Regulation of distribution network business

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Abstract- **The traditional distribution function actually comprises two separate activities: distribution network and retailing. Retailing, which is also termed supply, consists of trading electricity at the wholesale level and selling it to the end users. The distribution network business, or merely distribution, is a natural monopoly and it must be regulated. Increasing attention is presently being paid to the regulation of distribution pricing. Distribution pricing, comprises two major tasks: global remuneration of the distribution utility and tariff setting by allocation of the total costs among all the users of the network services. In this paper, the basic concepts for establishing the global remuneration of a distribution utility are presented. A remuneration scheme which recognizes adequate investment and operation costs, promotes losses reduction and incentivates the control of the quality of service level is proposed. Efficient investment and operation costs are calculated by using different types of strategic planning and regression analysis models. Application examples that have been used during the distribution regulation process in Spain are also presented.**

Index Terms- **Regulation, distribution, planning, power quality.**

I. INTRODUCTION

Legal, technical, and economic arrangements of the electrical systems are expressed in their regulation, a generic term encompassing laws, norms, and recommendations used in order to organise relations between the system agents and its functioning. Different deregulation and restructuring processes are taking place all over the world in the electrical sector. However, some regulation is still needed under these transformation processes. Competition in generation must be organised in such a way that the long-term supply is ensured. The natural monopolistic nature of transmission and distribution networks must be regulated by setting use-of-system charges and establishing power quality control mechanisms.

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Traditional utilities together with generation activities have performed two different distribution activities: distribution network and retailing. Retailing, which is also termed supply, consists of trading electricity at wholesale level and selling it to the end users or to other parties; this activity becomes critical in the competitive markets resulting from deregulation and restructuring of the power industry. The distribution network business, or merely distribution, is a natural monopoly and it must be regulated.

Two main tendencies can be distinguished from the point of view of distribution regulation. There is the traditional regulation, where distribution is considered a public service and is therefore strongly regulated, with a remuneration based on the cost of service. In the recently restructured and competitive power systems, increasing attention is presently being paid to the regulation of distribution pricing, in relation to investment and access issues, as well as efficient tariff design. In this new situation, the global remuneration of the distribution utility is determined by the service provided and not by costs thus introducing the incentives for improving efficiency [1-3].

Distribution pricing comprises two major tasks: global remuneration and tariff setting. Determining the global remuneration of a distribution utility can be approached in different ways which must acknowledge the need for an adequate remuneration for the investment, promote efficiency, reduce losses and achieve some prescribed level of quality of service. Once the global remuneration of a distribution utility has been obtained, the total costs have to be allocated to all the users, according to criteria of economic efficiency, transparency and non-discrimination.

A global remuneration scheme for distribution pricing is proposed in this paper. In Section II the annual remuneration formula and the regulatory period of application are discussed. In this formula, the determination of the remuneration payment at the initial year of the regulation period is a crucial aspect. This initial payment is closely related to the distribution costs that an ideal and economical efficient distribution utility would have in order to supply its area of service. Different models for computation of efficient operation and investment costs are proposed in Sections IV and V. Incentive programs to reduce losses and improve quality of service are established in the proposed remuneration scheme. The distribution utility is responsible for both technical aspects, which are analysed in depth in Section VI.

The previous remuneration concepts are common elements in the majority of distribution pricing regulations reviewed in different countries, although their formal expressions may vary [2-9].

II. GLOBAL REMUNERATION SCHEME

One of the two major distribution pricing tasks is the setting of a *global* remuneration scheme for network activities performed by distribution utilities. The remuneration formula is established for a regulatory period, which usually comprises several years. The proposed revenue path is based on a revenue limitation scheme [4]. Initial distribution costs, annual market increases and improvements in operation efficiency are all considered.

$$RT_{n+1} = R_{n+1} + P_{n+1} + C_{n+1} \quad (1)$$

$$R_{n+1} = (R_n + CM_n \Delta M_{n+1})(1 + IP_{n+1} - X) \quad (2)$$

where:

- RT_{n+1}: total remuneration of the distribution utility in year $n+1$.
- R_{n+1}: remuneration path of the distribution utility in year $n+1$ related to distribution costs.
- CM_n: market unitary cost in year n.
- $\Delta\ M_{n+1}$: annual market increment from year n to year $n+1$.
- IP_{n+1}: price index in year $n+1$.
- X: efficiency factor.
- C_{n+1}, P_{n+1}: Incentive terms related to loss reductions and quality of service improvements respectively, in year $n+1$.

Each distribution utility providing network services receives an annual remuneration given by formula (1) during the entire period of its application, usually four or five years. The company has incentives to improve its efficiency and reduce its costs, this reduction will pass on to improve its profit. A crucial issue is the remuneration in the starting year (R_0) which is based on the calculation of the utility efficient distribution costs taking into account the demand and the area of service supplied.

The initial remuneration is updated every year with the price index (IP). This index normally is chosen equal to the retail inflation index, although other indices can also be considered such as those related to specific business costs (materials, salaries, etc.) or general indices of industrial prices. The efficiency factor X is introduced in order to pass on to the users part of the improvements in efficiency achieved by the utilities. The setting of X could be made taking into account diverse considerations such as the efficiency of other industrial sectors, values used in other countries for distribution business, etc.

The annual market increment (ΔM), mainly the supplied demand and the number of customers increases, is also considered to update the annual remuneration. Market increment unitary costs (CM_0) are also computed at the initial year by using different types of distribution models. The determination of the variables that represent the distribution market evolution and the calculation of the unitary costs are also important issues in the proposed remuneration scheme, they are discussed in Section V.

Finally each year or throughout the entire period of regulation, the remuneration scheme could include incentive terms (P and C) for the implementation of programs to reduce losses and improve the quality of service. Distribution utilities control and are responsible for these two technical aspects.

III. DISTRIBUTION COSTS

In the previous section, it has been remarked that the assessment of the efficient distribution costs assigned to a utility is a key element in the global remuneration received during the regulatory period. This remuneration must not only be sufficient in order to ensure the economic feasibility of the utility but also to promote efficiency providing lower tariffs for users in the long term.

The efficient distribution costs essentially correspond to the investment, operation and maintenance costs of network installations needed for supplying the demand in the area of service. In Spain distribution network installations are classified according to:

- LV overhead and underground lines ($U \leq 1$ kV)
- MV overhead and underground lines (1 kV$<U\leq$33 kV)
- HV overhead and underground lines (33kV$<U<$220 kV)
- Number and capacity installed of MV/LV distribution transformers
- Number and capacity installed of HV/MV distribution substations

The distribution costs assessment problem usually is decomposed in two parts. The first step is to determine the number and type of network installations that are optimally needed in order to supply the demand in the area of service. The second step is to apply to those installations the corresponding unitary annual investment, operation and maintenance coefficient costs to calculate the total efficient annual distribution costs.

The distribution cost assessment is a difficult problem having non-symmetric information between the Regulator and the utilities [10]. The accounting of the utilities does not reflect distribution costs adequately, for example, homogeneous accounting criteria do not exist, costs associated with other activities are included as distribution costs, etc. The updating and above all verification of the number of installations that every year are set up is a task that the Regulator will not be able to perform satisfactorily. For instance, in Spain there are currently more than 250,000 km of MV and LV lines.

In this paper two types of models are proposed. These two models determine the optimal installations of the distribution network that are needed to meet the utility's demand in its area of service. Unitary standard cost coefficients are applied to these installations to obtain the total annual distribution costs.

The aim of these models is to help the Regulator with the task of setting an efficient, transparent and non-discriminatory remuneration among the different distribution utilities.

In that sense, the reference distribution networks obtained by the models are considered by the Regulator in order to divide the total remuneration allocated for the distribution activity among the utilities. The results provided by the models are used in a "yardstick competition" scheme in order to compare the installations needed by each one of the distribution utilities depending on the supplied areas. These results could be also used to detect excessive investments as well as inadequate planning practices.

Special circumstances related to local abnormal load growth, geographical difficulties in an area, etc. which are not considered by the models, could be taken into account by the Regulator during the negotiation process when a new regulatory period starts.

In Section IV, strategic distribution planning models are presented. These models build the optimal distribution network from scratch to supply the current demand geographically allocated in the area of service. In Section V, regression analysis models are proposed in order to obtain the distribution installations pattern which fits better in the standard planning practices that different distribution utilities are using in the country, that is in Spain.

Regression models represent an alternative and complementary way of determining the size of the reference networks. In absolute terms, strategic planning models generally estimate lower number of installations than regression models, because the former ones are based on ideal planning conditions while the latter ones consider the utility declarations of current distribution installations. In comparative terms, one utility compared to another, both types of models have shown similar results.

The proposed models have been used in the context of the presented global remuneration scheme for two objectives:

- To estimate the network installations needed in the initial year and their associated cost. The initial revenue for each distribution utility is set taking into account the evaluation of this cost.
- To determine the increase of distribution costs associated to an increase of demand in the supplied area. For this purpose, the latter model, based on regression analysis, has been proved especially useful.

IV. STRATEGIC PLANNING MODELS

Strategic planning models estimates the optimal network installations that are needed to supply the electric market of a considered service area possible. Following specific planning and operation criteria the size and location of the different installations is determined.

The aim is to design a distribution network that supplies the load at maximum cost effectiveness by minimizing network investments and losses while considering the operation and reliability constraints.

The algorithm takes into account the allocation of the distribution supply points, that is, HV substations in the transmission network, and from scratch finds the network which connects the transmission supply points with the customer demand supply points.

The model considers neither uncertainty in the location of the future loads, nor the evolution of loads throughout time. It is a static-planning model that is updated and run every regulatory period (four or five years). As mentioned before, the objective of the model is to provide reference networks in order to determine the remuneration of distribution utilities. The ideal planning hypotheses are the same for all the distribution utilities that are being compared.

A. Input data

The geographic location and size of HV substations in the bulk transmission network together with the geographic location and size of LV and MV loads are the input data. Part of these input data can be found in utility databases, such as HV substations and MV loads data, and other should be estimated from official statistics provided by the Spanish Ministry of Industry.

There is not much data about the actual location and the size of the load points, that is why several simplified hypotheses, such as uniform location of the LV load points within the settlements, have been raised in order to run the model. Therefor, the model starts from scratch and does not upgrade the reference network obtained in the previous regulatory period.

For each service area, the distribution network is optimized. In Spain, 45 provinces, which are administrative divisions of the national territory, have been considered as service areas. Input data is located in a digitalized map. Fig. 1 shows the outline of the settlements of Madrid, which is a Spanish province. Madrid is also the name of its provincial capital.

There are roughly 5 million inhabitants in the province shown in Fig. 1, 3 million of those living in the provincial capital. There are about 200 settlements and the total surface of the province is about 8000 km^2.

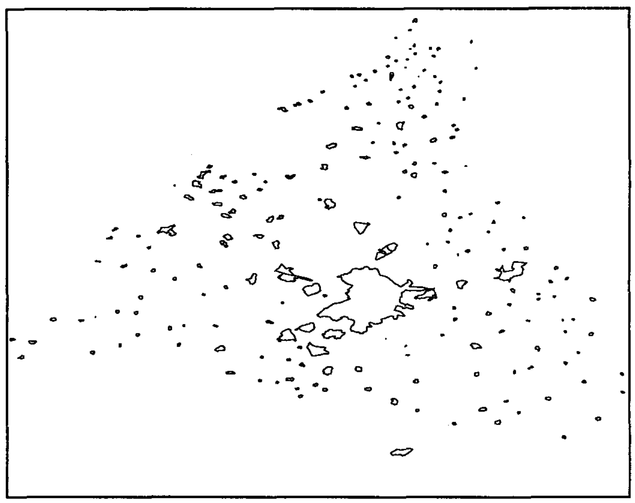

Fig 1. Plot of the province.

B. Solution algorithm

In order to design the whole distribution system, the algorithm developed solves the problem in several related phases due to the huge complexity of it.

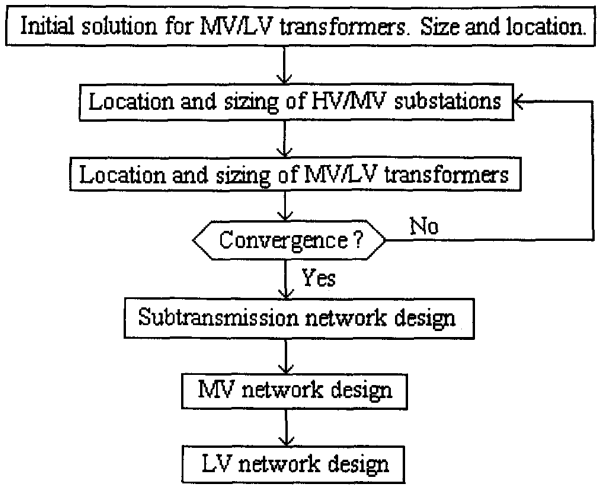

Fig 2. The solution algorithm

The algorithm involves the following steps.

(1) *Form a reasonable initial solution for the location of MV/LV transformers.* These transformers are located uniformly within the settlements using heuristics and simplified data such as power density and area of each settlement.

(2) *Location and sizing of HV/MV substations.* A genetic algorithm deals with the whole province and calculates the optimal number and location of these substations. The fitness function evaluates the investment costs of simplified subtransmission and MV networks and the costs of the corresponding substations. These networks connect the HV/MV substations to the HV substations and to the MV/LV transformers.

(3) *Location and sizing of MV/LV distribution transformers.* A heuristic algorithm deals with only one settlement at a time and calculates the optimal number and location of these transformers. This procedure minimizes the operation and investment costs of simplified MV and LV networks and the costs of the MV/LV transformers.

(4) *Repeat steps 2 and 3 until convergence is reached.* One or two iterations are usually needed.

(5) *Subtransmission network design.* The problem is formulated as an investment plus operation costs minimization. For this purpose, a decomposition method is used, in which the investment plans are proposed by a genetic algorithm and. the operation problem is a DC power flow with losses that considers different contingency scenarios. Operation costs and dual variables are returned to the investment module to guide the genetic algorithm's search.

(6) *MV network design.* A heuristic algorithm that considers only one change at a time improves an initial feasible network gradually. In this first step, voltage drops, line capacity constraints and line investment costs are considered. In a second step, a quality of service analysis is done in order to decide the installation of switching devices and network reinforcements.

(7) *LV network design.* A heuristic algorithm that considers only one change at a time improves an initial feasible network gradually. Voltage drops, line capacity constraints and line investment costs are also considered. A quality of service analysis is done in order to check whether the minimum levels of quality are satisfied.

C. Test results

A complete strategic planning package, based on the model presented in this paper, is being developed by IIT. This software is being used for evaluating distribution network costs in Spain.

The actual size of the problem dealt with is huge since there are 16 HV supply points and about 120000 LV load points to be connected by a distribution network. The CPU time for the whole optimization problem is about 6 hours in a SUN UltraSparc 1 (167 MHz).

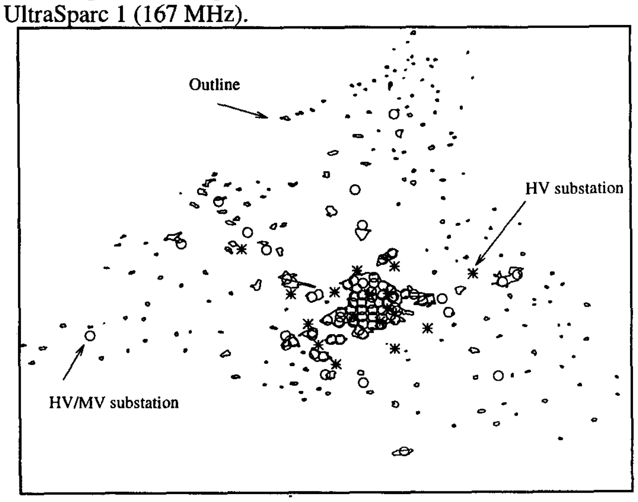

Fig 3. Location of HV/MV substations.

Fig. 3 shows a digitalized map of the settlement outlines of the province. The circles represent the HV/MV substations located by the algorithm.

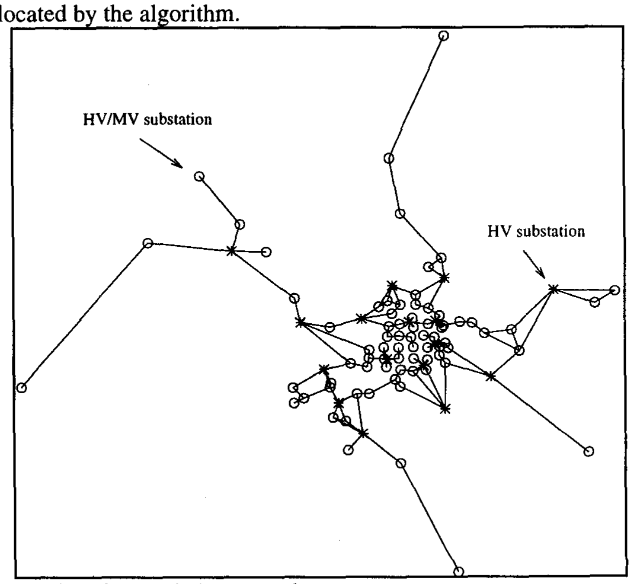

Fig 4. Subtransmission network.

Fig. 4 shows the subtransmission network designed by the model. The circles represent the HV/MV substations and the asterisks represent the HV substations, which are associated with the bulk transmission network and are the model's power source points.

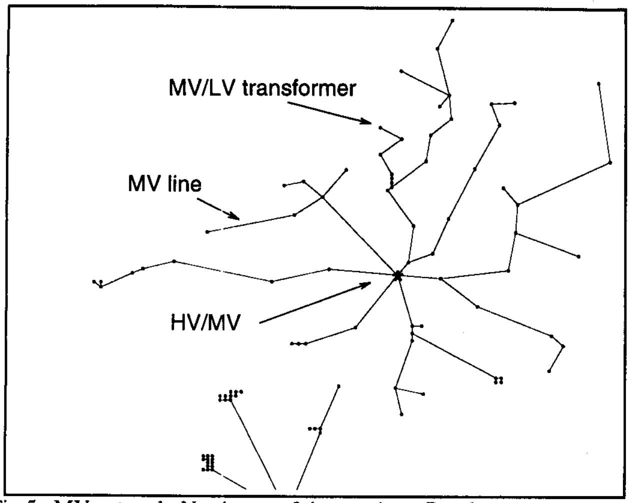

Fig 5. MV network. North part of the province. Rural area.

Fig. 5 depicts the MV distribution network associated to the northernmost HV/MV located substation, as it can be seen in Fig. 3. The asterisk represents the mentioned substation and the dots are the MV/LV transformers, which are practically distributed in a uniform way inside the settlements as it can be seen.

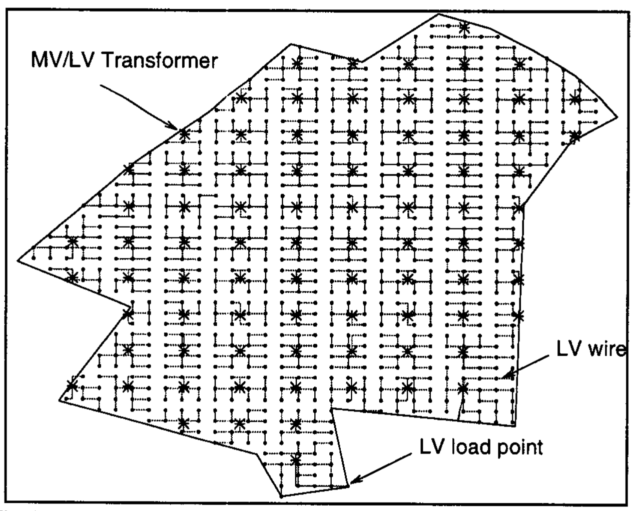

Fig 6. LV network & MV/LV transformers of a settlement.

Fig. 6 shows the LV network of a settlement called Parla. This settlement does not have any scattered dwellings. The dots represent the LV load points of the considered settlement. There are approximately 20000 dwellings in Parla and its surface is about 3 km^2.

V. LINEAR REGRESSION MODELS

Linear regression analysis is a statistical tool, which permits the characterisation of linear relations between variables from a set of samples. This characterisation can be used with two objectives: to identify the set of explanatory variables which justifies better the value of the explained variable and to estimate the value of the coefficients of the linear regression model. The application of regression models is described in the following paragraph.

The general form of a linear regression model is:

$$Y = C_0 + C_1 X_1 + C_2 X_2 + \ldots + C_n X_n + \varepsilon \qquad (3)$$

Where X_i $(i=1,\ldots,n)$ stands for the explanatory, input or independent variables, Y for the explained, output or dependent variable, C_i $(i=0,\ldots,n)$ are the regression coefficients and ε is a i.i.d white noise random variable.

The proposed models use explanatory variables related to the market to be supplied, coming from official statistics. This condition ensures the objectivity of the estimation. These models explain the distribution network installations for the supply areas. The coefficients of the models have a physical interpretation. They are km of distribution lines and kVA of installed capacity of transformation per unit in the considered supplied area. In this way, regression is equivalent to the adjustment of the parameters of a physical model and it has a clear interpretation.

The analyses carried out using regression models show that the variables of the electric market which explain best the distribution costs are the customers and their associated contracted power. In particular, the concentration of demand causes differentiated unitary costs. It is therefore necessary to classify customers according to their demographic setting (urban, semi-urban, or rural) and to consider the distribution of population settlements in each area. Furthermore, other explanatory factors of the distribution costs such as the operation and investments practices used by the companies could also be added. These factors are not considered to be explanatory variables, as those companies that maintain more efficient practices would benefit from the estimation of these costs, in comparison to other companies that incur higher costs due to inadequate policies.

In the case of Spain, it has been found out that MV and LV network installations in a province are greatly determined by the housing distribution of customers and population settlements. In this study the official population census was used.

Population settlements have been divided into three groups:

- S_{urb}: number of urban settlements (with more than: 10000 dwellings)
- S_{surb}: number of semi-urban settlements (1000 < dwellings < 10000)
- S_{rur}: number of rural settlements (25 < dwellings < 1000)

Family housing units have been classified as follows according to the type of settlement they belong to.

- D_{urb}: number of urban type dwellings (in urban settlements)

D_{surb}: number of semi-urban type dwellings (in semi-urban settlements)

D_{rur}: number of rural type dwellings (in rural settlements or scattered)

In addition to these explanatory variables, the LV customers' contracted power (P, in kW) was also considered as an independent variable for the model of installed capacity in MV/LV transformers (this data was also obtained from an official entity, the Spanish Ministry of Industry).

Five linear models were then identified using the distribution installations of 45 Spanish provinces as dependent variables (this data was collected by the National Regulator from 9 Spanish distribution utilities):

1. MV overhead lines length (km)
2. MV underground lines length (m)
3. LV overhead lines length (m)
4. MV underground lines length (m)
5. kVA of installed capacity in MV/LV transformers.

The relevant explanatory variables of each model were automatically selected by a stepwise procedure [11].

Provinces, which declared distribution installations did not match the models, were considered as outliers and set aside in the parameter estimation process [12]. These particular cases may correspond to errors in the data collection process, having a prejudicial effect on the models.

The resulting regression coefficients associated to the selected explanatory variables of each model together with the Determination coefficient R^2 (measure of the quality of the model) are shown in Table 1. Each column corresponds to one model and each row to an explanatory variable. The installations in a province are obtained by letting the values of the explanatory variables and applying the models. For instance in the third model, we can conclude that the length of the LV overhead lines can be estimated by assigning 4.7 m to each covered urban dwelling, 10.32 m to each semi-urban dwelling and 38.39 m to each rural dwelling.

The length of MV overhead lines model is the only one which uses the number of population settlements. The MV and LV underground lines are completely determined by the urban dwellings. The installed capacity in MV/LV transformers only depends on the LV customers' contracted power.

TABLE I
LINEAR REGRESSION COEFFICIENTS OF THE PROPOSED MODELS

	MV overhead lines (km)	MV underg. lines (m)	LV overhead lines (m)	LV underg. lines (m)	kVA of installed transform. capacity
S_{urb}	177.10				
S_{surb}	18.36				
S_{rur}	1.23				
D_{urb}		4.22	4.70	9.03	
D_{surb}			10.32		
D_{rur}			38.39		
P (kVA)					0.629
R^2	0.897	0.968	0.902	0.977	0.987

Fig. 7 and Fig. 8 show the estimations of MV and LV overhead lines length of each Distribution Utility. The results obtained reflect an adequate characterisation of the existing installations in the Spanish distribution system.

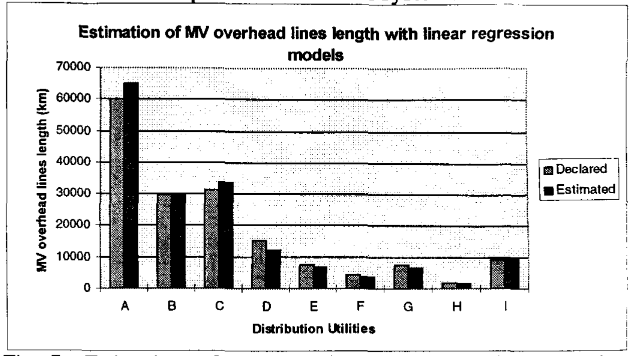

Fig 7: Estimation of MV overhead lines length for each Distribution Utility with linear regression models

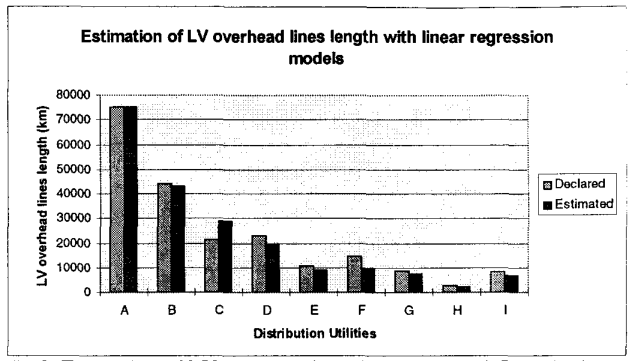

Fig 8: Estimation of LV overhead lines length for each Distribution Utility by linear regression models

After using the previously mentioned models to determine the network installations of each province, the corresponding standard unitary costs have to be applied in order to obtain the total annual investment and operation costs for each distribution utility, their respective covered areas have to be taken into account.

The regression coefficients have been also used to estimate the increase in network installations associated to the increase on the market variables of each utility. The market variables are the number of LV and MV customers, spread in the different types of settlements, and the associated contracted power. These variables are closely related to the explanatory variables identified in the presented models.

VI. LOSSES REDUCTION AND QUALITY OF SERVICE IMPROVEMENT PROGRAMS

The Regulator should establish specific incentive programs in order to improve network operation and the quality of supply provided by distribution utilities. Under the new scheme of activities -network and retailing- the distribution network business does not have natural incentives to cut losses and to improve power quality. Therefore, specific incentive terms are included in the global remuneration formula. This indirect type of regulation, which focuses on losses and power quality, is preferred to a direct type of regulation, which acknowledges the incurred costs in those activities.

A. Incentives for Loss Reduction

The network design and operation practices followed by the distribution utility affect the amount of distribution technical losses directly.

A mechanism based on the assignment of a loss reference level to each distribution utility has been proposed to encourage loss reduction. This reference level takes into account the type of distribution network installations the utility has. The utility obtains a loss payment corresponding to this reference level by means of network charges, which considers losses. The utility should be economically responsible for the actual losses, which are obtained from the difference between the purchased energy on the Wholesale Market and the energy delivered to final customers. Therefore, the utility gets a profit if actual losses are lower than reference losses.

Reference losses are calculated by multiplying the energy delivered to final customers by the corresponding standard loss coefficients. Standard loss coefficients are established depending on the supply voltage level. Different loss coefficients are applied to LV supply points regarding their location, namely urban, semi-urban or rural areas.

B. Incentives for Service Quality Improvements

Continuity of supply associated to the number and duration of long supply interruptions is also directly related to the investment, operation and maintenance practices performed by the distribution utility.

Different continuity indices such as SAIDI and SAIFI, which take into account the number and duration of interruptions in HV and MV distribution networks, have been proposed to measure the quality of supply. The Regulator could propose incentive mechanisms to lead the system from actual continuity index values to better quality levels. In the global remuneration formula could be included an incentive term which is obtained by multiplying the improvement in continuity indices by unitary cost coefficients. These incentives should represent as much as the customers are willing to pay for the quality improvement achieved.

Other technical aspects of quality of service associated to voltage quality, such as voltage disturbances: flicker, harmonics, voltage sags, etc. are not considered in the incentive mechanism that is proposed above. The utility should bare in mind these voltage quality aspects regarding the features of the users. Special care must be taken when connecting potential disturbing users to the network [13].

Commercial services given to franchised customers, such as maximum response time for new connections, limitation of billing based on estimated metering, etc. could be also regulated by incentive or penalty mechanisms with similar formulations to the one proposed in the regulation of continuity aspects.

VII. CONCLUSIONS

The distribution of electricity comprises two separate activities: distribution network and retailing. The distribution network business is a natural monopoly, so it must be regulated. Distribution pricing is a way of regulation which comprises two major tasks: calculate the global remuneration for the distribution utility and set tariffs by allocating the total costs among all the users of the network.

A global remuneration scheme, which acknowledges adequate investment and operational costs, considers annual demand increments, promotes loss reduction and incentives the control of the quality of service level, has been proposed.

In this paper, distribution planning models and regression analysis models have been proposed in order to determine the efficient distribution costs, which is the basis of the presented revenue mechanism. Different application examples, which have been used during the distribution regulation process in Spain, have also been described.

Regulation and pricing of the distribution network business brings together technical and economic issues in a unique way. This paper presents an original approach to this problem, which is embedded in an area that is open to new developments and where international experiences exchanges could be productive.

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IX. REFERENCES

[1] Edison Electric Institute, "Restructuring and sale of the electric supply industry in England and Wales". May 1991.

[2] Office of Electricity Regulation, "The distribution price control: proposals". United Kingdom. August 1994.

[3] Office of Electricity Regulation, "The distribution price control: revised proposals". United Kingdom. July 1995.

[4] Comnes G.A., "Review of performance-based ratemaking plans for U.S. Gas Distribution Companies", Lawrence Berkeley Lab., University of California. November 1994.

[5] Comnes G.A., Stoft S., Greene N., and Hill L.J. "Performance-based ratemaking for electric utilities: Review plans and analysis of economic and resource planning issues", Vol.I, Lawrence Berkeley Lab., University of California. November 1995.

[6] Mackerron G., "Regulation and the economic outcome of electricity privatization in England and Wales", Revue de l'Energie. Jan/Feb 1995.

[7] Australian Competition and Consumer Commission, "National electricity market. Network Pricing Forum", July 1996.

[8] Marmolejo A., Williams S., "The Argentine Power Book", Latin-America Research Electric Utilities. Keinwort Benson Research. March 1995.

[9] Moen J., "Electric utility regulation, structure and competition experiences from the Norwegian Electric Supply Industry". Norges Vassdrags-OG Energiverk (NVE). Norway.1995.

[10] Khan A.E., "The economics of Regulation: Principles and Institutions", Volume I, Mit Press, 1988.

[11] Hocking R.R., "The analysis and Selection of Variables in Linear Regression", *Biometrics*, vol.32, pp 1-49, 1976.

[12] Madansky A., "Prescriptions for Working Statisticians", Springer-Verlag, 1988.

[13] European Norm EN-50160: "Voltage characteristics of electricity supplied by public distribution systems". CENELEC 1994.

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