POWER APPLICATIONS – A POWERFUL TOOL FOR DISTRIBUTION NETWORKS MANAGEMENT

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SUMMARY

The modern integrated distribution management system (DMS) consists of three basic components: Data Base, SCADA and DMS Applications. The Data Base is the basic information and integration platform of the entire DMS. SCADA provides the practical functionality of the DMS. Finally, DMS Applications are the set of software and algorithms that enable the most efficient decision making, i.e., the most efficient utilization of a DMS and all the equipment installed in the distribution network. While the Data Base and SCADA are fully developed and have been applied in the practice in distribution utilities world-wide for a long time, DMS Applications are not yet established in industrial-grade form. There are several reasons for that. First, before privatisation and the restructuring of the power industry, the power engineering area was not commercially attractive, which had as a consequence poor interest for the education of appropriate personnel. Second, the DMS was fairly neglected as far as energy management systems (EMSs) were concerned. Third, many efficient algorithms developed for EMSs are practically useless in the DMS environment. Fourth, the algorithms for DMSs have usually been developed separately, in different places, without an overall co-ordination. Also, mutual functional connectivity of DMS Applications imposes requirements for their integration and centralized coordination. Beside, large distribution utilities have imposed a demand for the development of a wide range system of applications that would provide an efficient and multiobjective operation of the distribution networks in a deregulated environment. This paper is devoted to the design of one such integrated system of DMS Applications.

An integrated system of 25 DMS Applications is proposed in this paper (Figure 1). They are organised as modular libraries. They are integrated in the DMS as a unified software package used in four main modes: operation management, operation planning, development planning and analysis, as well as simulation and training. All applications are developed on the basis of specialised algorithms aimed for distribution networks. The modular organisation of applications provides their simple upgrading, extension and adaptation to the new demands of the market. This system provides, on one hand, an increase of the quality and quantity of delivered energy, and on the other hand, it decreases operating costs and enables investment postponement. Finally, DMS Applications significantly increase the profit from investments into distribution networks, with relatively small cost compared to other investments.

This paper consists of six parts. After the Introduction, in the second part the system of DMS Applications is presented. In the third part the main modes of the DMS Applications are described. In the fourth part the experience and benefits of the utilizing of this system are described. The conclusion and the list of references are the final parts of the paper.

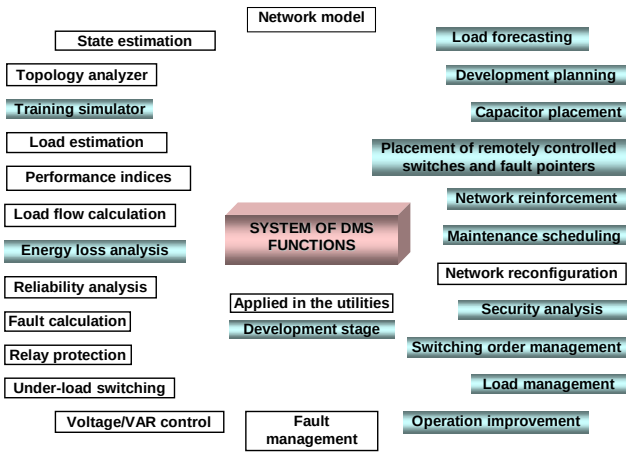

Figure 1 – System of DMS Applications

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ABSTRACT – An integrated system of power applications for management of distribution networks is presented in this paper. First, there is a definition of what overall performances should be achieved in such an integrated system in order to meet completely the needs of modern distribution utilities in the deregulated environment. Then a rich set of functional possibilities is described, which such an integrated system offers in four main modes. Finally, the positive experience and benefits of the utilization of this system in several distribution utilities is presented.

Keywords: Distribution automation, distribution management system, integrated applications system, deregulation.

1. INTRODUCTION

The modern integrated distribution management system (DMS) consists of three basic components: Data Base, SCADA and DMS Applications. The Data Base is the basic information and integration platform of the entire DMS. SCADA provides the practical functionality of the DMS. Finally, DMS Applications are the set of software and algorithms that enable the most efficient decision making, i.e., the most efficient utilization of a DMS and all the equipment installed in the distribution network [1]. While the Data Base and SCADA are fully developed and have been applied in the practice in distribution utilities world-wide for a long time, DMS Applications are not yet established in industrial-grade form. There are several reasons for that. First, before privatisation and the restructuring of the power industry [2], the power engineering area was not commercially attractive, which had as a consequence poor interest for the education of appropriate personnel. Second, the DMS was fairly neglected as far as energy management systems (EMSs) were concerned. Third, many efficient algorithms developed for EMSs are practically useless in the DMS environment. Fourth, the algorithms for DMSs have usually been developed separately, in different places, without an overall co-ordination. Also, mutual functional connectivity of DMS Applications imposes requirements for their integration and centralized coordination [1]. Beside, large distribution utilities have imposed a demand for the development of a wide range system of applications that would provide an efficient and multiobjective operation of the distribution networks in a deregulated environment. This paper is devoted to the design of one such integrated system of DMS Applications.

An integrated system of 25 DMS Applications is proposed in this paper. They are organised as modular libraries. They are integrated in the DMS as a unified software package used in four main modes: operation management, operation planning, development planning and analysis, as well as simulation and training. All applications are developed on the basis of specialised algorithms aimed for distribution networks. The modular organisation of applications provides their simple upgrading, extension and adaptation to the new demands of the market. This system provides, on one hand, an increase of the quality and quantity of delivered energy, and on the other hand, it decreases operating costs and enables investment postponement. Finally, DMS Applications significantly increase the profit from investments into distribution networks, with relatively small cost compared to other investments.

This paper consists of six parts. After the Introduction, in the second part the system of DMS Applications is presented. In the third part the main modes of the DMS Applications are described. In the fourth part the experience and benefits of the utilizing of this system are described. The conclusion and the list of references are the final parts of the paper.

2. DMS APPLICATIONS SYSTEM

The proposed system of DMS Applications consists of 25 applications that are shown in Figure 1. They are divided into four groups according to the complexity and to the utilization purposes: A) Preparatory applications, B) Applications for analysis, C) Basic applications, D) Composite applications.

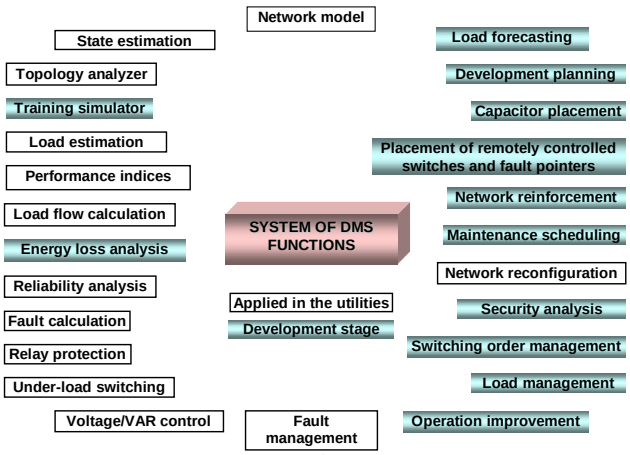

Figure 1 – System of DMS Applications

2.1 Preparatory Applications

A preparatory application executes the preparation of data for running the other applications. In this group are the following applications [1]: A1) "Network model", A2) "Topology analyser", A3) "Load estimation [3]", A4) "Load forecasting" [4].

2.2 Applications for Analysis

Applications for analysis are used for evaluating operating states. The following applications belong to this group [1]: B1) "Load flow calculation" [5], B2) "Fault calculation", B3) "Reliability analysis" [6], B4) "State estimation", B5) "Performance indices".

2.3 Basic Applications

Basic applications execute the main DMS functionalal calculations in the distribution network. In this group, the following applications are included [1]: C1) "Under-load switching"; C2) "Switching order management"; C3) "Voltage/VAR control"; C4) "Relay protection"; C5) "Energy loss analysis"; C6) "Network reconfiguration"; C7) "Maintenance scheduling"; C8) "Load management"; C9) "Placement of remotely controlled switches and fault pointers"; C10) "Development planning" [7,8]; C11) "Network reinforcement" [8]; C12) "Capacitor placement".

2.4 Composite Applications

Composite applications provide running of a multiple combinations of the other applications in an organised way, thus making very sophisticated and useful analyses possible. These complex applications are one of the special advantages of such an integrated system of DMS Applications. In this group, the following applications are included [1]: D1) "Operation improvement"; D2) "Fault management" [9,10]; D3) "Security analysis"; D4) "Dispatcher training simulator". A description of the composite application follows.

D1) Operation Improvement is used for the periodic and systematic checking of possibilities for using certain control actions to improve the economy, security and quality of the current operating state [1]. This application runs either automatically (periodically) or on demand. It consists of the following analyses: 1) economy – can an energy loss be minimised by network reconfiguration and by better VAR compensation; 2) security – can a better load balance of the supply transformers and feeders be achieved by network reconfiguration; 3) reliability – can the reliability be maximised by minimisation of undelivered energy; 4) quality – is it possible to increase the quality of the voltage by resetting and co-ordination of the voltage/VAR resources, etc.

D2) Fault management is used for determining the optimal plan for control actions in cases of faults (or maintenance), overloading, as well as other problems in the distribution network [9-10]. Fault management is one of the most significant issues in real time management of distribution networks. By using this application it is practically possible to minimise the duration of a de-energised time (or to minimise undelivered energy). The "Fault management" application consists of the "FDIR" and "Large area restoration" modules. The "FDIR" module is used for the most efficient fault detection, its isolation and to determine the restoration supply plan when fault is occurred at a feeder [9]. The "Large area restoration" module is used for determining the optimal supply restoration plan for larger parts of the network, which remain de-energised after the fault of a supply transformer [9]. The "Fault management" application is of general character, in the sense that it can be used in networks with any degree of fault detection equipment and feeder automation, and of any network type regarding to the grounding, topology and structure of lines.

D3) Security analysis is used for analysing faults of specified network's elements and testing the possibilities of, after the faulty elements have been isolated, ensuring resupply to the de-energised consumers [1]. The output from this application is a list of critical outages, after which power cannot be restored to all consumers, as well as a list of candidates for reinforcement the distribution network which would allow the problem to be overcome. This application is based on simulations of faults of specified elements, testing the possibilities of returning power to the de-energised parts of the network, and the final testing of the possibility of reinforcement the network in all cases when, after a fault of some element, it is not possible to return power to the de-energised part of the network in a satisfactory way. In that sense, this application uses the following applications practically as modules: "Load flow", "Fault management" and "Network reinforcement".

D4) Training Simulator is used for the training of staff in the distribution utility [1]. This application is used in three modes: 1) training of dispatchers, 2) training of operative engineers, and 3) training of engineer planners. This is an exceptionally important application, since the proper training of staff is the basic precondition for efficient use of existing capacities, along with the equipment for feeder automation.

3. MAIN MODES

The proposed system of DMS Applications is used in four main modes: 1) Operation management, 2) Operation planning, 3) Development planning, 4) Analysis, Simulation and Training. A more detailed description of the functional relations of the applications in all four modes follows here.

3.1 Operation Management

In the operation management mode, the distribution network is monitored and controlled in real time. In addition, in this mode a "what if" analysis is done on the actual operation state.

Initialisation of this mode is carried out through the export of the actual data from the Data Base (Figure 2). Then that data is process by the first preparatory application – "Network model". This application generates an actual mathematical network model. This model is then processed over by the other two preparatory applications: "Topology analyser" and "Load estimation". After these analyses are completed, the model of the distribution network is completely ready for the main analysis. Namely, "Load estimation" and "Load flow calculation" are used to run "State estimation". The result of "State estimation" is the complete operating state. Over this state all the other applications are run. Next, "Performance indices" is run. This application reports on violations (current and voltage) and overall operation performances for the actual operating state (losses, load balances, critical reserves, reliability, voltage quality, etc). Next, the "Voltage/VAR" (in real time mode) runs to co-ordinates all voltage/VAR resources which are on-voltage controllable. Finally, the "Relay protection" application checks the functionality of the actual relay protection settings on the basis of the fault calculation results. The application under consideration practically relates to the analysis of actual state and automatic control of on-line controllable voltage/VAR resources. However, this system also allows "what if" analyses.

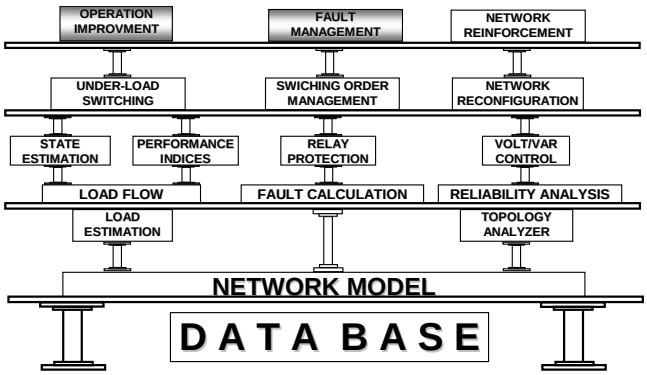

Fig. 2 – Operation management

The simplest "what if" analysis is the simulation of a single switching operation and the load flow calculation that is established after one such action (e.g. the opening of a switch). For more complicated analysis of this type, the applications "Switching order management" and "Under-load switching" can be used. The "Switching order management" application is used for determining the optimal order of a switching operation for the transition from the current configuration to a target configuration, while the "Under-load switching" application is used for testing whether certain switching operations in that transition can be done under load. Beside, the integrated system of DMS Applications makes much more sophisticated analyses possible by using composite applications. All these analyses are run periodically and in an organised way, using the application "Operation improvement". These analyses include testing the possibility if changing the status of certain switches and resetting voltage/VAR control resources (even those which are controllable only in off-voltage conditions) could improve the operation performances of the current state.

The "Fault management" application is used for co-ordinating control actions in case of fault (maintenance) or the overloading of elements. In case of faults (maintenance) of feeders or supply transformers, the corresponding modules "FDIR" or "Large area restoration" is used. It is especially interesting that, in the study mode of these applications, the "Network reinforcement" application can be run. Namely, this application, which is characteristic for the development planning mode, can be used also in this case. The "Network reinforcement" application is activated as the last step in "Fault management", always when after a specified fault it is not possible to re-energise all consumers. Thus, during the year a list is generated of element candidates for network reinforcement and of the corresponding benefits that would be realised with such reinforcement. In this way, a list is established at the end of the year of the necessary network reinforcements that bring the highest profit.

3.2 Operation Planning

In the operation planning mode, the optimal operating performances are planned at the levels of day, week and season. In this mode the mathematical network model is generated on the basis of the save cases which are stored in the Data Base (Figure 3). The overall system load for the save cases is corrected for the observed period by using the "Short term load forecasting" module. Then, this overall forecasted load is distributed to all the nodes of the network using the "Small area load forecasting" module. The states obtained on this way are analysed using the applications "Load flow calculation", "Fault calculation", "Reliability analysis", "State estimation" and "Performance indices". After these analyses, the observed states are ready for running the basic applications for the operation planning mode. First, the optimal configuration is determined using the "Network reconfiguration" application, and then on the basis of this optimal configuration the relay protections and voltage/VAR control resources are set, by running the "Relay protection" and "Voltage/VAR" applications, respectively. The "Load management" and "Maintenance scheduling" applications are run on the optimal configuration obtained in that way. The "Load management" application then determines the definitive system load in the observed period. On the basis of that load is planned the schedule of the maintenance. Finally, on the perspective state, the "Security analysis" and "Network reinforcement" applications are run in the same way as in the operation management mode.

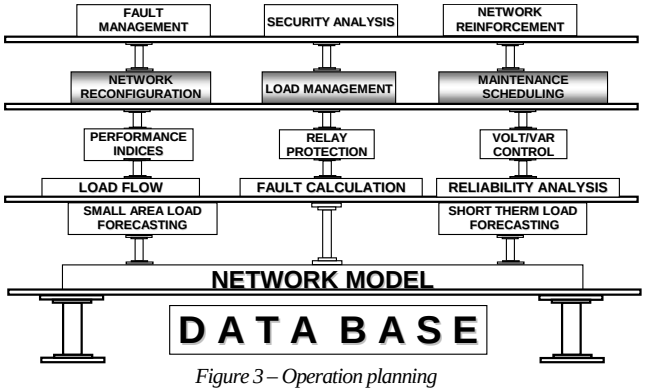

Figure 3 – Operation planning

3.3 Development Planning

In the development planning mode, the dynamics of reinforcement of the existing network are planned, as well as the development of new networks. In this mode, for the generating of network models, in addition to the elements of the existing network, all new elements/corridors are used which are candidates for network reinforcement. The list of candidates is found in the Data Base and is verified through the operation management and operation planning modes in the before mentioned way. In this mode as well, the overall network load and the distribution of this overall load to the nodes of the distribution network for the observed period are obtained using the "Medium and long term load forecasting" and "Small area load forecasting" modules, respectively (Figure 4). The prospective states obtained in this way are then analysed using the proper applications: "Load flow calculation", "Fault calculation", "Reliability analysis" and "Performance indices". Thereby, the complete insights into all representative states are obtained. Then, on these states are run the basic applications of the development planning mode: "Development planning"; "Network reinforcement", "Capacitor placement" and "Placement of remotely controlled switches and fault pointers". The "Capacitor placement" application determines the type, number, size and location of the capacitor banks. When the configuration with suitable voltage/VAR performances is determined, the "Placement of

remotely controlled switches and fault pointers" application is run for the final design of equipment for fault management.

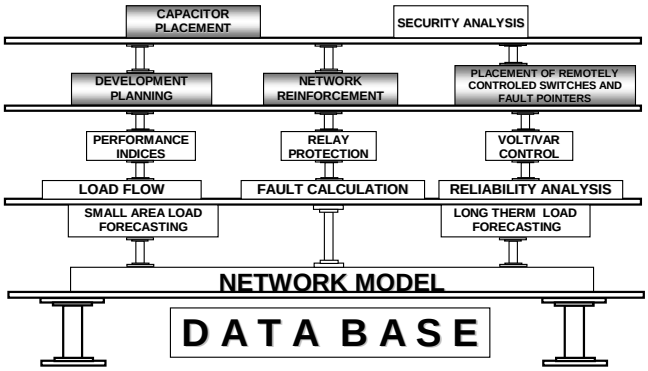

Figure 4 – Development planning

3.4 Analysis, simulation and training

In the analysis, simulation and training mode, analysis and simulation are done of certain representative states from the future and past, as well as the training of dispatchers, operative engineers and engineer planners. The states, which are analysed in this mode, are stored in the Data Base as save cases (Figure 5). In doing so, the minimal structure of data necessary for their reconstruction is memorised in the Data Base. The complete reconstruction of the representative state is obtained by sequential running of the "Network model" and "State estimation" applications. On such states, all other applications can be run. Practically, the following analyses are done: testing of the possibility of increasing the quality of the operating performances of the observed state through various control actions and simulations of installing new elements, efficiency of dispatcher control actions after a fault in the network, analysis of the functionality of the automation equipment. The special significance of this mode lies in staff training (dispatchers, operative engineers and engineer planners). The proper training of personnel is the essential precondition for the maximal use of the existing capacities and automation equipment, along with timely installation of new equipment and its co-ordination with the existing equipment.

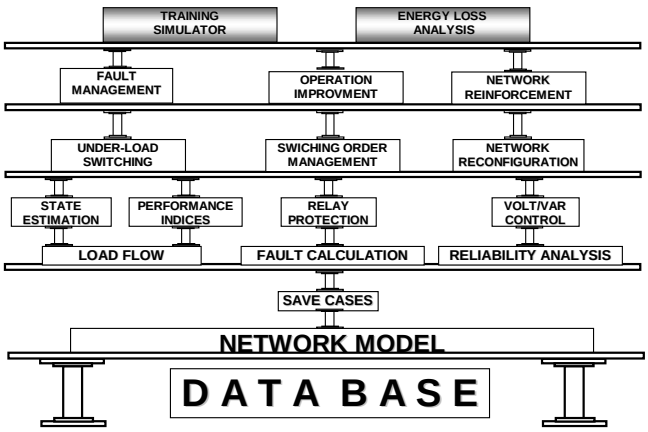

Figure 5 – Analysis, simulation and training

4. VERFICATION

The proposed set of DMS Applications is being developed at the "Faculty of Engineering", Serbia and at the "Octavia" – DMS Group Company, USA. Of the 25 DMS Applications, 13 have been completely developed and applied up till now (they are marked by light squares in Figure 1), while the development and integration of the remaining 12 applications is in process (they are marked by dark squares in Figure 1).

4.1. Installations of DMS Applications Software Package

This system of DMS Applications has been practically used in 7 Balkan distribution utilities, with sites in 12 cities (Table I). All the cited utilities have made several installations on their pilot networks and then tracked the effects of the utilization of this software package over a year. These utilities/pilot networks are of various sizes and configurations (urban, rural), and have varying levels of automation.

The integration of this system into the DMS of "ELSAG"–"ENEL" companies (Italy) is underway. Beside, the DMS Applications system is built-in DMS of the city of Rio de Janeiro, (Brazil) with 3.000.000 customers in co-operation with international company "SAINCO".

Table I – Utilities that are using the DMS Applications at this moment

No	Name of company/ Headquarters	Number of customers	Annual energy [GWh]	Peak power [MW]	Installa-tions number
1	Elektrovojvodina/ Serbia	820 000	7 500	1 500	2
2	Elektrosrbija/ Serbia	650 000	6 000	1 200	1
3	Elektromorava/ Serbia	170 000	1 300	300	4
4	Elektrotimok/ Serbia	150 000	870	190	1
5	Elektrodistribucija Leskovac/ Serbia	120 000	520	130	1
6	Elektrodistribucija Niksic/ Montenegro	110 000	410	100	1
7	Elektrokrajina/ Republic of Srpska	190 000	1 250	650	2

4.2 Experience and Main Benefits

The early experiences with the utilization of this software package have been exceptionally positive. First, the utilization of this software package was the initial step in the updating and completion of the technical documentation about the available capacities and existing equipment. Second, using "State estimation", the technical inadequacy of certain measurement equipment was discovered. Third, the technical level of the dispatchers, operative and planning engineers was significantly raised. Fourth, a several technical benefits were obtained. In Table II the benefits are given that have been obtained in last 12 months of the utilization of the system of DMS Applications in several distribution utilities. The following operation aspects were considered: 1) Energy losses reduction; 2) Improvement of voltage quality; 3) Reduction of the average duration of the supply interrupt and undelivered energy; 4) Improvement of the load balance of supply transformers and feeders and 5) Postponement of the planned investments.

For each observed aspect a range of values is given from the lowest to the highest attained benefit. Likewise, each benefit was expressed in three ways: 1) in an absolute amount, 2) in a relative amount, and 3) in a corresponding monetary amount, wherever it made sense.

The benefit of energy loss reduction is brought about by reconfiguring the network at a seasonal level and through the

corresponding co-ordination of VAR resources. For that purpose, the "Network reconfiguration" and "Voltage/VAR" applications were used, respectively. The realised energy loss reduction ranged from 250 kWh to 1050 kWh, which represents a percentage decrease in loss from 5 % to 20 %. If the price of 1 kWh energy at medium voltage is calculated at 4 cents, then the greatest one year savings on this basis is 630 000 $. This saving is realised in an urban cable network of a city of about 300 000 inhabitants.

Table II – Benefits from use of the DMS Applications

	Value of benefit		
Benefits	Total amount	%	Millions $ USD
Energy losses	250÷1050 kWh	5÷20	0.05÷0.63
Voltage quality	0.30÷0.70	30÷70	÷
Average duration of the supply interrupt	2÷25 min	43÷50	÷
Undelivered energy	0.15÷1.70 GWh	40÷52	0.55÷1.25
Load balance of transformers	0.48÷0.70	48÷70	÷
Load balance of feeders	0.32÷0.50	32÷50	÷
Postponement of the planned investments	÷	10÷90	0.1÷2.4

The benefit of improvement of voltage quality is brought about by proper real time co-ordination of the on-voltage voltage/VAR controled resources, as well as by proper setting off-voltage controlled resources on seasonal level. For that purpose, the "Voltage/VAR" application was used. The largest improvement in the voltage quality was achieved in rural milieus with long feeders, where the voltage profile is problematic anyway.

The benefit of the reduction of average duration of the supply interrupt is realised using the "Fault management" application in real time mode, and with the proper training of dispatcher staff by using the "Training simulator". The highest achieved reduction was 25 minutes, which represents a reduction of total time by 50 %. This benefit was achieved on a network with a very low level of automation. In companies with a high level of automation, this benefit is smaller, amounting to about 2 minutes, which is a time reduction of 40%. A direct result of the above benefit is also the benefit of the reduction of undelivered energy. Practically, the greatest time saving of 25 minutes corresponds to the highest money amount of 1.25 million $. This value is realised in a network with a low level of automation.

The benefit of the improvement of the load balance of supply transformers and feeders is achieved by better balancing the load through the utilization of "Network reconfiguration" application on a seasonal and weekly level. These types of benefit cannot be directly expressed in monetary terms, but its value can be expressed indirectly through much shorter outage duration, and through the postponement of new investments. Namely, if the proper load balance is attained, simultaneously the corresponding uniform distribution of reserves in the system is also achieved. Such a distribution of system reserves is the precondition for successful fault management. A direct result of the above mentioned benefit is the benefit of the postponement of planned investments. The greatest benefit on this basis is 2.4 million $. This benefit was realised in an urban distribution network where, by better load balancing, meaning better use of existing capacities, the installation of a new transformer substation HV/MV and two new feeders of an average length of 4 km were postponed till next year.

All the above mentioned positive experience with the one year utilization of the DMS software package on pilot networks has contributed to the fact that all companies without have decided to expand the use of DMS Applications from the pilot networks to their entire networks.

5. CONCLUSION

In this paper an integrated system of DMS Applications has been presented. A rich set of functional possibilities was described, which one such system offers in four main modes. Finally, through a sample of various distribution utilities**,** the positive experiences and benefits of utilization of this integrated system were shown. That experience can be poured into a single sentence: Only when the capacities of a DMS are connected and ennobled by a system of DMS Applications, does that DMS gain its full meaning and functionality.

6. REFERENCES

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