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COMPUTER AIDED PLANNING OF DISTRIBUTION SYSTEMS AND CONNECTION WITH MEDIUM TERM LOAD FORECAST

F.di Salvatore - W.Grattieri - F.Insinga
L.Malafarina - M.Mazzoni - G.Nicola

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COMPUTER AIDED PLANNING OF DISTRIBUTION SYSTEMS AND CONNECTION WITH MEDIUM TERM LOAD FORECAST

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ABSTRACT

In order to perform planning studies on HV (40-150 kV), MV and LV networks, ENEL has developed a computation system, composed by a set of integrated programs, which utilizes the information stored in several data bases, with the aim to:

- provide energy consumptions forecasts for each area of the country;
- transfer consumptions for each area to the distribution network nodes and to evaluate the electric demand using a statistical power/energy correlation model;
- analyse several development alternatives of the network and select the optimum development plan comparing the overall costs (investments, operation, risk).

In order to make easier its utilization by planners, the aforesaid computation system will be operated with interactive and graphic procedures, made available by the use of graphic work stations.

The report describes the main objectives and the basic hypothesis assumed to prepare the computation system and its general architecture.

1. INTRODUCTION

ENEL has carried out a technical guide concerning planning and conception criteria of HV (40-150 kV), MV and LV distribution networks.

The easy way by the operative units to employ such criteria requires the knowledge of the network and load situation for a long term period (up to 15-20 years for strategic planning; 3-10 years for operating planning). Strategic planning studies consist in defining the general network options (such as the voltage level, the size of standardized network elements, the network diagrams, the reliability levels, etc.).

These options, referred to large parts of territory, must take into account the whole variability field of those parameters which define the different local situations. They require some elaborations that would result extremely difficult if some suitable global models were not used. Such models description is not the subject of this document.

Operating planning studies, on the contrary, need the elaboration of actual network data.

These studies involve several variables some of which are uncertain:

- characteristics and geographical distribution of loads and their evolution in time;
- installed power, location, and technical-economic characteristics of the generating and transmission power plants;
- types and technical-economic characteristics of the subtransmission and distribution equipments.

At ENEL the information systems allowing distribution network planning are:

- SPIRA system connected to BICE data base, for HV network operating planning;
- MEPR system, for MV network operating planning.

Such systems are diffused and used through ENEL territorial distribution units and they are used as an instrument by the line units to accomplish both medium term planning activities and the ones related to the choice of the interventions to be made on the distribution system in the short term.

This document, afterwards, analyses more in depth HV network planning procedures and also the relative hardware means.

Moreover, with the aim to complete the picture, also the automatic MV planning procedures are shortly mentioned.

2. LOAD FORECAST

The applied methodology [1] consists in the analysis and extrapolation of energy time series belonging to the geographical Enel organization according to their historical trend and respecting the constraints given by the national and regional load forecasting performed by the Planning Central Department (PCD).

Such energy time series are disaggregated by subdividing the users connected to the network into 5 classes for each voltage level of supply (LV, MV and HV).

Moreover, in order to transform energy forecasts into power demand a statistical load model is then used allowing to obtain the load shape on each typical day of the year.

The load forecasting activity below regional level, has been subdivided into the three following steps:

- spatial energy forecast;
- network energy forecast;
- network power forecast.

2.1 Spatial Energy Forecast

Spatial load forecasting involves prediction of both the magnitude and location of future load and is a necessary prerequisite for a correct and meaningful planning. The analysis of location must be made with sufficient resolution to allow allocation and selection of the supply system components. A spatial forecast is therefore not only a forecast of load, but also of its geographic site.

The evolution in electric energy consumption in a given geographical area is due to variations in one or both of the following variables: number of users and per capita consumption.

These, in turn, depend, in a more or less complex way, on social and economic phenomena regarding the area under study such as: resident population, per capita income, cost of energy, economic situation, land-use plans and industrialization level.

Also load management and strategic conservation that can modify the load curve shape must be considered.

The relationships existing among the social and economic variables and the final energy demand can be well taken into account only by using complex econometric models which require not only a long introductory study but also a great quantity of data and special expertise.

Moreover, past experience has shown that such models, which work well at a national or regional level, are not easy to implement on a much smaller area, primarily because of the lack of statistical information.

Then, considering the possibility of utilizing historical data on the electric energy invoiced by ENEL, it was decided to choose the more traditional technique of trending, supplemented by an adjustment procedure which brings results closer into agreement with regional forecasts, which instead are calculated according to econometric model by the PCD.

The analysis of the time series (last 10 years) was carried out by performing direct trending (least squares fitting) and extrapolation of the electric energy delivered to each customer class. The past trend of the electricity consumptions presents different aspects depending on the size of the area under study.

In a small area the growth has not a regular trend: it can be observed an initial stage of rather slow growth followed by a sharp increase which lasts till a saturation level is reached; from this point on, the energy consumption is unlikely to increase any further.

Such a phenomenon can be well described with Gompertz or logistic type functions which have the characteristic "S" shape.

In a larger area, the trend is composed of the combined trends of the smaller areas included and the growth curve is generally smoother and more continuous.

Given a time series and having calculated the coefficients of the trending functions considered [2] one proceeds by filtering the curves and eliminating the ones which, according to the values of the computed coefficients, are likely, when extrapolated, to have shapes very different from those observable in practice (i.e. exceedingly sharp increase or decrease).

Finally, among the remaining growth curves, the one having the highest index of determination is chosen.

Moreover, since the sum of the forecasts of small areas belonging to the same Region must correspond, at the regional level, to the PCD forecast, an adjustment is made to the projection to eliminate the differences.

Then we adopted, for each customer class of a given Region, the following procedure:

- Calculation, for each Area belonging to each Region, of the consumption in the horizon year by means of the "filtered" fitting curves;
- Conversion, in the horizon year, of the regional PCD forecast into the corresponding Area values, by multiplying the PCD forecast by the ratio: "Area forecast consumption"/"Sum of the consumptions of all Areas of the Region";
- Addition of the so calculated Area values to the Area time series, getting a new series; the interpolation of this series and the extrapolation of the new trending functions produce a revised forecast;

- Adjustment of the Area projections, for the different years of the study period, in order to have full agreement with the regional PCD forecast.

Successively, the above procedure is then iterated to obtain the projections for smaller and smaller geographical areas. An example of the computer program results is shown in Fig. 1.

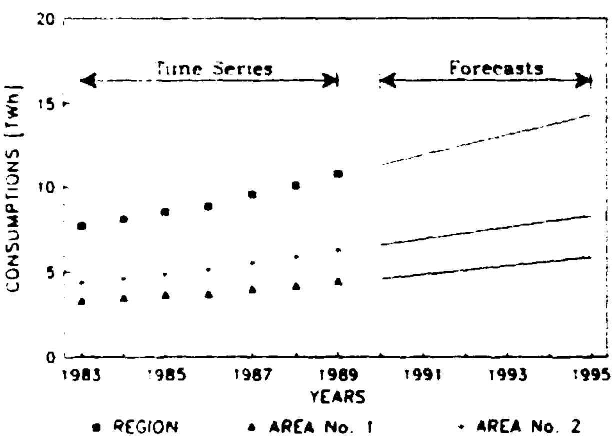

Fig. 1 – Example of the Computer Program Results

2.2 Network Energy Forecast

Once the spatial consumption forecasts have been completed, the annual energy values for each year of the development period and for each area of the Region are broken down among the substations (HV/MV and MV/LV) and the users (HV and MV) belonging to the area under study.

The breakdown, for each year of the planning period, is realized by assigning to each substation or user a part of the area forecast related to the ratio between the energy of the substation and the energy of the area in the last year of the time series.

This ratio is directly calculated when the energy consumptions per customer class are filed into the data base for each substation (1); otherwise, if these data are lacking, an approximate method is used which allows to obtain such a ratio proportionally both to the land serviced by the individual substation and to its rated power. This breakdown can be modified in consequence of variations to the supplied areas due to added/removed substations resulting from network developments decided in previous years and of load modifications derived by local information available particularly for the early years of the study.

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(1) This can be easily accomplished by giving the correspondence between the addresses of users, retrieved from the billing files, and the feeding substations.

2.3 Network Power Forecast

After transferring the yearly energy values from the territory to the network nodes, utilizing the statistical load model [3] based on the 30 load classes, it is possible to estimate the power values at any time of the year.

The estimated values consist of the average value, variance, and relative covariance of active and reactive powers; they relate to each fifteen minutes of the typical day (working day, Saturday, holiday) of various periods of the year (winter, summer, etc.).

The use of the load model for forecasting power values in the nodes assumes that the typical curves of the various load classes included in the model, remain unchanged through the various years. Of course, an interactive procedure to modify the network power according to the demand side objectives (load management and strategic conservation strategic load growth) must be defined.

3. HV NETWORK PLANNING

3.1 Architecture of the BICE-SPIRA System.

To define the procedures used in HV network planning, based on the use of graphic Work-Stations (GWSs), the following priorities were kept in mind:

- to allow powerful graphic and alphanumeric work-stations available for use of planners in order to deal in real time with large networks;
- to ease the interaction with the computer while bringing the network diagrams up-to-date by means of the realization of graphic interfaces;
- to permit an automatic full agreement among network diagrams and data;
- to ease the information interchange both among local network connected GWS and with the mainframes through which the ENEL's interdepartmental information interchange is realized.

The system utilizes the following hardware resources [4]:

- a host computer where the centralized data base (BICE) is hosted;
- GWSs dedicated to network calculations and installed at the system user premises. The application programs and the relational working data bases (REST), one for each distribution network to be studied, are hosted by them.

BICE data base has been arranged to contain the following information:

- topology of the current and projected EHV, HV power networks and of the HV/MV substations, and characteristics of components (lines, transformers, generators);
- EHV and HV network diagrams;
- current and forecasted load data.

Moreover, a link with MEPR and STU (see point 4) systems allowing the automatic transfer in BICE of the information regarding measurements of electric parameters and present and forecasted demand will be performed (see figure 2).

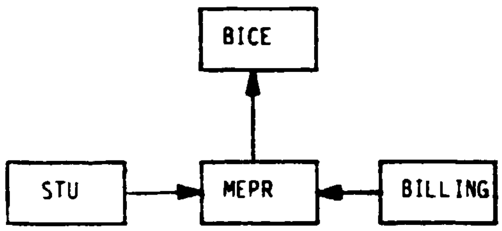

FIG. 2 - Chart of the information flow about loads, measurements and forecasts, necessary for the HV network study.

The GWSs have a microprocessor, with high computing capacity and advanced graphics characteristics with multitasking operating system capable of managing high-speed local networks, with sharing of all resources.

In selecting software for data and graphics management, a relational data base - DBMS (Data Base Management Systems) - was chosen together with a two dimensional - type CAD (Computer Aided Design) package, which can be easily interfaced with both applications programs and DBMS.

So the programs constituting the network computations system have in common an only local working data base (REST), that is composed of a relational data base, where time after time the studied network, taken from the centralised data base, is stored.

3.2 Description of the SPIRA system

The structure of the SPIRA system is shown in fig. 3.

Each REST data base receives the data of the existing and designed networks from BICE, through a selection procedure (SELRET). SELRET permits the selection of a network from BICE

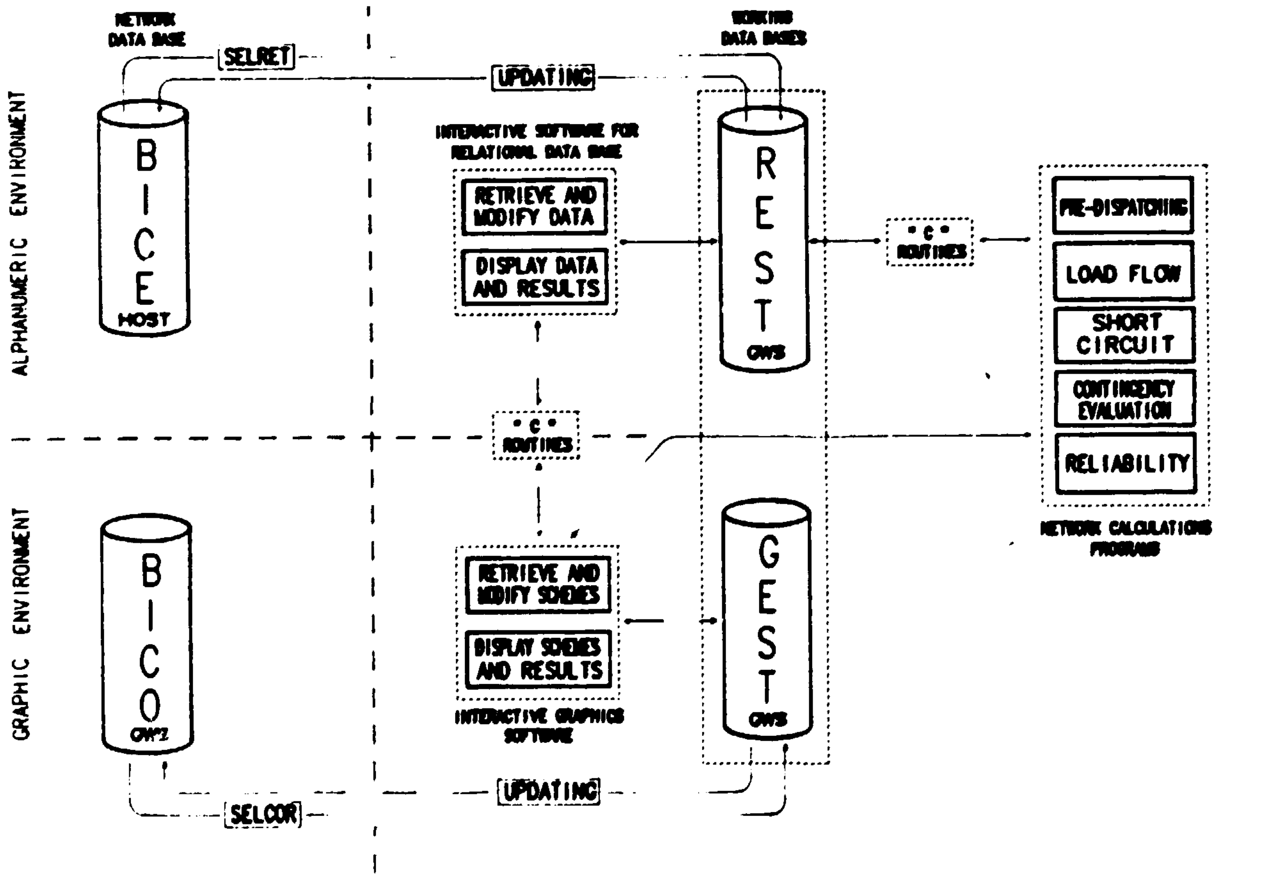

Fig. 3 - Software structure of S P I R A system .

(general data base) on the basis of area, voltage level and the reference date of the study.

Application programs receive from REST the input data and store back in it the results of the calculations executed.

In a similar way, the network diagram is retrieved from a graphic file (BICO), through a selection procedure (SELCOR), and stored in a graphic working file (GEST).

Man-machine interaction is achieved through a set of procedures, named CARDIGAN, which provides:

- graphic and alphanumeric display of network components and data;
- simultaneous updating of REST and GEST files with graphic alphanumeric procedures;
- run of application programs for network planning;
- display of results in graphic and alphanumeric form.

Modifications in the initial configuration of the network, introduced during the study (i.e. variations in the development plan), are then stored in BICE and BICO.

Thus, by means of SPIRA system, a complete integration has been achieved among the three environments (graphics, data base, application programs), so that information can be exchanged efficiently.

In this way the software can also be rationalized taking into account the fact that the various functions are performed by specialized software modules: data management is performed by DBMS, display of data and results is entrusted to the graphics package, and the application programs consist of computational algorithms only.

3.3 Description of the REST data base

As mentioned earlier, the structure of the REST data base is relational (see fig. 4): the data stored are organized into different tables, which are related to each other according to common attributes. An example: the electrical network is described by the tables "nodes", "lines", "transformers", etc.; the common attributes of tables "nodes" and "lines" are the node codes, and the same is true for tables "nodes" and "transformers".

This structure is flexible, because it is easy to add columns (new attributes) to the tables or to introduce new tables to be related to the existing ones.

Such flexibility, in the case of network calculation packages, make easy the addition of new programs and the implementation of the existing ones.

The information content of the data base is also accessible by the various computation programs: this eliminates duplications of data and ensures their uniqueness in the various applications, avoiding all possibilities of error.

REST is used both for the input data of the various programs and for the calculation results which serve as input for other programs. Example: the line power flow computed on a load-flow program is an input to the results display program. In this way, no interface files and programs are necessary between the various applications, which also helps to simplify the management of the system.

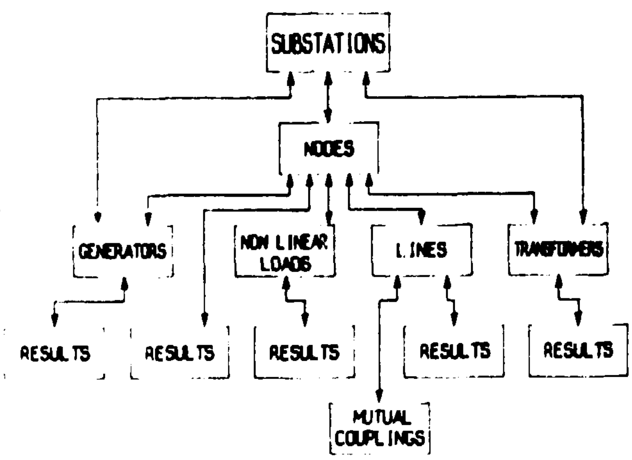

Fig. 4 - Simplified relational structure of R E S T data base.

3.4 Description of graphic functions

The results of a network calculation are easier to analyze when they are presented graphically: in fact using a one-line diagram of

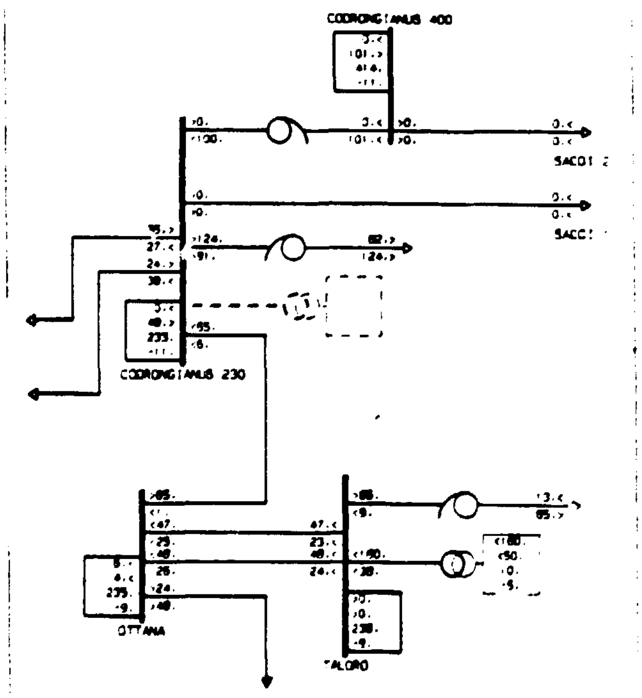

Fig. 5 - Graphic visualization of load-flow results

the network such as the one shown in fig. 5, an immediate, complete view of power distribution can be obtained.

To prepare the diagram, a specially developed menu of graphic functions is used, which enables the user to construct, manipulate, and query the electrical diagram stored in GEST.

The menu also contains some functions for direct access to the REST data base, where the alphanumeric information of the network and of the calculation results are stored.

Acting through the menu, the DBMS functions can be activated for querying and/or modifying the parameters of the network components.

Through these functions, all the information related to a network component (node, line, etc.) displayed on the graphic screen can be obtained by pointing and clicking at it: for example, by pointing to a line it is possible to know its electrical parameters.

Another important function is the one for producing network diagrams with display of variable information containing, according to the choice, electrical parameters or calculation results (as shown in fig. 5).

4. MV NETWORK PLANNING

4.1 MEPR system

MEPR data base has been arranged to contain the following information:

- physical and electrical topology of the MV power network and of the HV/MV substations;
- electrical states of MV power network;
- information about transient, semi-permanent and permanent interruptions and about components in fault conditions;
- measurements;
- present and forecasted load data.

Nowaday MEPR architecture includes interactive and batch procedures activated by personal computers used as remote terminals, located at the line units premises.

The available procedures allow to make:

- statistical analysis of the electrical plants amount;
- Statistical analysis of supply continuity;
- electrical computations (load-flow, short-circuit, voltage regulation).

The forecasted implementations of the system are the following:

- connection with the Standardized Telecontrol System (STU) for the automatic transfer of the information regarding interruptions and measurements;
- connection with the billing files for the automatic updating of sold energy and power data, in order to realise development data forecast;
- use of local graphic workstations (GWSs) connected to the host computers; more in detail, such stations will host graphic and alphanumerical information and all the application programs (for example the electrical computations), while host computers will be employed store and process, alphanumerical data;
- contextually with the GWSs introduction, the loading of graphic and alphanumeric information concerning LV networks will start.

4.2 Analysis of network development alternatives

This activity consists of numerous steps sequentially performed, by which the network operation is analyzed and checked for the capability of feeding loads respecting voltage and current constraints and the modifications and possible reinforcements are defined for the various years of the study period.

4.2.1 Network data retrieval from MEPR

The MV networks are often composed of one or more feeders belonging to one or more HV/MV substations: since the distribution network is radially operated, the portion of the grid to be studied is retrieved from the data base by specifying the first branch of the network. This may be any branch of a MV feeder departing from a HV/MV substation or may be a HV/MV transformer.

The data are retrieved for each year of the development period or just for the more significant ones; the retrieved data, consisting of the topology, the electrical parameters and the annual consumption forecasts for each MV user and for each MV/LV substation, are temporarily stored in a Working Network Data Base to be elaborated by the planning application software.

4.2.2 Allocation of new substations

For each HV/MT and MV/LV substation it is possible to forecast transformer overloads. The site of the new substations is defined by the planner by analyzing the position of the overloaded substations and the respective area of influence.

4.2.3 Definition of development alternatives

The reinforcements to be made in the network during the development period are defined by computing load-flow under maximum network load conditions and analyzing violations of minimum/maximum voltage constraints in the nodes and of maximum current in the branches.

By analyzing the extent of violations and locating them, the planner is able, according to the general planning criteria, to identify the best modification and/or installation of new facilities to reinforce the network.

5. ECONOMIC COMPARISON OF ALTERNATIVES

The Minimum Revenue Requirements Method is the procedure by which ENEL decides what investments to make [5]. Revenue requirements consist of all the elements of a utility's cost of service, including losses, operating and maintenance expenses, depreciation, taxes, interest, minimum acceptable net income and risk cost.

The application of the revenue requirements method involves projecting these costs over the useful life of an investment and discounting them to obtain the present value. This present value is a basis for choosing among investment alternatives that provide an equivalent amount and quality of service. The decision rule is to choose the alternative for which the present value of revenue requirements is a minimum.

The aim of the evaluation of risk cost is to equalize from an economic point of view the reliability of all the plans studied.

The present value of revenue requirements is equal to the sum of four components: the present value of capital outlays, the present value of income taxes, the present value of operating expenses, and the present value of risk cost.

The present value of income taxes can be determined by solving for the present value of operating cash flows under the condition that the net present value of the investment is equal to zero (no profit).

Once the configuration structure of the network for each development year has been determined, also the capital cost of reinforcements and of removal of network components will be determined together with the running cost due to losses and to operation and maintenance in each year studied.

To these costs is added the cost of risk, calculated by estimating the average annual expected value of energy not supplied and multiplying it by a unit risk cost [6].

Finally, the described procedure determines year by year the total annual costs and the relative present-worthed cost.

Other alternatives can be developed by repeating the procedure (wholly or partially); all the various alternatives studied are recorded in the network Data Base. In dealing with some expenditures that will occur at a future time, it is necessary to consider the effect of the yearly real escalation rate. Moreover, if the calculation is made in current money, the analysis must include also the annual inflation rate.

6. CONCLUSIONS

The systems described above, matches the need of automatic data processing facilities for planners in applying the planning criteria for distribution networks.

A great effort has been made to solve the problem of load forecastings, in order to make the load estimation easier and to assure congruence at different hierarchical and or geographical levels.

An iterative planning procedure is adopted to study the network development alternatives and to select the optimum development plan.

A particular attention has been given to graphic interactive facilities as they are a necessary condition to the successful utilization of the planning procedure.

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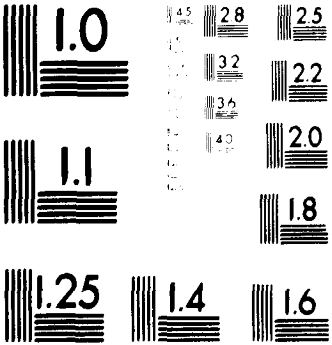

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