Peak-load Pricing Based Planning for Distribution Networks under Change

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***Abstract*-- Distribution network development planning is a complex task due to the size of a typical distribution network, the interconnectivity of its elements and the presence of various uncertainties. The recent technological and organizational changes in the electric industry sector have had an influence on the operations and planning objectives of distribution network systems. New price regulation, technologies, and types of customer demand require new paradigms of distribution network planning and operations. The corresponding models in support of these new paradigms should include not only the information about load forecast, but economic analysis, risk assessment and the impact of the new technologies. In this paper, we propose a model for distribution development planning that is based on the concept of peak-load pricing and optimal distribution capacity expansion.**

***Index Terms*--Electrical Distribution Network, Electric Power Restructuring, Development Planning, Optimal Network, Peak-load Pricing.**

I. INTRODUCTION

The recent changes in the electric industry have had an influence on the operations and planning of distribution network systems. New price regulation, technologies, and types of customer demand require a new model of distribution network planning.

Part I of this paper briefly reviews the ongoing industry changes.

In part II of this paper the price regulations of the old and new distribution systems are described. The advantages and disadvantages of rate-of-return and performance based regulation are assessed as well as the related problems in distribution development planning.

In part III a model for distribution development planning that is based on the concept of peak-load pricing and optimal distribution capacity expansion [1] is proposed. This model is useful for utilities that supply price-responsive customer demands. At least in principle, such customers could enable the utility to postpone its investment and make a bigger profit. These customers would contribute to a decreasing peak load and, therefore, to reduced requirements for new capacity.

The model is applied to a simple distribution network in the later part of this paper. The given solution is optimal with respect to both the optimal network reconfiguration and optimal time investment.

II. BACKGROUND

During the last decade of the 20th century, developing countries were faced with the serious problem of how to satisfy future demand. Load demand was increasing rapidly, power system operation was ineffective and tariff policy did not satisfy customer needs [2]. These were the first signals that something should be changed in the electrical industry

A. Price Regulation

Traditionally, electric utilities have had an obligation to serve their "native" customers according to the state-regulated electricity tariffs [3]. Rate-of-return regulation has been a basic method of price regulation. It allows utilities to recover their operating and capital costs and make a profit based on guaranteed rate-of-return.

The rate-of-return has several well-known drawbacks, such as general lack of incentives to reduce cost and/or improve efficiency, as well as incentives to over-invest because of the guaranteed return. In addition, it does not provide explicit incentives to innovate.

Restructuring has dramatically changed this situation. It was expected that restructuring would encourage utilities to minimize the cost of electricity delivery and to indirectly improve power quality using new technologies, such as distributed generations, FACTS, automation and demand response load.

Performance-based regulation (PBR) [4]-[6] was one of the ways to overcome some of the rate-of-return problems. PBR sets a limit on the utility's revenue. To increase profit some utilities will decrease operating and maintenance (O&M) costs or will postpone investments because PBR does not have ways of regulating quality of service.

B. Problems in distribution network planning

Decreasing O&M costs and postponing investments are not problems unique to the de-regulated distribution utilities. However, these problems are emphasized by the fact that utilities face under so-called "open access" increased uncertainties of customer location, quantity, shape of the daily diagram of consumption and load quality in the network.

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A second novel problem facing the distribution planner is the need to consider distributed generation. Distributed generation is potentially very useful for increasing the marginal capacity of the distribution network. In addition, it could be used to increase reliability of supply. At the same time, distribution generation creates a few serious problems, such as [7]:

- Increasing fault currents due to the parallel connection with the system;
- Inaccurate measurement of fault currents;
- Opposite direction of current flows through the relay;
- Two directional power flows in a structure that was developed for radial unidirectional operation;
- Potential separation of DG supplied mini-grids within a distribution network.

Old programs for distribution planning that include simple analyses such as power flow and fault analysis are the next problem. New tools that can involve economic analysis, risk assessment and the impact of the new technologies should be developed. In addition, serious attention should be given to customers that can adapt their consumption based on the situation in the distribution network.

III. Problem Solution

Our suggested model of development planning is based on the concept of peak-load pricing and optimal distribution capacity expansion. The idea is that the optimal plan cannot be determined based on the load forecasts only but also on information about different price structures. In addition, the model gives an optimal solution that minimizes the sum of the total operating, maintenance and investment costs.

A. Model for Distribution Network Development Planning

A possible metrics for measuring the long-term performance of a utility can be expressed as a quadratic optimization problem subject to linear constraints, where the performance objective is (1).

The first term in the objective's function represents the charge that costumers are paying to the distribution utility. This is the total benefit that the utility will have from the delivery of electric power. The second term denotes the utility's cost of power delivery. The third term is the cost of building a new line, and the fourth term is the cost of replacement for an existing element.

The terms in (1) are as follows:

NoP - the number of years over which the optimization is attempted; n – the number of network nodes; m – the total number of branches in the network ($m = m_{old} + m_{new}$); m_{old} – the number of existing branches; m_{new} – the number of potential new branches; N_i^t – the number of customers in the node i; a_i^t and b_i^t - the constant and time-varying terms, respectively, in the annual price function that is paid by the customer at node i at period t; P_{di}^t - the average annual power at node i at period t; a_l^t - the capital cost of power delivery; b_l^t - the variable cost of power delivery (linear part); c_l^t – the variable cost of power delivery (quadrate part); P_l^t – the power flow at the branch l at period t; l_l - the length of line l; T^t - the length of the period; x_l^t – the integer variable which presents the status of the switch on the branch; $C_{builLine}$ – the cost of building a new line; rwz_l^t - the integer variable that represents the year when some line should be built (it has value 1 at the year when the new line is built and 0 otherwise); rw_l^t – the integer variable that represents the year when some line should be reinforced (it has value 1 at the year when the existing line is replaced and 0 otherwise); $C_{reiLine}$ – the cost of reinforcement of the existing line and ρ – the discount rate.

$$\max_{P_l^t, P_d^t, x_i, rz_i, rzw_i} \Omega = \sum_{t=1}^{NoP} \Bigg[\rho^{t-1} \cdot \Bigg(\sum_{i=1}^{n} \left(N_i^t \cdot a_i^t + b_i^t \cdot P_{di}^t \right) \cdot T^t - \sum_{l=1}^{m} \Big(a_l^t \left(x_l^t + x'^t_l \right) + b_l^t \left(P_l^t + P'^t_l \right) + c_l^t \left(\left(P_l^t \right)^2 + \left(P'^t_l \right)^2 \right) \Big) \cdot l_l \cdot T^t - \sum_{l=1}^{m_{new}} C_{buiLine} \cdot rwz_l^t \cdot l_l \cdot P_l^{\max} - \sum_{l=1}^{m_{old}} C_{reiLine} \cdot rw_l^t \cdot l_l \cdot \Delta P_l^{\max} \Bigg] \tag{1}$$

Optimal power flow, average annual power, network topology and time of investment are the solution of the optimization problem. Optimal power flow can have both directions - from the supply substation to the load or from the load to the supply substation. To avoid a negative sign of optimization variables, a fictive variable is defined and marked with an apostrophe.

The optimization problem is subject to the following constraints [8]:

1) Power balance:

$$\sum_{P_l^t, P_l^t{}' \in G_{in}} \left(P_l^t + P_l^t{}' \right) - \sum_{P_l^t, P_l^t{}' \in G_{out}} \left(P_l^t + P_l^t{}' \right) = P_{di}^t \tag{2}$$

$$i = 1...n, \quad t = 1...NoP$$

The constraint states that the power balance must be met at each node. G_{in} – denotes a set of branches directed toward the node, and G_{out} – denotes a set of branches which come out from the node.

2) Capacity constraints:

$$P_l^t - x_l^t \cdot P_l^{\max} - \Delta P_l^t \le 0 \tag{3}$$

$$P_l^{t}{}' - x_l^{t}{}' \cdot P_l^{\max} - \Delta P_l^{t}{}' \leq 0 \quad (4)$$

$$l = 1...m_{old}, \quad t = 1...NoP$$

Power flow through the line must be smaller then the sum of the maximum line power flow $P_l^{\max}$ and additional capacity ΔP_l^t. The value of x_l^t and $x_l^{'t}$ is calculated from this inequality. If power flow at branch l exists, x_l^t or $x_l^{'t}$ has value 1. Based on the value of x_l^t and $x_l^{'t}$, the constant part in the power delivery function ($a_l^t \cdot l_l \cdot (x_l^t + x_l^{'t})$) will be included in the calculation just for the branches with nonzero power flow.

3) Limit on capacity increases:

$$\Delta P_l^t - x_l^t \cdot \Delta P_l^{\max} \leq 0 \quad (5)$$

$$\Delta P_l^{t}{}' - x_l^{t}{}' \cdot \Delta P_l^{\max} \leq 0 \quad (6)$$

$$l = 1...m_{old}, \quad t = 1...NoP$$

The capacity increase also must be limited. If the branch exists, $x_l^t = 1$ or $x_l^{'t} = 1$, additional capacity can exist.

4) Capacity of a new line:

$$P_l^t - x_l^t \cdot P_l^{\max} \leq 0 \quad (7)$$

$$P_l^{t}{}' - x_l^{t}{}' \cdot P_l^{\max} \leq 0 \quad (8)$$

$$l = 1...m_{new}, \quad t = 1...NoP$$

Final capacity of the new line will be calculated as maximum needed capacity through all periods of analysis: $P_l^{new} = \max\{P_l^t\}$.

5) Limit on the average annual power

$$P_{di}^{\min t} \leq P_{di}^t \leq P_{di}^{\max t} \quad (9)$$

$$i = 1...n, \quad t = 1...NoP$$

This constraint presents an elastic demand. Based on the peak-load theory some customers have the ability to transfer consumption from an on-peak to an off-peak period.

6) Radial network constraint:

$$\sum_{x_l, x_l' \in G_{in}} \left(x_l^t + x_l^{'t}\right) \leq 1 \qquad l = 1...n, \quad t = 1...NoP \quad (10)$$

The constraint expresses that there is only one supply path for each node in the network. State of switch can be changed through the years so the network topology in one year can be different from the network topology in another year.

7) Uniqueness constraint:

$$x_l^t + x_l^{'t} \leq 1 \qquad l = 1...m, \quad t = 1...NoP \quad (11)$$

There is no possibility for a branch and the corresponding fictive branch to co-exist at the same time, because it is not possible for line power flow to go in both directions at the same time.

8) Reinforcement time:

Variables x_l^t and $x_l^{'t}$ carry information about the state of a switch and they can be changed from one period to another. To keep information about the new line that has been built or reinforced, it is necessary to include new variables. The new variable will have value 0 until the year when the new line is built or reinforced, and after that time it will have value 1. Once the new line has been built, or the existing one has been reinforced, it will not be built/reinforced again.

$$\Delta P_l^t - w_l^t \cdot \Delta P_l^{\max} \leq 0 \quad (12)$$

$$\Delta P_l^{t}{}' - w_l^t \cdot \Delta P_l^{\max} \leq 0 \quad (13)$$

$$l = 1...m_{old}, \quad t = 1...NoP$$

There is no variable $w_l^{'t}$ because it is not important if a line or its fictive line is reinforced. In both cases, this implies a reinforcement of the same branch.

9) The time of building a new line:

A new decision variable associated with the time of building a new line is introduced. The reason is the same as in the case of reinforcement, i.e. to keep track if the line from a set of potential new lines has been built or not.

$$P_l^t - wz_l^t \cdot P_l^{\max} \leq 0 \quad (14)$$

$$P_l^{t}{}' - wz_l^t \cdot P_l^{\max} \leq 0 \quad (15)$$

$$l = 1...m_{new}, \quad t = 1...NoP$$

10) Building/reinforcement information expansion

To keep track of the building/reinforcement line status, starting with the year when the line was built/reinforced through the future years, the status is enabled with constraints:

$$w_l^t \geq w_l^{t-1} \qquad l = 1...m_{old}, \quad t = 1...NoP \quad (16)$$

$$wz_l^t \geq wz_l^{t-1} \qquad l = 1...m_{old}, \quad t = 1...NoP \quad (17)$$

If variables w_l^t or wz_l^t have value 1 at the time t, they will have value 1 for all subsequent years, while their value for all prior years will be 0. This keeps information about building a new line through the periods of analysis.

11) The time of the investments

These constraints define the time t when the element should be built. It enables the cost of the investment/reinforcement to be included only once. Values for w_l^t and wz_l^t are equal 0 up to time t, and after that time their values are equal to 1.The difference of the corresponding variables will be equal to 1 only for year t, and will be equal to 0 otherwise, i.e.,

$$rw_l^t = w_l^t - w_l^{t-1} \qquad l = 1...m_{old}, \quad t = 1...NoP \quad (18)$$

$$rwz_l^t = wz_l^t - wz_l^{t-1} \qquad l = 1...m_{new}, \quad t = 1...NoP \quad (19)$$

The constraints cannot be a part of the objective function because in that case the information concerning the time when something should be built will be lost.

B. Example of the model application

The developed model can be applied to both elastic and inelastic load demand. For inelastic demand inequality constraint number 5 is transferred to an equality constraint.

For simulation commercial software, TOMLAB was used.

The above formula is illustrated on a test network shown in Fig. 1.

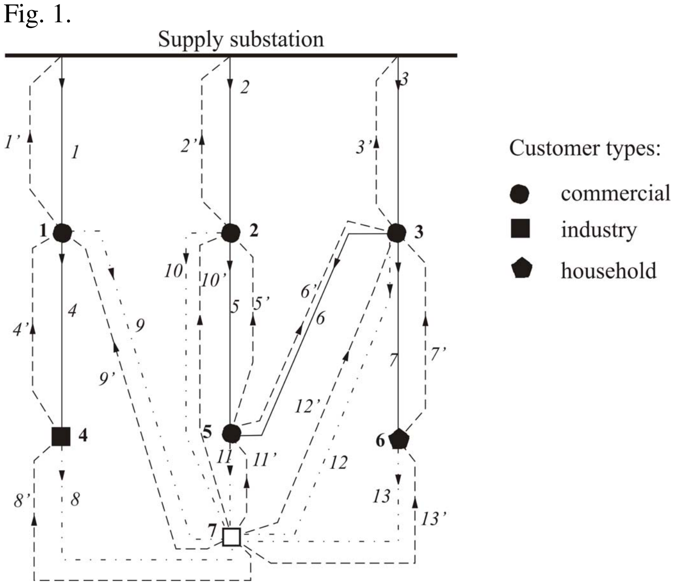

Fig. 1. The test network-Simple distribution system

The chosen test network consists of 7 nodes and 13 branches. The existing branches are presented with a full line, while new lines are presented with dot-dash-dot lines. The corresponding fictive branches are presented with dotted lines and they are indicated with an apostrophe ('). Black nodes present existing consumption, while the white node denotes the new load. There are 6 existing nodes and one new one.

Branch characteristics are presented in Table I. Ind denotes the branch index; l1g and l2g denotes respectively the index of the node from the first and the second end of the branch; $P^{\max}$ denotes the maximum capacity of the branch; $\Delta P^{\max}$ is the maximum additional capacity of an existing branch.

TABLE I
BRANCH CHARACTERISTICS

Ind	l1g	l2g	l (km)	$P^{\max}$ (p.u)	$\Delta P^{\max}$ (p.u)
1	0	1	1.0	1.0	1.0
2	0	2	1.0	6.5	1.0
3	0	3	1.0	6.5	1.0
4	1	4	2.0	3.5	4.0
5	2	5	1.5	5.0	2.5
6	3	5	3.0	5.0	2.5
7	3	6	2.3	3.5	4.0
8	4	7	2.0	1.7	0.0
9	1	7	5.0	1.7	0.0
10	2	7	4.3	1.7	0.0
11	5	7	1.0	1.7	0.0
12	3	7	3.5	1.7	0.0
13	6	7	2.0	1.7	0.0

The power consumption at the nodes is given in Table II. The planning period is chosen to be 10 years. Ind stands for the node index; numbers from 1 to 10 denote years.

The number of customers at each node is shown in Table III.

The price of the power delivery that is paid by householders (h), industry (i) and commercial (c) is [9]:

- $p_h = (N_i^t \cdot 146 \dfrac{\$}{year} + 109500 \dfrac{\$}{MW \cdot year} \cdot P_D)$
- $p_i = 64800 \dfrac{\$}{MW \cdot year} \cdot P_D$
- $p_c = (51 \cdot \dfrac{\$.}{year} + 87600 \dfrac{\$}{MW \cdot year} \cdot P_D)$

TABLE II
NODE CONSUMPTION PER UNIT

Ind	1	2	3	4	5	6	7
1	0.52	0.75	0.49	0.08	0.93	0.08	0.00
2	0.54	0.75	0.50	0.08	0.93	0.08	0.00
3	0.60	0.75	0.51	0.08	0.93	0.08	0.00
4	0.65	0.75	0.52	0.08	0.93	0.08	0.00
5	0.82	0.75	0.55	0.08	0.93	0.08	0.56
6	0.87	0.75	0.56	0.08	0.93	0.08	0.58
7	0.92	0.75	0.58	0.08	0.93	0.08	0.62
8	0.98	0.75	0.60	0.08	0.93	0.08	0.70
9	1.05	0.75	0.62	0.08	0.93	0.08	0.90
10	1.29	0.75	0.68	0.08	0.93	0.08	1.47.

TABLE III
THE NUMBER OF CUSTOMER AT NODE

Ind	1	2	3	4	5	6	7
1	100	125	100	001	150	003	0
2	100	125	100	001	150	003	0
3	100	125	100	001	150	003	0
4	120	125	110	001	150	003	0
5	120	125	110	001	150	003	100
6	120	125	110	001	150	003	100
7	150	125	110	001	150	003	100
8	150	125	110	001	150	003	120
9	180	125	115	001	200	003	250
10	250	125	115	001	200	003	250

The utility's cost of delivering 1 MW along 1 km per year is [5]:

$$p_{per\_year} = 4250 \frac{\$}{km} + 206 \frac{\$}{MWkm} \cdot P_l^t + 244 \frac{\$.}{MW^2 km} \cdot (P_l^t)^2$$

The cost of building and reinforcing an existing line respectively is \$46,000.00/MWkm and \$100,000.00/MWkm [5]. The discount rate is 0.9.

Three cases will be analyzed:

(a) $0.7 P_{di}^{\max t} \le P_{di}^t \le P_{di}^{\max t}$;

(b) $0.9 P_{di}^{\max t} \le P_{di}^t \le P_{di}^{\max t}$;

(c) $P_{di}^t = P_{di}^{\max t}$.

The first two situations present an elastic load, and the third presents an inelastic load.

The given solution is shown in Fig. 2 and Fig. 3. Optimal load flow is given in Table IV, Table V, and Table VI respectively.

Solution (a) is the best solution for the distribution utility. Because there is an elastic load, the utility can avoid any reinforcement in the system, but still must build new lines to satisfy new consumption. The total profit for case (a) is \$2,832,105.00.

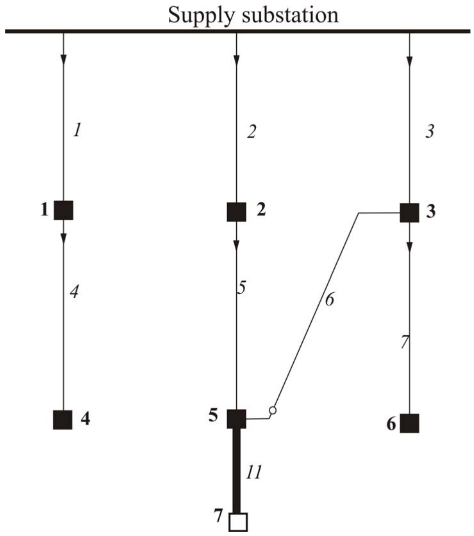

Fig. 2. Optimal solution for 10 years planning – (a)

In case (b) the benefit has decreased. Its value is \$2,809,497.00. The utility still has the possibility to postpone investment for one year, but in the 9th year it must reinforce line 1, because customers put stronger limitations on its elasticity. Line 11 should be built to satisfy new consumption.

It can be seen that in case (c) line 11 should be built in the 5th year to satisfy a new load, and line 1 should be reinforced in year 8, because load flow will exceed line capacity. The total benefit for case (c) is \$2,807,663.00.

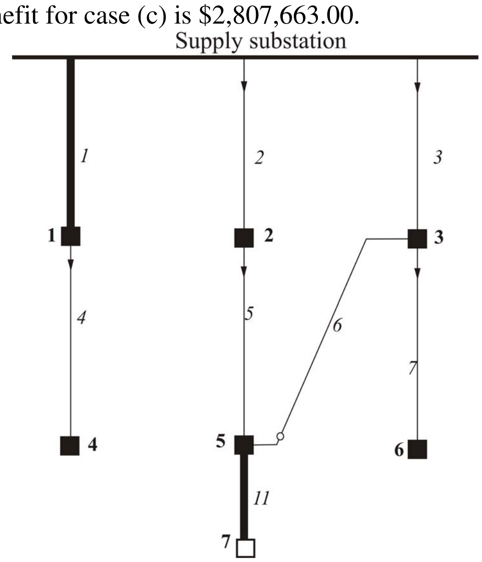

Fig. 3. Optimal solution for 10 years planning – (b) and (c)

All solutions are optimal not just as an optimal network reconfiguration but also as an optimal time investment.

If the benefits from the different cases are compared it can be seen that a utility can save between \$1,834.00 and \$24,442.00 if there is an elastic load.

What will happen if the same capacity that was added to line 1 in the 8th year is added in some other year can be seen in Fig. 4.

The total profit is a parabolic function of investment time. It is not a surprise to get this type of dependency. It is obvious that for investment before year 8, the distribution utility does not have a need to expand the existing capacity. The investment will not decrease its operating and maintenance costs. Profit will decrease because there is no congestion line and there is no additional cost for electrical power distribution.

TABLE IV

OPTIMAL LOAD FLOW P.U. FOR 10 YEARS PERIOD – (A)

Ind	1	2	3	4	5	7	11
1	0.60	1.68	057.	0.08	0.93	0.08	---
2	0.62	1.68	0.58	0.08	0.93	0.08	---
3	0.68	1.68	0.59	0.08	0.93	0.08	---
4	0.73	1.68	0.60	0.08	0.93	0.08	---
5	0.90	2.24	0.63	0.08	1.49	0.08	**0.56**
6	0.95	2.26	0.64	0.08	1.51	0.08	**0.58**
7	1.00	2.30	0.66	0.08	1.55	0.08	**0.62**
8	1.00	2.38	0.68	0.08	1.63	0.08	**0.70**
9	1.00	2.61	0.70	0.08	1.86	0.08	**0.90**
10	1.00	3.24	0.76	0.08	2.49	0.08	**1.47**

TABLE V

OPTIMAL LOAD FLOW P.U. FOR 10 YEARS PERIOD – (B)

Ind	1	2	3	4	5	7	11
1	0.60	1.68	057.	0.08	0.93	0.08	---
2	0.62	1.68	0.58	0.08	0.93	0.08	---
3	0.68	1.68	0.59	0.08	0.93	0.08	---
4	0.73	1.68	0.60	0.08	0.93	0.08	---
5	0.90	2.24	0.63	0.08	1.49	0.08	**0.56**
6	0.95	2.26	0.64	0.08	1.51	0.08	**0.58**
7	1.00	2.30	0.66	0.08	1.55	0.08	**0.62**
8	1.00	2.38	0.68	0.08	1.63	0.08	**0.70**
9	**1.13**	2.61	0.70	0.08	1.86	0.08	**0.90**
10	**1.37**	3.24	0.76	0.08	2.49	0.08	**1.47**

TABLE VI

OPTIMAL LOAD FLOW P.U. FOR 10 YEARS PERIOD – (C)

Ind	1	2	3	4	5	7	11
1	0.60	1.68	057.	0.08	0.93	0.08	---
2	0.62	1.68	0.58	0.08	0.93	0.08	---
3	0.68	1.68	0.59	0.08	0.93	0.08	---
4	0.73	1.68	0.60	0.08	0.93	0.08	---
5	0.90	2.24	0.63	0.08	1.49	0.08	**0.56**
6	0.95	2.26	0.64	0.08	1.51	0.08	**0.58**
7	1.00	2.30	0.66	0.08	1.55	0.08	**0.62**
8	**1.06**	2.38	0.68	0.08	1.63	0.08	**0.70**
9	**1.13**	2.61	0.70	0.08	1.86	0.08	**0.90**
10	**1.37**	3.24	0.76	0.08	2.49	0.08	**1.47**

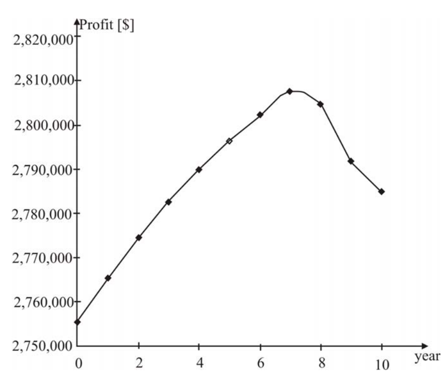

Fig. 4. The profit of the distribution utility for different times of investment in distribution network expansion

For investment after the 8th year, benefits will decrease because the distribution utility does not have enough capacity to satisfy demand and it must pay for non-delivered energy. If it exists, the cost of non-delivered energy is an additional cost that the distribution utility should avoid.

The proposed model is a combination of technical and economic analysis. It takes into account the fact that capital investments are limited, and should be used effectively. At the same time the model takes care of technical limitations such as radial power flow and capacity limitation

IV. Conclusion

Distribution network development planning is a complex task due to the size of a distribution network, and the interconnectivity of its elements and uncertainties.

The structure of a distribution system is still not precisely defined. Some people think that a utility should stay with the monopoly franchise for delivery and supply. Others think that it should have the monopoly franchise just for delivery. Regardless, whatever the final decision it is obvious that the tools for distribution system planning should be changed.

There are a few reasons:

- “open access”;
- distributed generation;
- price regulation;
- new technologies;
- automation.

The distribution system planners should take into consideration customers that are willing to respond to price signals and have an elastic consumption. The customers could enable the utility to postpone its investment and make a bigger profit. The customers would contribute to a decreasing peak load and, therefore, to reduced requirements for a new capacity.

The traditional utility had an obligation to satisfy demand quantity, while reliability was satisfied by improving system reliability. In the de-regulated industry, it is equally important to satisfy quantity and quality. In addition, the possibility for a customer to choose the level of quality and reliability that he wants to have cannot be neglected.

Planners should look for models that do not just resolve technical analysis of the system, but also can conduct economic analysis. Planers should be able to compare increasing cost due to the increase of reliability with increasing of revenue as a consequence of applied PBR.

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VI. Biographies

Marija Prica is a full time student at Carnegie Mellon University. She is a student member of IEEE. She was teaching and researching assistant at the Faculty of technical sciences in Novi Sad, Power Engineering Department, and a part time employee in DMS group Novi Sad from 2000-2005. Her interest is in distribution network planning. She received her B.S. degree in Electrical Engineering from the Faculty of technical sciences, Novi Sad in 2000. Marija Prica is pursuing a M.Sc. in Power Systems at Faculty of technical sciences, focusing on distribution network planning.

Marija Ilic received the M.Sc. and D.Sc. degrees in systems science and mathematics from Washington University, St. Louis, MO, and the Dipl. Ing. and M.E.E. degrees from the University of Belgrade, Yugoslavia.

She is a Professor in the Electrical and ComputerEngineering and Engineering Public PolicyDepartments, Carnegie-Mellon University, Pittsburgh, PA. She was a Senior Research Scientist at the EECS Department at the Massachusetts Institute of Technology (MIT) since 1987, and currently holds an Appointment of a Visiting Professor in the newly formed Engineering Systems Division at MIT. Her interest is in control and design of large-scale systems. From September 1999 until March 2001, she was a Program Director for Control, Networks and Computational Intelligence at the National Science Foundation. Prior to her years at MIT, she was a faculty at the University of Illinois at Urbana-Champaign, Cornell University, Ithaca, NY, and Drexel University, Philadelphia, PA.

Dr. Ilic is a recipient of the First Presidential Young Investigator Award for Power Systems. She is also an IEEE Fellow and an IEEE Distinguished Lecturer.

She has co-authored several books on the subject of large-scale electric power systems: *Dynamics and Control of Large Electric Power Systems* (New York:Wiley, 2000; Ilic, Galiana, and Fink (eds.), *Power Systems Restructuring: Engineering and Economics* (Norwell, MA; Kluwer Academic, 2000; 2nd printing): *Price-Based Commitment decisions in the Electricity Markets* (London, U.K.: Springer-Verlag, Ltd., 1999); *Hierarchical Power Systems Control: Its Value in a Changing Industry* (London, U.K.: Springer-Verlag, Ltd., 1996), and *Valuation, Hedging and Speculation in Competitive Electricity Markets: A Fundamental Approach* (Norwell, MA: Kluwer Academic, 2001).