INVESTMENT SELECTION AND SCHEDULING IN AN ELECTRIC DISTRIBUTION NETWORK

L.F. Escudero(1), E. Gómez(1), J. Salmerón(1),
R. Criado(2), E. Valtierra(2)
(1) IBERDROLA Ingeniería y Consultoría,
Avda. de Burgos, 8-B Madrid (Spain)
Tel: +34 91-383-31-80 Fax: +34 91-383-33-11
(2) IBERDROLA
Gardoki, 8 Bilbao (Spain)
Tel:+34 94-415-14-11 Fax: +34 94-415-45-79

SUMMARY

SISPIR is an integrated tool for investment planning in an electric distribution network along a planning horizon (one to several years) which was presented at the CIRED '97. Now, we report on some important new features that have been included in the system as well as on the experience gained by running it for cases with more than 13.000 candidate investment items to be scheduled within a 5 years planning horizon.

INTRODUCTION

Investment planning is one of the most important activities at electric distribution utilities, telecommunication companies and other services companies. The individual analysis provides specific information of each investment (economical rates, contribution to distribution network improvement, etc.). However, a long-term global investment plan must take into account the impact of each individual decision in the system. For this reason, the decision making process is devoted to face with such a problem, where a very large number of combinations is possible and the trade-off between conflicting objectives leads to a very complex analysis.

At present it is very usual the usage of individualized analysis systems. With this information, expert analysts have implemented satisfactory investment plans, by selecting the most profitable ones and attending the needs of the system (meeting the demand, service quality, security, legislation requirements, etc.). As mentioned, the difficulty of this task is the necessary time to attain such a plan meeting all system requirements. Moreover, this is only a small problem compared with the difficulty of adjusting existing plans to unexpected new conditions in the system (e.g. the increasing of an investment yearly cost, delays in the expected planning performance, etc.).

Thus, we deal with two problems: First, assuming certain system requirements, external conditions and the company policy, 'how can we obtain the most suitable investment plan?'. Secondly, assuming that the most attractive plan has been obtained successfully, we are interested in reflecting possible changes in the conditions, so the question is 'how can we guarantee that the plan is robust?' and 'how to easily make a new plan satisfying the new conditions and with the minimum deviation from the old one?'.

Our research has been focused in developing a mathematical formulation of these problems, as well as implementing the necessary optimization and mathematical programming based techniques to solve the implicated models. As a by-product, the methodology has been used as an external software that can be easily invoked from the analyst user interface, where different cases with multiple conditions can be simulated.

THE PROBLEM

The final objective of the investment plan is to maximize a merit function (let Z), where the merit of performing each individual investment (let j) at a given period (let t) is m_{jt}, given by one of the following alternatives provided by the individual analysis of each investment:

- $m_{jt} = NPV_{jt}$ (net present valve) ($)

- $m_{jt} = \nabla ENS_{jt}$ (improvement of non-supplied energy) (MWh)

- $m_{jt} = NPV_{jt} + K\nabla ENS_{jt}$, where k = $/MWh is fixed

Individually, NPV and ∇ENS will be referred to as "objectives". Other objectives may exists, and their contribution to the objective function can be combined like in the previous case.

There are a number of constraints and characteristics that a feasible plan must satisfy. Among them, we point out the following:

- The investment character may be mandatory (i.e., the investments that must be performed within the planning time), non-mandatory or the belonging to a group, which means that the decision about them depends directly upon the decisions concerning other investments. Each investment has also a time window for execution.

- The use of a limited amount of resources is another constraint of the problem. These are: Total budget per year (maximum and minimum), total budget per year and geographical area (maximum and minimum), total budget per year and investment type (maximum and minimum), human resources (e.g., working hours) and material resources.

- Other Relations among investments can be considered: (a) A group of investments must be jointly accepted or rejected for the plan (although the related investments can be scheduled at different time periods). (b) One only investment must be selected from a group of investments (e.g., different alternatives for a project). (c) Time-lag between two investments

- Balance conditions refer to the maximum deviation allowed in the yearly investment between regions, and the minimum and maximum deviation between consecutive years each region as well.
- Finally, besides the alternative to be maximized, individual minimum satisfaction levels can be imposed for each objective (e.g., a yearly minimum for the improvement in non-supplied energy)

The mathematical formulation of this problem leads to a very complex model under a mathematical optimization point of view. Two main difficulties are pointed out: The integrality of decision variables and the problem size for real cases

The model is very difficult to be solved until optimality. So, instead of providing optimal solutions and in order to overcome these difficulties we have developed a specific algorithm that takes the advantage of advance intensive computation in integer programming. In particular, we have implemented a combined data preprocessing and an exact-heuristic algorithm known as 'Fix & Relax', that exploits the stair-case structure of the constraint matrix, due to our multi-period scheme. This speeds up the convergence to a quasi-optimal solution (a maximum gap is guaranteed, and the user can choose weather total optimality is desired or a satisfactory gap is allowed). For more details, see [1]-[2].

RELEVANCE OF THE SYSTEM

The potential improvement of this tool to distribution electric systems is very high. The first point of improvement is the economical profitability of the plan. The possibility to perform a number of simulations, evaluating the consequences of each new hypothesis as well as the detailed information of the results and plan comparisons provides the planners a quick analysis tool, until a global plan that takes all the necessary elements into account is achieved.

As an instance, consider the possibility of increasing the weight of quality in the system (i.e., the cost per non-supplied MWh), creating a trade-off between this objective and its profitability. This is the well-known cost-of-quality, due to the most attractive investments to improve the quality of the service are usually unprofitable.

The explicit treatment of a multiperiod investment plan is an added-value concerned with determining a global plan rather than a year-to-year dependent plan. A more simplified single-period planning system can be used sequentially in order to produce an investment plan for each year, though the results of this analysis might not be optimal for the whole planning horizon: since the plan for a given year would not consider how much it affects the next one, all the decisions in further periods are strongly conditioned by the precedent periods. Because of this dependence, consistency and feasibility of plans are not guaranteed for any but the first year.

Our approach allows to consider inter-relations among periods, such as:

– Multi-year investments (i.e., investments whose duration is more than one year)

– Resource transferring: Resources are acquired at the beginning of each year, so simulations, performed with a tool as SISPIR where the surplus of previous years is allowed to be transferred to the next one, could be used to adjust better the resources to require each year.

– Individual merit associated to each investment per year, in order to maximize the total merit over the planning horizon as well as satisfying individual levels per objective and year.

SYSTEM CHARACTERISTICS

Besides the kernel (mathematical model), the integrated system consists of a database and a user's interface. The last allows the parameter specification, alternative to be maximized, problem conditions and start of the kernel run (which is completely transparent to the user). It also permits to add new elements to the database (e.g., a new investment and its attributes, a new objective, a new type of resource, etc.). When the solution is available, it is represented in graphical and numerical form and can be stored and compared with other solutions, Figure 1.

At present, the hardware supporting the system is a Pentium with 32 Mb of RAM and at least 100MHz speed.

The user's interface and database are supported under the Windows 3.x (or higher) operative system. The former was made with Visual Basic. The database is supported in Access 7.0.

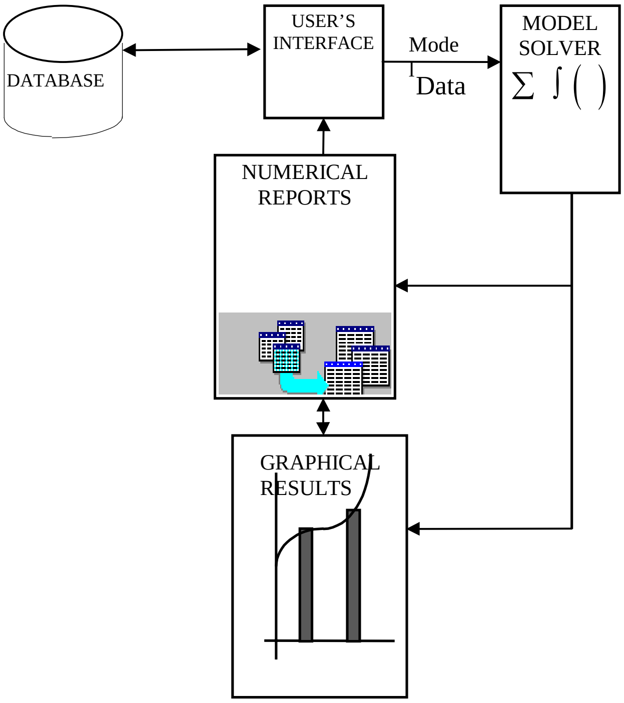

Figure 1. SISPIR chart

COMPUTATIONAL RESULTS

During the last two years we have applied the proposed formulation and methodology to real cases drawn from “Iberdrola Distribucion y Clientes”, the most important private distribution utility of the Spanish electric system. Even if the planning horizon for each plan is five years time, these plans are typically revised yearly, so an existing plan may be modified adequately to new information available at the end of the year.

The first 5-years plan for the 1997-2001 period has a dimension that allows to attain the optimal solution by means of the multi-period planning. However, in the planning for the next 5-years from 1998 until 2002 year, some of the investments of interest for the first plan were disaggregated into new ones, so that each of these required a specific time period to be executed, increasing considerably the problem complexity. As a consequence, it was decided to run a sequential single-period algorithm for this case.

Period 1997-2001

The hardware supporting this test has been a standard PC486 with 66MHz speed.

The input data used consisted of 1072 investment items and 5 time periods. The 9 resources considered by year represent the total budget, the budget per ‘Plan’ and the budget per ‘Region’. Note: Here, ‘Plan’ and the ‘Region’ are the two main attributes for each investment. The possible values for ‘Plan’ are ‘Plan 1, Plan 2, Plan 3, Plan 4’. The options for ‘Region’ are ‘Norte, Centro, Este, Oeste’.

We focus in the case of maximizing the merit function that consists of the sum of the NPV and K∇ENS, for a given K, let K = 300 Pts/KWh:

Z = NPV + 300 ∇ENS

As mentioned, a minimum and maximum budget is required per year and for each type of attribute.

We first attempt to solve the problem by a sequential single-period procedure instead of the global multi-period planning. Thus, we start at period 1997 and try to maximize Z. The result is indicated in Table 1, Z = 7.883 MPts.

As a consequence, we proceed to eliminate the chosen investment of the database and re-run the optimization kernel for the next period, 1998. Now, Z = 5.884 MPts.

The next logical steps are continuing until the last year, 2001, is solved. In this case, the problem for year 1999 is infeasible under the initial conditions. Of course, by relaxing these conditions, we can obtain a dummy solution Z = 2.402 MPts. for 1999. It is a decision of the end-user whether this solution is satisfactory enough or not, provided that he may analyze the plan at the end of the first or second year, achieving a new feasible solution from that year onwards. The last year (2001) results infeasible at the end with the possibility to relax others conditions in order to get a feasible solution for each year.

Table 1. Yearly profit (Mill. Pts.). Comparison of solutions

Year	Single-Period	Multi-Period
1997	7.883,232	7.833,390
1998	5.884,969	5.466,761
1999	*(2.402,347)*	2.752,150
2000	977,073	699,763
2001	*(17,440)*	260,954

On the other hand, the multi-period approach leads to a global feasible solution that can be implemented year-by-year without violating any of the initial conditions (rightmost column in Table 1).

Figure 2 shows the slight difference between both approaches (assuming that the single-period system does not verify all the conditions between 1999-2001).

The derived integer model has 6332 integer variables and 1140 constraints. The computational time required is 5 minutes for the single-period and 30 minutes for the mult-period.

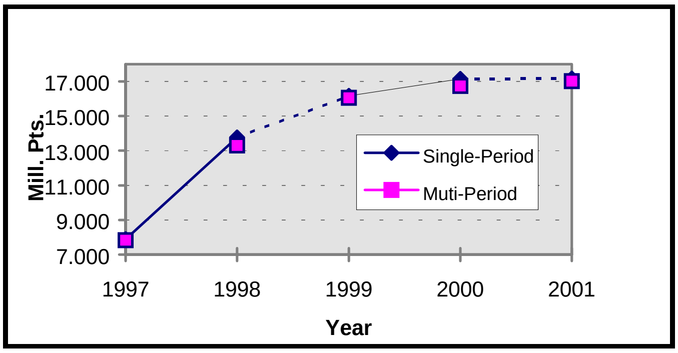

Figure 2. Cumulative profit for the 1997 planning

We have tested other alternatives either in the number of investments, periods, resources and objectives. The results are indicated in Table 2.

Table 2. Other Computational results

Case	$\|J\|$	$\|T\|$	$\|R\|$	m	n	d	Gap	Time (secs)
S-100	100	10	10	197	577	4.0	0.01	34
S-250	250	10	10	561	1527	3.3	0.03	410
S-400	400	20	20	1012	4610	2.5	0.035	4883
S-500	500	10	50	1022	3050	1.3	0.01	737
S-600	600	20	50	1856	6763	2.0	0.02	30441

m: No. of constraints; n: No. of integer variables;
d: Matrix density (%)
J: Nº of candidate investments; T: nº of periods;
R: nº of resources

Period 1998-2002

As indicated above, for this case the algorithm is run sequentially year by year. So, optimality cannot be proved though the results seem to confirm that excelent improvements can be achieved compared with the use of other strategies using spreadsheets or typical merit order lists.
The hardware for this test was a Pentium 133 MHz.
The number of candidate investments is 13271, which represents a considerable increase in the problem complexity and numerical difficulties.
The resource types considered are the same as in the 1997 planning.
We present the results obtained in the following 4 cases:
#1: This is a heuristic solution provided by the user by other means apart from SISPIR.
#2: The only constraint is the Total Budget for the plan
#3: Besides the Total Budget, additional budgets are included by ‘Plan’ and ‘Region’ attributes
#4: The budget is limited by the resultant solution of case #1
In all the cases the objective function to be optimized is

$$\text{Maximize} \qquad Z = NPV + Ks\, \nabla ENS$$

where Ks is a constant for each region, so that investments in those regions with a current inferior quality of the service are prioritized.

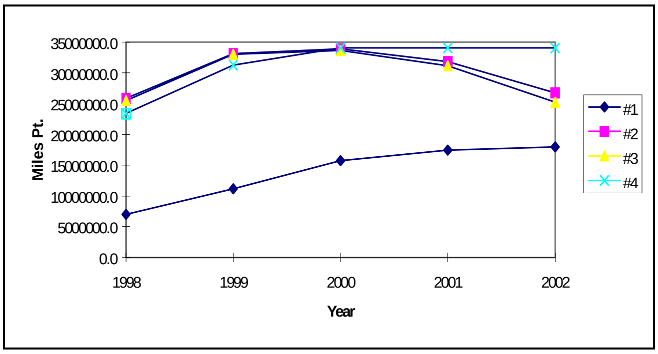

Figure 3. Cumulative profit for the 1998 planning

It can be observed that the final benefit for the last year is much larger in the three SISPIR cases #2, #3 (with budgets and constraints fixed in advance) and case #4 (with the budget fixed by the budget used in case #1, provided ‘heuristically’ by the user).
The total time to run each case is approximately 15 minutes.

CONCLUSIONS

This paper has presented SISPIR, an investment planning tool based in integer mathematical programming models.
SISPIR presents the advantages of integrating specialized mathematical techniques in the investment decision making are emphasized, in comparison with classical general purpose tools, such as spreadsheets and others and the most remarkable aspects of SISPIR are twofold. First, the simultaneous consideration of a multi-objective and multi-period system that takes into account all the available information of the planning horizon. On the other hand, the development of specialized mathematical techniques to solve the model with success. To complete the process and its potential utility, the system has been integrated within an easy to use user’s interface and database where multiple simulations with different investment environments, assumptions, planning criteria and policies and result evaluations can be carried out even by non mathematical programming specialized planners.
At present, the results provided by the system are satisfactory, and the necessary time to achieve a reasonable quasi-optimal solution is computationally acceptable.
Overmore the potential improvements of the system lead to important economical savings, the satisfaction of all the proposed objectives and a quick evaluation of the impact in the investment plan due to unexpected changes in conditions, parameters and priorities.
Our next steps are focused in a more detailed goal programming for prioritizing objectives as well as adding new relevant conditions and improving the numerical algorithms. These are ongoing researches which results we expect to provide in the near future.

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REFERENCES

[1] Dillenberger, C., Escudero, L.F., Wollensak, A. and Zhang, W. “*On practical resource allocation for production planning and scheduling with different setup types*”, Eur. Jour. of Op. Res. 75 (1994) 275-286.

[2] Escudero, L.F., Gómez, E. and Salmerón, J. “*Sistema Integrado de Selección y Periodificación de Inversiones*”, XXII Congreso Nacional de Estadística e Inv. Op., Sevilla (1995).