailed load forecast is necessary. Therefore, a set of small areas that will serve as a basis for the breakdown of all the extensive variables such as the area covered by land use type, the population, the number of consumers and the consumption. The gathering of all these data and their allocation on those small areas is a time consuming process. Coherency checks of this allocation can be made through specific ratios (population densities, connection rate and specific consumption). GIS (Geographical Information System) software and thematic maps are mandatory in this phase of the study. The detailed load forecast is made of the following steps: the land use forecast, the population forecast, the consumer number per category and finally, the consumption forecast. For urban areas, saturation levels, i.e. the maximum demand linked to the type of land use may improve the load-forecast process.

The analytical forecast. Very often, a particular forecast has to be made for each additional load. This occurs specifically when industries are using their own generation means or for population centers located in zones not yet connected to interconnected networks. These cases cannot be covered by a global analysis and require a detailed forecast because the economic opportunity of the connection of each load center has to be defined separately. Another case that needs specific analytical load forecast consists in the fast developing industrial zones. When studying the potential demand of such zones, it is important to obtain as much details as possible on the industry types, capacities and daily operating modes so that a demand forecast, energy and power, for the zone could be prepared

The peak forecast. The demand forecast has to be converted into peak loading of equipment to allow the design of new networks. For new electrification, an analogy with existing demand centers is used. Therefore, peak records will be made for a sample of substation or feeders and analyzed and a peak-demand relation is established. For the development of existing systems, the peak contribution of each MV/LV substation has to be determined by multilinear regression analysis. The data required for these calculations are the peak values of the different feeders of the system and the available information for each MV/LV substation. Then, depending on its type and location, appropriate growth rate has to be computed.

Equipment standard optimum definition

Taking into account the planned load densities and the existing network architecture, cost effective (“optimum”) equipment sizes at different voltage levels, regarding investment and losses (power lines, transformers, substation type), are established to be used as building blocks for the development of the system. This is made through the use of Tractebel’s “Dimensioning” model.

The design of electrification projects

The third step of the methodology refers to the design of electrification projects.

A project comprises all network investments and reinforcements required for the connection of a set of interdependent additional loads or for the supply of growing loads. For example, in rural electrification, the connection to the grid of a given load not only depends on its location and size but also on the presence (or the absence) of other potential loads in the close vicinity.

Usually, several different development alternatives can be envisaged for a specific project or a specific area. To ease the design of these network development projects, the Consultant uses, for isolated areas such as villages or agro-industrial loads, two new concepts: the equivalence sphere and the attraction sphere. The equivalence circle has a radius equal to the distance from the existing network where dispersed generation has the same rate of return as the connection to the grid. The attraction circle has a radius such that the connection of that potential load to a power line crossing the sphere will have a rate of return above a given threshold value.

The feasibility of all these alternatives has to be carefully checked and must comply with pre-defined technical criteria of operation. The technical calculations should be carried out for each loading condition, for each network operation condition and for the various years of the study period. Specific modeling tools have to be applied for this evaluation: distribution load-flows (constant current loads) classical power load-flows and calculations adapted to low-voltage networks.

The quality of service must also be assessed and remedies found when the supply conditions become critical: e.g. by ensuring a sufficient meshing or redundancy of the system. Here again, various techniques can be adopted depending on the problem considered. If the reliability of a feeder must be examined, the computation method used will be different than when the reliability of a transmission network has to be evaluated. In the case of a feeder reliability examination, the method used is based on the examination of the various sequences of detection of the faults, operation of the feeder switches and supply of the load by redundant network paths. In the case of a transmission network, or a system with a higher degree of meshing, it becomes possible to use more global computation techniques, based on the “Monte Carlo” techniques or network states decomposition techniques. The resulting indices of unserved energy can be used in the economic appraisal of each project.

Finally, the impact of the proposed project or projects on the main transmission grid is carefully checked. This impact usually consists in the necessary addition of HV/MV substations, transformers and line reinforcements. It is important to note that the results of the distribution load flow, in terms of transformer loading must be coherent with the transmission load flow and suitable techniques are adopted to transfer the results from the medium voltage to transmission voltage level.

The economic and financial appraisal of the projects

Usually, three main solutions exist for the supply of new, additional loads: the first solution consist in dispersed generation sources, the second one in the creation of small networks around a power plant of greater size and finally connecting the area or the project to a main transmission network. The final evaluation of these various options requires a global approach and the ability to compare the total discounted costs over the planning period or even to optimize and find the trade-off between the proposed solutions. This optimization is frequently carried out by the use of linear programming techniques and takes into account the dynamic aspect of the fast developing areas for which the demand growth constitutes an important parameter of the economic evaluation.

An important aspect of the economic evaluation of projects consists of the correct appraisal of the value of the sold energy. This value is determined by the capacity of contribution of each customer or type of customer. In the case of industrial plants where self-generation is substituted by centralized generated and transmitted energy, these costs can easily be computed by means of cost comparisons with the cost of stand-alone generators. In the case of domestic customers, the analysis is more difficult and requires frequently approximations and estimates of the substituted energy sources and costs.

Finally, in the financial project appraisal phase, a merit criterion is determined as a basis for project ranking. The merit criterion can be defined in various ways. It can be defined strictly on financial criteria such as the financial IRR or can be defined as the number of electrified load centers or as the connection rate (percentage of households connected to the electricity). The two latter values are used in rural electrification, so that a larger population can benefit from the advantages of centralized electricity supply for a given investment budget.

APPLICATION OF THE METHODOLOGY TO REAL WORLD CASES

Applying the methodology to real world cases is challenging because of the large size of the systems under consideration from the point of view of the number of load nodes and lines to be taken into account. The methodology as a whole requires therefore a large automation that powerful computerized tools practically allow putting into operation at reasonable costs.

The tool developed by Tractebel Energy Engineering for this purpose is called GIPSY (Graphical Integrated Planning System).

The main characteristics of GIPSY

The GIPSY software is a combination of a technical database, a geographical network database, a graphical interface and a set of electricity systems analysis tools embodied into the software.

The basic principles underlying the design of this software were:

- a detailed and object-oriented representation of the different components of an electrical system, close to their physical reality;
- a explicit representation of the time, including the years of the study period, states of operation and load curves;
- the reuse of several existing (in house) planning tools;
- a performing software development tool using a meta-object protocol for the design of alternative development scenarios.

The main features of this software are:

- A geographical object-oriented database of existing and planned networks;
- A graphical interface for network data introduction and design;
- The use of a layered description of the background, networks and labels;
- A sub-networking facility allowing the grouping of networks components together;
- The management of alternative development scenarios organized in an hierarchical way;

- The integration of existing computerized planning tools such as: a distribution load flow (medium voltage and low voltage), a power load flow and a combined network and generation investment planning tool (PRELE);
- The possibility to have, at the same time, different representation of the system in different windows;
- The existence of several types of coherency checks: topological, spatial, hierarchical and temporal;
- An interface with other drawing software and spreadsheets;
- The concept of project, grouping investments shifted into time;
- The possibility to choose, for each network element, a geographical representation and a one line diagram representation.

Original characteristics of this software are presented into more details hereafter.

The graphical interface

The complexity of real MV networks requires the integration into a single repository of many different kinds of information.

The network can be introduced geographically with a background or as one-line diagram.

The geographical background can be introduced in the graphical database through digitized maps. Each type of item of the background can be introduced on a specific layer: road, rivers, lakes, contours, etc. Backgrounds at various scales can be introduced and displayed in specific windows. This facility is a key element for the study of dense urban MV networks or of LV networks.

Network drawing (one-line or geographical) and topology are entered at the same time, reducing by this way the number of incoherencies that may arise during that phase.

The network elements are associated to specific layers. By this mean, it is possible to select a specific set of voltage levels for which the network components have to be displayed.

The sub-networking feature of Gipsy allows the user to group and hide networks components together. As an example, the main network representation may be geographic, corresponding to a scale of 1/25000, then a sub-network at a scale of 1/2500 may be used to enter data corresponding to a small town and finally, HV/LV substations may be entered as single line diagrams in a third sub-networking level.

All the networks components can be introduced and their characteristics obtained by selection on the screen. Some of the technical components of the network can also be manipulated directly from the screen. For example, it is possible to open or close any switch to adapt the operating scheme of the networks.

Finally, each network component can be introduced and drawn either under a synthetic appearance (very often a simple box), more convenient for geographical representation of the system or under a detailed appearance (with an exact representation of all the busbars, switches, nodes).

The loads

The system loads are represented using yearly load curve, either chronological or with a load duration curve and load states. The loads can be introduced or modified directly in the graphical user interface or through the import of a spreadsheet file. In that case, each load must be provided with its exact geographical location, for example down-loaded from GPS system records captured during field reconnaissance works.

The time

Detailed time consideration is a major asset of the GIPSY tool. The representation of the time allows the correct identification of each development strategy of a system. Indeed, a development strategy extends over several years and it is the sequence of investments that actually defines the strategy. The time representation also includes load curves for each demand node. This allows the correct calculation of the losses, the calculation of the unserved energy and more generally the calculation of the total discounted costs of a development strategy of a system. All these calculations require the summation (integration) over time of time dependent functions. These calculations can be automated only if time is described explicitly in the database.

The representation of several periods as the base time concept allows the check of the coherency of the investment sequence. Indeed, for a specific year of the planning period, the network elements are activated only if they are already commissioned. Therefore, it is impossible to connect an element to any other that would not be identified as already commissioned.

Finally, it is possible to display the networks at a given time, or to display all the periods together, using different colors for investments made at different periods.

The management of scenarios of development

One of the most interesting features of this software is its ability to deal not only with the future evolution of the system but also with alternative development scenarios. At any time, it is possible to start developing an alternative scenario, characterized by other investment programs, other load flow conditions, other operating schemes, etc.

The scenario management is organized around the concept of “worlds” that are hierarchically organized. Starting from the root-world that represents the existing system and the information common to all the possible scenarios (example: demand data), the user can create scenarios of development able to satisfy the technical and economical requirement of the system during the study period. If the system is modified in a specific world this modification will take place in all its “child” worlds, but not in its “parents” worlds. Of course, the user has to verify, possibly by running again network analyses tools, that in the context of each “child” world the operability of the system has not been affected by the modification.

The scenario management in GIPSY has the benefits of a meta-object protocol and is supported by the object oriented database. Therefore, a large number of scenarios can be envisaged, even for systems embedding numerous network elements.

Coherency checks

They are 4 types of coherency checks inside the Gipsy software. Topological coherency checks insure that a line is always connected to a node. Inside large-scale (ex: 1/2500) maps, spatial coherency avoids the placing of two network facilities exactly at the same place, or in one-line diagrams, to have two equipment with superimposed drawings. With the temporal check, the database is protected against incoherencies such as the connection of feeders to a substation that do not (yet or anymore) exist at this time period. Finally, specific checks are linked to the hierarchical structure of the worlds: an action taken in a world may lead to incoherencies in sub-worlds. At that time, the user has the opportunity either not to do that action, or either to do so, and to have an “incoherent” sub-world.

The planning tools linked to the GISPY software

Several planning tools are connected or embedded into the GIPSY software:

- A LV distribution calculation tool;
- A MV distribution load flow;
- A classical load-flow;
- A reliability analysis program;
- A long term planning tool.

The GIPSY environment allows each of these tools to run in specific windows and in the context of any particular “world”. The data required by each model is extracted directly from the world network data. Data and results of particular calculations can always be re-accessed later.

Equivalent networks required by a specific analysis tool are automatically generated and updated when required (addition of a new equipment or modification of a switch status). Application software can immediately be run.

The low voltage calculation tool: Due to a very high variation of the simultaneity factor along LV feeders (from 0.1 or 800 hours/year to 0.5 or 4400 hours/year), a specific software is required for the calculations of voltage drops and losses in LV networks. The delivered energy constitutes the starting point of these calculations that are based on a quadratic energy-peak relation.

The distribution load-flow. This load flow is specific to distribution networks where thousands of loads have to be represented by constant current equivalent (there is no on load tap changer on MV/LV transformers). This load flow is embedded into the GIPSY software. The user can very easily check the status of the alternative under study, highlight the possible overloading or abnormal voltage drops (with colors). Used repetitively over the time periods, the system states and the load curve levels, this load flow allows to compute fairly precisely the energy losses of the distribution network over each year of the planning period.

The classical load-flow. This load-flow is available to compute networks at a higher voltage level or meshed networks as in urban or densely electrified areas. This load flow also allows the analysis of the impact of distributed power generating units on the electrical behaviour of the network. It should be stressed that the system load, as measured by the distribution load flow, is automatically transferred to the higher voltage level taking into account a diversity factor. As a consequence, the analysis carried out at the higher voltage level remains coherent with the load described at the lower voltage level.

The reliability analysis tool. The MV feeders reliability can be analyzed and the non-delivered energy evaluated from the data stored (and calculated such as the currents) in the database and transferred to a spreadsheet. This allows the evaluation of the economic viability of investments aimed at the improvement of the quality of service and of the reliability of distribution networks. The program is based on the knowledge of the feeder structure and the analysis for all successive elements of the consequence of their possible failure knowing parameters such as the probability of their failure, the fault detection time, the time to reconfigure the network and the repair time.

The long term investment program. The GIPSY software is connected to a long-term investment planning tool: the PRELE model. The PRELE model is aimed at the technical and economical optimization of the investments in generation and transmission of an electrical system. The model incorporates a simultaneous representation of the load, the transmission system and the generation, even dispersed in the system. The tool is associated to a linear programming optimizer. It minimizes the total discounted cost of a system (i.e. the investment cost in generation and transmission, fixed maintenance cost and variable generation cost). The optimization must comply with a set of constraints such as the load satisfaction, the line and generating capacities, specific energy constraints on the generation power units…

The PRELE model also includes a certain number of operating conditions of the system. Each operating condition is specified by a specific condition of the load, of the network element availability or of the generation availability. A probability of occurrence is associated to each state and weights its impact in terms of variable operation costs in the total system cost.

The PRELE model allows the determination of the optimal development strategies in rapidly developing areas where the load growth over a set of several years constitutes an important parameter of the complexity of the problem. The dynamic aspects linked to the rapid development of areas are taken into account explicitly into the optimization process.

The PRELE model needs a specific representation of the system. This representation is constructed inside the GIPSY software by an adequate aggregation data processing interface. A new window of the system is created, where the data needed by the PRELE model are displayed using a one-line diagram representation. The aggregation process may be controlled forward and backward by the user and is memorized by the GIPSY software. The GIPSY software then generates the PRELE input data. The optimization process is carried out outside the GIPSY environment as it can last for a while, thus allowing these calculations to be performed on other computer resources.

Once finished, the optimization results are re-imported into the GIPSY environment that allows the creation, in the current world, of the actual investments as indicated by the optimization results. The load flow and reliability tools can then be applied on the proposed strategy.

In a single PRELE run, the optimization tool elaborates a development strategy for the whole planning period.

CONCLUSIONS

The rapidly developing areas impose a challenge to the planning engineers of electrical systems. This challenge consists usually in the large size and complexity of the problems involved: a rapidly growing demand, the presence of dispersed generation and the vast number of possible scenarios of development.

The authors have presented a methodology to overcome these difficulties while taking into account a precise representation of the system and determining development strategies in a context of minimization of the total system costs.

The authors also presented the computerized support of the methodology, the GIPSY planning software. It is graphically oriented and is built around an object-oriented database that allows taking real world large size problems into account. The two figures hereafter show some features of this software.