OPTIMAL SECTIONALIZING SWITCHES ALLOCATION IN DISTRIBUTION NETWORKS

G. Celli Member, IEEE and F. Pilo Member, IEEE
Department of Electric and Electronic Engineering
Cagliari University - Piazza d'Armi
I09123 Cagliari, ITALY

Abstract: Automatic devices that locate and automatically sectionalize faulted branches in MV voltage power distributions systems restrict drastically the extent of disruption caused by long power interruptions when properly positioned. Some algorithms and automatic calculation procedures are proposed here for determining the optimum number and location of automatic sectionalizing switching devices. Using these algorithms, the optimal solution can be found for both radial and meshed systems. The procedure is based on Bellmann's optimality principle which, combined with thinning techniques yields finding the optimal solution in a few ms for real size problems.

Keywords: MV Network Planning Optimization, Service Quality, Sectionalizing Switches, Optimality Principle.

I. INTRODUCTION

Today, in MV power distribution systems planning, increasing attention is being paid to improve customer service reliability. Thus it is important to examine those aspects associated with amplitude and frequency fluctuations of the distributed voltages, interruptions in power supply to carry out maintenance because of a fault , etc.

This paper is concerned with service reliability in case the duration of an outage is longer than one minute. Interruptions of this kind involve a loss of revenue that can usually be quantified as the energy not supplied to the customer and the resulting cost to the utility.

Now a number of options are available for restricting the extent and the duration of service disruptions. The planner has to decide which precautionary measures should be taken [1-4]. In general, these consist in designing suitable network configurations and making provisions for restoring supplies in the event of a fault, introducing automatic sectionalizing switching devices (*ASSD*'s) that are able to diagnose the fault and eventually to automatically reschedule the configuration.

PE-465-PWRD-0-10-998 A paper recommended and approved by the IEEE Transmission and Distribution Committee of the IEEE Power Engineering Society for publication in the IEEE Transactions on Power Delivery. Manuscript submitted July 31, 1998; made available for printing November 10, 1998.

Here a new automatic calculation procedure is proposed that allows the determination of the optimal number and position of such devices for both radial and meshed networks. This type of procedure is normally implemented in programs for large MV power distribution systems and is required to comply with strict specifications as to computation times [1].

II. OPTIMIZING THE USE OF ASSD'S

A. Bellmann's optimality principle

To solve the problem of optimizing the use of ASSD's, heuristic techniques were resorted to, but these do not guarantee the accuracy of the results obtained [5-8]. Moreover, such techniques require a large amount of computing time and they are not well suited for computer aided real size network planning and optimization.

To find the exact solution of this problem, Bellmann's optimality principle [9], upon which all sequential optimization algorithms are based, was used. Below the terms of the problem are briefly recalled.

Consider a system whose state may change in every phase D_i for a given decision. The number of phases D_i ($i= 0,1,...,n$) may be finite or numerably infinite. A certain sequence of decisions from D_0 to D_n is defined as "policy", and a sequence of decisions belonging to a policy is defined as "sub-policy". If a function with values related to the changes in state is assigned, and it is required to optimize that function, the following statement holds:

"An optimum policy can only contain optimum sub-policies".

By applying this principle, the objective function can be optimized, e.g. such as ν function defined in III.B.I, associated to the number and position of ASSD's, such that the maximum benefit, in terms of service reliability, is obtained. In practice, the application of Bellmann's principle leads to a combinatorial explosion of the problem and it actually becomes impossible to apply it to real size networks. This is because for every possible site combinations there is a preliminary calculation of the benefits to be derived from installing ASSD's.

With this new method, which is based on Bellmann's principle and on the application of some logic rules derived from a knowledge of the mechanisms underlying fault regime management, the number of combinations to be explored is drastically reduced.

B. Radial networks

B.I. The problem

The cost of an MV power distribution system, for which all the characteristics of technical and economical parameters are known, can be estimated as the sum of the cost of every branch. Of course, the total cost will also include the cost of outage. In a radial network, depending on the type of connection arrangement and whether or not automatic switching devices exist [4-8], a faulted branch usually causes the interruption of power supplies to a large portion of customers.

Thus the problem is to optimize the number and position of these devices such that the resulting benefits, in terms of reduction in outage costs, justify the capital investment for their installation. The function ν takes into account the advantages to be derived from using ASSD's in a mathematical form.

Let C_{d0} be the cost of outage for the whole network in the absence of ASSD's and C_{dj} the cost of outage when a single ASSD exists in node j. The expression:

$$n_j = C_{d0} - C_{dj} \tag{1}$$

define a benefit ν_j.

Denoting with C_{ASSD} the unit cost of an ASSD, the installation of the ASSD in node j will produce a benefit if and only if $\nu_j \geq C_{ASSD}$ or, in other words, if the diminished cost of service disruption exceeds the installation costs.

To install an ASSD in node k in addition to the one in node j, the benefit ν_{jk} may be defined by the difference as:

$$n_{jk} = C_{dj} - C_{djk} \tag{2}$$

where C_{djk} is the outage cost estimated in the case of one ASSD in node k plus another one in node j.

This argument may be generalized evaluating the function ν for the addition of the n^{th} ASSD (when n-1 others are present) by means of:

$$n(n) = C_d(n-1) - C_d(n) \tag{3}$$

Therefore, the objective function to be optimized for positioning the ASSD's consists of the sum of the above defined incremental benefits, minus the installation costs of the devices. In the case at hand, it is desired to maximize this function. The optimum combination of ASSD's will in fact be the one that minimizes the outage cost function, if the installation costs are added to this.

B.II. Fault model

For a better understanding of what follows, the procedures normally adopted when a fault occurs on one of the MV network branches are recalled here. The duration of the fault is usually divided into two phases: fault location and fault repair. The use of automatic devices, possibly co-ordinated with emergency connections, restricts the extent of the fault and the number of customers affected. The repair stage consists of the time required to isolate the faulted branch, connect any emergency ties and repair the fault. It is in this phase that the presence of emergency feeders, that enable power to be restored to the nodes downstream from the sectionalized branch, becomes extremely important.

In conclusion, the introduction of automatic devices reduces the energy not supplied during the fault detection stage, especially if provision has been made for emergency feeders with auto-sectionalizing devices. Obviously, it is possible to use the same considerations for closed loop networks. Moreover, the emergency ties play a fundamental role in restoring the service during the repair stage.

B.III. Assessment of outage cost

For a generic combination of ASSD's, the service disruption cost can be evaluated using (4) which employs a more detailed fault model than those reported in [7]:

$$C_d = \sum_{j=1}^{N_b} C_{kWhns} \cdot \lambda_j \cdot L_j \cdot \left(\sum_{i=1}^{N_{loc}} P_i \cdot t_{loc} + \sum_{i=1}^{N_{rep}} P_i \cdot t_{rep} \right) \tag{4}$$

where:

N_b = Number of branches in the network
λ_j = Number of faults for every 100 km of feeder, different for cables and overhead lines
L_j = Branch length (km)
C_{kWhns} = Cost of not supplied energy ($/kWh)
N_{loc} = Number of nodes isolated during fault location
N_{rep} = Number of nodes isolated during fault repair
P_i = Node power (kW)
t_{loc} = Duration of the fault location (h), different for cables and overhead lines
t_{rep} = Duration of the fault repair (h), different for cables and overhead lines

N_{loc} is the number of the nodes positioned after the nearest ASSD through which the energy that supplies the faulted branch flows and N_{rep} is the number of the nodes directly supplied by the faulted branch. N_{rep} depends on the presence of throwover feeders, while N_{loc} decreases with the number of ASSD's and their co-ordination with emergency connections. Besides, the greater ASSD's number, the smaller t_{loc}, because the fault location becomes easier.

The application of (4) for radial networks does not require the analysis of the network transient behaviour, which is negligible for the assessment of outage cost, and does not involve the check of the electrical constraints that are automatically satisfied in the rescheduled network. If emergency connections exist or closed loop network are considered, electrical calculations must be performed in order to verify that technical constraints are complied with.

B.IV. Thinning techniques

The function ν has certain properties that can be used advantageously for diminishing computational effort required by an optimization algorithm based on optimality principle. For radial networks, these properties stem from the following logical considerations:

a) the advantages to be derived from installing an ASSD in one of the network nodes diminish as the number of nodes containing ASSD's increases;

b) the overall advantages obtainable by installing ASSD's in n nodes does not depend on the order in which they are installed, in other words:

$$v_{\alpha} + v_{\alpha\beta} = v_{\beta} + v_{\beta\alpha} \quad (5)$$

where $v_{\alpha\beta}$ is the gain yielded by installing an ASSD in node β when one already exists in node α and $v_{\beta\alpha}$ is that yielded by installing an ASSD in node α when one already exists in node β;

c) The number of candidate nodes can be reduced by deleting all those sites for which the gain produced by the presence of the ASSD, when no others exist at the same time, is lower than the cost of the device. This rule is justified by the fact that the benefits of installing an ASSD where others already exist are still smaller.

d) The advantage of installing ASSD's in n nodes, belonging to n separate trees, is equal to the sum of the advantages of each ASSD (the advantages are independent of each other). The fact that the advantages are independent, for separate trees where power cannot be restored, means that the number of candidate nodes to be explored contextually is reduced insofar as optimization can be performed singly on sub-trees having a limited number of nodes.

By combining these properties, the number of combinations of ASSD's to be examined during optimization can be drastically reduced.

C. Meshed networks

C.I. The problem

For a given closed loop power distribution system the identification of the ASSD's that minimize both the energy not supplied in the event of a fault and the costs of installing the devices at the same time, is of major importance. In fact in this type of network the occurrence of a fault on one edge of the network affects all those nodes, through direct or indirect routes, which are electrically connected to that portion of the network it is required to isolate to repair the fault. In the worst case, this means that in the absence of ASSD's a faulted branch will de-energize all the nodes in the interconnected network for the time required to detect the fault.

C.II. Assessment of outage cost

In a closed loop power distribution system the cost of disruptions may be evaluated by means of (4), taking into account that only the fault location phase has to be considered, because all branches may be resupplied when the faulted branch is identified and sectionalized. In this case technical constraints on feeder thermal capacity and voltage drop are of major concern and the rescheduled network must comply with them.

C.III. Application of thinning techniques

The function v enjoys, also in the case of meshed networks, certain properties that can be advantageously used for alleviating the computational effort involved in applying Bellmann's principle.

The properties a) b) and c) described above for purely radial networks also hold for meshed networks. For the property d) note that the benefits gained by installing ASSD's on feeders supplied by different sub-stations or having different routes out of the same source, cannot be considered independent. In fact, because of the meshing, all the nodes belonging to the same grid have to be examined simultaneously. Consequently, as opposed to radial networks, the application of property d) requires, in general, to explore a large number of nodes simultaneously. As a result the implementation of the proposed algorithm becomes more tedious.

Luckily, the property c) still holds for meshed networks which means that the number of sites to be explored for assessing the convenience of installing ASSD's is reduced considerably. Here again, those candidate ASSD's to be installed in sites for which the benefit to be gained from the presence of ASSD's is less than the cost of each ASSD, can be deleted unless other are present at the same time.

III. THE ALGORITHM

Examination of Fig. 1 gives a clear picture of how the optimization algorithm is able to rigorously identify the network nodes where ASSD's can be installed.

The aim is to find an optimum policy that starting from the initial situation (no ASSD's in the network) arrives at the final situation (with ASSD's in the most convenient positions) [9].

At each decisional level $D_1, D_2, ..., D_n$, we may introduce 1,2,...,n ASSD's. The nodes $\alpha, \beta, ..., \eta$, are "candidate" nodes in which the ASSD's may be conveniently installed, in other words the nodes obtained with the thinning procedure described in II.B.III. In Fig.1, which shows the graph of the possible decisional procedures, the edges are weighted with the value of the function v (1) [3]. Thus the edge between D_1 and D_2 which joins nodes α and β will have as its "length" the advantage $v_{\alpha\beta}$, that is the gain yielded by installing an ASSD in node β when one already exists in node α.

X_i is a vectorial variable whose elements are the nodes of the graph in Fig. 1 at the level D_i.

Define the function $V[X_0, X_1, ..., X_n]$ where:

$$X_i = [a, b, g, ..., h] \qquad i = D_0, ..., D_n \tag{6}$$

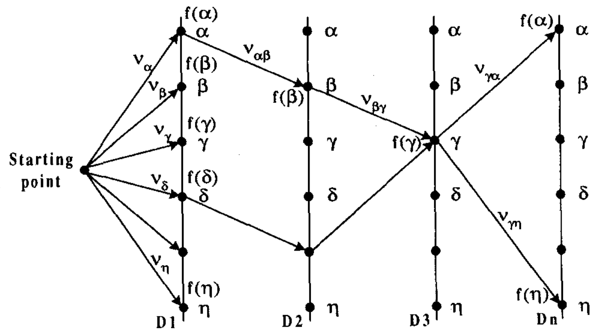

Fig. 1 This picture shows how the algorithm works.

and X_0 is the starting situation (no ASSD's in the network).

The function V may be expressed as the sum of advantages obtained by moving from D_1 to D_2, from D_2 to D_3 and so forth.

$$V = V[X_0, X_1,..., X_n] = n_I(X_0, X_1) + n_{II}(X_1, X_2) + n_{III}(X_2, X_3) + n_{IV}(X_3, X_4) + ... + n_{nth}(X_{n-1}, X_n)$$

where v_x denotes the advantage gained by moving on from one decisional level to the next; for instance v_{II} is the advantage gained by moving from D_1 to D_2; this is of course a function of the variables X_1 and X_2, in other words $v_{II} = v_{II}(X_1,X_2)$.

The V calculated for the *ennupla* of values X_0, ..., X_n, will be the overall advantage obtainable installing the ASSD in the nodes selected from that set.

For every node at each level the function f is defined, which expresses the maximum advantage obtained from connecting that node to any one of the others existing at the previous level. The function f corresponds therefore to the maximum gain derived by adding an ASSD to a node of the decisional level D_i, when other i-1 ASSD's already exist. For example, referring to node α in level D_3 we have:

$$f_{II,III}(\alpha)=\max_{X_2=\alpha,\beta,...,\eta}[f_{II}(X_2)+v_{III}(X_2,\alpha)]$$

Based on the value of the function f, the nodes shown in the graph of Fig. 1 can be labelled as follows:

a) The algorithm starts off by associating to each node at level D_1 its individual gain, in other words labelling the generic node α with the value of $f(\alpha)$ at the first step:

$$f_I(\alpha) = v_I(X_0,\alpha)$$

b) Moving on from D_1 to D_2, for node α at level D_2, the overall advantages obtained by connecting α to all the nodes at level D_1 (combining ASSD in α with another in any other node in the level D_1) are evaluated, excluding the connection from a in D_1 to a in D_2. Once this operation has been completed, the node α is labelled with the maximum overall gain obtained. By so doing, the pair of nodes that yield the greatest advantage are found, when the second node in which an ASSD is installed is α. In this case: the result is:

$$f_{I\,II}(\alpha) = \max_{X_1=\alpha,\beta,...,\eta}[f_I(X_1) + v_{I\,II}(X_1,\alpha)]$$

The procedure is repeated for each node at level D_2 so that all the nodes are labelled. This operation proceeds until every node at each level in the graph of Fig. 1 has been labelled.

Should the value of the function f calculated for the generic node α at the decisional level D_1 be smaller than the maximum value of that same function in the level D_{i-1}, in the graph of Fig. 1 the edge joining this node with the level D_{i-1} is missing. This means that the cost of introducing another ASSD in node α added to any of the combinations of the previous step is not offset by the reduction in outage cost obtained. Consequently, when one attempts to connect any node at the level D_{i-1} with node α at the level D_i, the corresponding combination is deleted since no edge joins α with the level D_{i-1}. In this way, the number of combinations to be explored in the search for the optimum one is gradually and drastically reduced.

c) Once all the levels have been examined as described above, every node will have been labelled with the value of the function f, while those nodes that have not been connected in the previous step will be labelled zero. In so doing, the best route can be determined for each node. The combination of n ASSD having the maximum gain is determined as follows:

1 - Starting from the n^{th} level, find the node at that level labelled with the highest value, take for example node α;

2 - Subtract from the value of this label the value of the advantages $n_{X_{n-1},\alpha}$: the node to which α will be connected is the one whose label coincides with the difference;

3 - Repeat this procedure up to level D_1.

The choice of the route with the greatest gain in the graph of Fig. 1 allows the determination of the optimum installation policy of the ASSD's which corresponds to introducing the devices at each node along that route.

The weights assigned to the graph edges could be computed prior to optimization using the combinatorial technique. However, in the case at hand, it was preferred to evaluate them for each decisional level so as to avoid useless calculations. For example, the ones for placing more than one ASSD in the same node.

With this algorithm it is possible to determine the optimum number of ASSD's to be installed in a given network or its best combination, in the case where a maximum number of ASSD's to be installed has been predetermined.

In the first case it is sufficient to assign the maximum number of levels to the algorithm described above to obtain the desired result. Should the number of ASSD's have been overestimated with respect to actual convenience, then stopping rules are applied if, when moving on to the next decisional level, no improvements are obtained that justify the introduction of another ASSD. The optimum number in this case coincides with the decisional level being examined prior to initiation of the stopping procedure. Conversely, if the number of ASSD's has been underestimated, it is possible to continue the optimization procedure until such time as the maximum benefit has been achieved. In this case when the last decisional level has been examined, it is sufficient to introduce another level and apply the stopping rules described above. If the procedure does not come to a stop then the addition of another ASSD is justified and so forth until the procedure ends.

If, on the other hand, the number of ASSD's has not been established beforehand, then one proceeds as above, starting with one ASSD and gradually increasing their number. The procedure will stop when the installation of additional ASSD's proves to be inconvenient. With this method the number of possible combinations to be examined is restricted insofar as the analysis is not extended to decisional levels that do not offer any further advantages a priori.

IV. EXAMPLES

To demonstrate the features of the algorithms implemented here, two cases are examined below that exemplify typical situations. The first (Fig. 2) refers to an existing radial system, the second (Fig.3) to a partially built meshed system.

Fig. 2 shows a distribution system that supplies 36 customers who were considered to exist at the beginning of the study period.

In the calculation the following parameter values were taken:

- Cost of energy not supplied 3 $/kWh
- Cost of one ASSD 7,000 $ (the 50% may be amortized over the study period)
- Study period : 12 years
- Number of faults : 24 in one year for every 100 km of feeder
- Duration of the fault : 2 h (1 hour to locate the faulted branch and 1 hour to repair it.)

The cost of outage in the system of Fig. 2, when it contains no ASSD's is 266,600 $. It is shown that this cost can be reduced to 137,600 $ installing three ASSD's in nodes labelled with 17, 12 and 7. Given that the cost of installing these three devices is, for the study period , 21,000 $ the total net cost of outage is therefore 158,600$. Thus the incorporation of automatic devices results in significant savings.

Table I shows the results of implementing the algorithm. The numerical values correspond to the outage costs (inclusive of plant costs required for installing the ASSD's) for the combinations explored by the algorithm. The automatic calculation procedure proceeds as follows:

a) Search for suitable installation sites for a single ASSD; these sites are represented by the one whose individual benefit n is greater than the cost of the ASSD. There are 17 nodes that satisfy this condition and the algorithm for optimizing the position of the devices is applied thereto. The first column of Tab. 1 shows, for simplicity, only the most convenient 9 sites of the 17 ones examined.

b) Explore node combinations to assess the benefit of using two or more ASSD's simultaneously. In this situation all those combinations that yield either an incremental gain lower than the cost of one ASSD, or overall gain lower than the maximum gain obtained with one ASSD less than the combination being examined are deleted.

The second column of Tab. 1 gives the pair of nodes in which two ASSD's can be conveniently installed. The pairs in

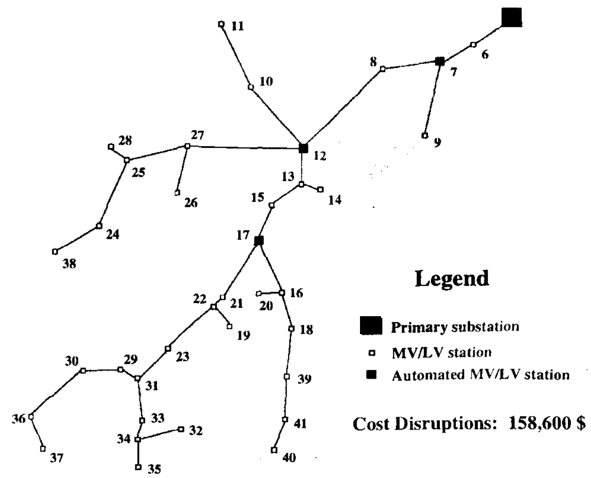

Fig. 2. Application of ASSD's optimization algorithm to an existing radial network.

bold print yield a total cost that does not justify installing another ASSD. As can be seen the best pair is 12-17.

If it is desired to examine the possibility of installing a set of three ASSD's, then only the 6 pairs of nodes selected by the algorithm for the installation of two ASSD's need be considered and possible combinations of these nodes with the candidate will be explored. In this case the analysis is restricted to 6 (pairs of nodes) x 15 (number of candidates -2) = 60 combinations, i.e. a very small number compared to the total number of possible combinations (4080).

Likewise the search for the nodes where a set of four ASSD's can be conveniently installed, only requires the combinations of the set of three nodes (12-17-7) with the other candidates to be explored. Thus the search is restricted drastically: 14 combinations against the 57120 possible ones. Their total costs are shown in the last column of Tab. 1.

It clearly emerges that using the above described procedure prevents the exponential explosion of node combinations to be explored. Moreover, it yields the solution with the absolute least total cost (cost of outage plus the cost of the ASSD's employed). Proceeding in this way, computation times can be reduced enormously (in the order of a few ms on a PC486/33 MHz for networks containing 36 nodes) which means that the algorithm can be used in iterative routines for power distribution system planning [1].

TABLE I
Cost of power interruptions for different combinations of ASSD's (combinations in bold print are not convenient)

Cost of interruptions with one ASSD		Cost of interruptions with two ASSD		Cost of interruptions with three ASSD		Cost of interruptions with four ASSD	
Node	Cost(x1000 $)	Nodes	Cost(x1000 $)	Nodes	Cost(x1000 $)	Nodes	Cost(x1000 $)
12	179.4	12-17	160.5	12-17-7	158.6	**12-17-7-31**	**159.2**
13	203.1	12-31	171.6	**12-17-22**	**164.6**	**12-17-7-22**	**163.0**
17	212.3	12-22	171.7	**12-17-23**	**165.4**	*	*
22	239.0	12-23	174.9	*	*	*	*
21	241.8	12-21	175.1	*	*	*	*
31	245.2	12-7	177.8	*	*	*	*
23	246.4	**12-13**	**182.7**	*	*	*	*
27	248.6	**12-27**	**187.2**	*	*	*	*
7	249.4	*	*	*	*	*	*

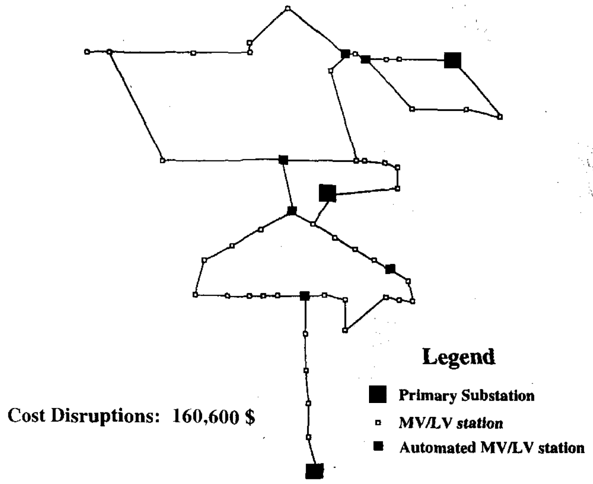

Fig. 3. Meshed network with 6 ASSD's.

Figure 3 shows the results of an application of the proposed calculation procedure to a meshed system. In the calculations the same parameter values used in the previous example have been employed. In this case a large number of automatic devices are required to minimize the effects of outage during the fault location stage. The cost of energy not supplied is 331,600 $ if no ASSD's are present in the network. This cost decreases to 160,600 $ if the 6 optimal ASSD's are present while the total cost of ASSD's is 42,000$.

This solution has been found with the calculation of 582 combinations, a very low number considering that, with a combinatorial algorithm, it should be necessary to examine all combinations of 47 nodes (2.6E+59).

Thus the algorithm is also able to determine the absolute least of objective function for meshed networks with limited computer resources and running time of few hundreds of ms in real size network.

V. CONCLUSIONS

The problem of the optimum installation of automatic sectionalizing switching devices in radial and meshed networks has been examined. The possibility of applying Bellmann's optimality principle for solving this class of problem is seriously hindered by the fact that the situations to be explored increase enormously with increasing network size, given the intrinsic combinatorial nature of such problems.

Here, criteria and logic rules are defined that when properly implemented in the optimization process, allow a drastically reduction of the computational effort. In this way it is possible to find the optimum solution applying the optimality principle to large systems too, without the need to resort to heuristic techniques that do not guarantee the goodness of the results obtained. The extremely short computation times, a few ms, mean that the described procedure may also be employed in heuristic type programs for optimal planning of power distribution systems.

VI. ACKNOWLEDGMENTS

The authors gratefully acknowledge Prof. Francesco Mocci, who suddenly died in July 1997, for his work on the original version of this paper and for his unforgettable teachings.

VII. REFERENCES

[1]A. Invernizzi, F. Mocci and M. Tosi, "Planning and Design Optimization of MV Distribution", *Proc. of 1995 T&D World '95 Conference*, New Orleans, session 306, pp. 549-557.

[2]F. Mocci and F.Pilo, "Il miglioramento della qualità del servizio nelle reti MT mediante modifiche strutturali ed impiego di dispositivi per la selezione automatica dei tronchi guasti", *Proc. of the 95th AEI Annual Meeting*, Bologna 1994, Italy, vol. A1, pp. 67-77.

[3]F. Mocci and F.Pilo, "Miglioramento della qualità del servizio nelle reti MT; algoritmi e modelli per l'ottimizzazione dei dispositivi per la selezione automatica dei tronchi guasti", *Proc. of the 95th AEI Annual Meeting*, Bologna 1994, Italy, vol. A1, pp. 79-91.

[4]F. Mocci, C. Muscas and F. Pilo, "Network planning and service reliability optimization in MV distribution systems", *Proc. of the ESMO'95 Conference*, Columbus (U.S.A), 95CH35755, pp. 36-46.

[5]Levitin, Sh. Mazal-Tov and D. Elmakis, "Optimal Allocation of Sectionalizers in Radial Distribution Network", *Proc. of the 1995 Stockholm Power Tech Confrence*, PS 25- 01- 0034, pp. 761-764.

[6]Levitin, Sh. Mazal-Tov and D. Elmakis, "Optimal sectionalizers allcocation in electric distribution systems by genetic algorithm", *Electric power systems research*, no. 31, 1994, pp. 97-102.

[7]Billinton and S. Joannavithula, "Optimal switching device placement in radial distribution system", *IEEE Trans.on Power Delivery*, vol. 11, no. 3, July 1996, pp. 1646-1651.

[8]Li-Hui Tsai, "Network reconfiguration to enhance reliability of electric distrubution systems", *Electric power systems research*, no. 27, 1993,pp. 135,140.

[9]Kaufmann, *Méthodes et modéles de la recherche opérationnelle*, Volume II, Paris: Dunod, 1972, pp. 83-171.

VIII. BIOGRAPHY

Gianni Celli was born in Cagliari, Italy, in 1969. He is Assistant Professor in the Power System group at the Dept. of Electrical and Electronic Engineering of the University of Cagliari, Italy. He holds this position from January 1997. He graduated in Electrical Engineering at the University of Cagliari in 1994 and since 1996 he has been research collaborator of Power System group at the same University. Current research interests are in the field of MV distribution network planning optimization, Power Quality and use of Neural Networks in the field of Power System.

Fabrizio Pilo was born in Sassari, Italy, 1966. He received the Dr. Eng. degree in Electrical Engineering from the University of Cagliari in 1992. He became Assistant Professor of Electrical Engineering in 1995 at the Department of Electrical and Electronics Engineering of the University of Cagliari. His major field of interest includes electrical power systems, network planning and optimization and neural networks.

He is author of several papers published on international journals or presented in various international conferences.