Reliability Evaluation in Power Distribution System Planning Studies

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***Abstract*—In distribution system planning studies, reliability evaluation is performed during optimization procedure to calculate the interruption cost, DISCO's income and to check the viability of constraints related to reliability indices. In each iteration of the optimization algorithm a special plan is evaluated that is different from other plans. So the configuration and specification of the network which is one of the input information for reliability evaluation is changing continuously that makes difficulties for this evaluation. To solve these difficulties, this paper presents a systematic method for reliability evaluation in distribution planning studies. The proposed approach can be implemented as a subprogram in comprehensive software of distribution system planning and design.**

Keywords—distribution system planning; heuristic optimization approaches; reliability evaluation

I. INTRODUCTION

Planning is a decision making process that seeks to identify the available alternatives and choose the best one. Applied to electric utility planning, that process seeks to identify the best schedule of future resources and actions to achieve the utility's goals. Usually, among the major concerns of planning are financial considerations -minimize cost, maximize profit- or some similar goals. In addition, service quality and reliability are almost always considerations, too [1].

In power distribution networks, the results of distribution system planning (DSP) would be a roadmap for preliminary or detailed engineering design in network development or new network construction projects [1]. Generally in DSP studies, the planner considers the standards and regulations, the constraints and limitations, the available resources and existing infrastructures, as well as the results of some technical and economic studies, and aims to optimize the followings:

- Location/ route, construction time, and capacity of new substations/ lines, and reinforcement of existing ones (Capacity planning) [2];
- Location, installation time, and type of switching devices (Switch planning) [3];
- Location, installation time, and type of automation devices (Automation planning) [4];
- etc.

To make decision in DSP studies, the optimization model of the problem is created, i.e. the objective function is derived and the constraints are defined. Usually DISCO's profit or total cost he would incur during time horizon of the plan is considered as the objective function, respectively in max-profit or min-cost models [5]. So the income and total involved cost including investment cost, operation cost, maintenance cost, and service interruption cost should be calculated for the period of time horizon. Among these terms, reliability evaluation is required for calculation of DISCO's income as well as the interruption cost.

Regarding the constraints, in some cases system regulators specify thresholds for some reliability indices. Thus the network should be designed or expanded in such a manner that it can provide the service with the required standards [5]. In these cases, the constraints of reliability indices should be considered in addition to other technical constraints such as active and reactive power balance in nodes, loading limit of lines and transformers, voltage limits, etc. Regarding these facts, in distribution system planning or design studies, reliability evaluation should be performed during optimization process, as well as other technical analysis such as power flow and short circuit. In many of recently presented DSP models, reliability indices have been included in objective function or constraints of the model [5]-[10].

After creating the optimization model of DSP problem, it should be solved using mathematical [6] or heuristic optimization methods. Due to mixed-integer and non-linear nature of this problem, heuristic methods are preferred and most of recent works have used these methods such as genetic algorithm (GA) [5], particle swarm optimization (PSO) [4], simulated annealing (SA) [3], tabu search (TS) [7]-[8], etc.

Regardless of applied method, optimization is an iterative process, and in each iteration of DSP problem optimization algorithm a different plan is evaluated in which the configuration and specification of the network is different from other developed plans. Besides, in each plan the network characteristic will also be subject to change during the time horizon, e.g. lines, substations and other devices may be added to/removed from the network and the capacity and specification of them may be changed. So, the frequent changes of the network structure and equipment specification make difficulties in evaluation of the reliability indices which play important roles in the decision-making process in DSP problem [5].

In the literature, most of the DSP models -which have taken into account reliability- have not explained how the above described difficulty in reliability evaluation is dealt with [7]-[10]. In [3] a simplistic method has been used to solve the above mentioned difficulties. In this method first a number of the optimal solutions are obtained using the optimization algorithm without considering reliability. Then reliability evaluation is done for these solutions and the best one is selected according to this criteria. However, it is very likely that this procedure does not lead to the global optimal solution which can be obtained with incorporating reliability evaluation through optimization algorithm.

Previous work of these authors [5] briefly introduces the fundamentals of a method for reliability evaluation of distribution system in DSP studies. So based on [5], this paper comprehensively presents a method for distribution reliability evaluation in planning studies, illustrate the steps of the procedure and present the formulation in detail.

The rest of the paper is organized as follows. Section II outlines general tips of distribution system reliability studies. The proposed approach for reliability evaluation of distribution systems in planning studies is presented in Section III. Then, in Section IV, the performance of the method will be evaluated in the five-year planning for an illustrative distribution test network, and finally Section V draws conclusions.

II. Reliability Evaluation of Distribution Systems

Distribution system reliability evaluation is usually performed assuming the generation and transmission system are fully reliable. However the result of the composite system reliability can be used as the input of the distribution system studies. The most frequently used indices for assessing system reliability are as follows [11]:

- System average interruption duration index per customer, *SAIDI*
- Expected energy not supplied, *EENS*
- Average energy not supplied per customer, *AENS*
- Average annual outage time, *U*

To calculate these indices as well as the interruption cost several data are required as follows:

1. The failure rate (λ) and outage time (r) must be given for each component its failure is taken into account in reliability evaluation. This paper only considers the probable failure of subtransmission substations and permanent failure and fault on the medium-voltage lines (primary distribution system).
2. Configuration of distribution network must be specified. Usually in distribution system the radial configuration is preferred rather than ring, network and mesh configurations due to simplicity of fault location and protection and lower short circuit power. Therefore, despite the problems such as excessive voltage drops and extended interruptions in radial configuration, most of the distribution networks are operated with radial configuration, and other solutions are used to solve the problems of this configuration, such as using capacitors to reduce the voltage drop and emergency connection to adjacent feeders to reduce the outage duration. So in this paper it is assumed that the feeders are radial and reserve connections are used in case of main supply interruption, if it is possible [12].
3. Protection scheme, i.e. the location of protection devices such as circuit breakers, fuses, reclosers, and other switches must be given. In this paper the probable failure of these devices is also considered.
4. The fault management process and involved times such as fault detection time (t_{fd}), fault location time (t_{fl}), switching time (t_{sw}) and repair time (t_{rp}) must be given. Usually after a service interruption, the fault management procedure starts with fault detection. Then fault location (approximate and precise) is started and simultaneously the faulty zone is isolated and service is restored to healthy sections [13]. As the process goes on, the fault is located more precisely and the faulty zone become smaller, so the service of more customers is restored. However the customers in faulty zone and downstream of it which have no alternative supply, would be energized after the fault repair process. The distribution systems may be equipped with some automation technologies, so some actions involved in fault management process would be performed automatically and remotely and so in shorter time. However the proposed method can be used for any distribution system with any level of automation, from conventional to fully automated system.
5. Other necessary data for interruption cost calculation must be given, such as type of customers (residential, industrial, commercial, agriculture, public), the number of customers supplied from each load point, the value of lost load (*VOLL*) or customer damage function (CDF), etc.

The proposed method for reliability evaluation is presented in the following section

III. Proposed Method

As explained before, because of frequent changes of the network configuration and specification in the optimization process of DSP problem, reliability evaluation is faced with some difficulties. Using heuristic optimization techniques like GA, there is a population of solutions in each iteration of the algorithm. Each solution (e.g. chromosome) represents a different plan for expansion of the distribution network. Thus, the fitness calculating program faces with a different network in each run. So in the beginning of the reliability evaluation subprogram, the network structure and characteristic must be completely identified and updated using the value of related decision variables (e.g. genes). So the network identification is the heart of the proposed method.

A. Network Identification

Network identification process is performed with definition and construction of five matrices. This section introduces these matrices.

It should be noted that dimension of each matrix is specified as the subscript of its name, in terms of total number of buses (N_b), number of load buses (N_{lb}), number of substation buses (N_{sb}) and number of lines of the network (N_f). To illustrate the proposed method, the simple network of Fig. 1 is considered.

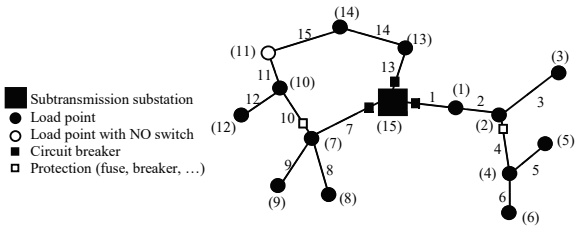

Fig. 1. Simple network to illustrate the identification process

- Matrix I: $connect_{N_b \times N_b}$

This matrix represents the connection between the buses of the network. The elements of this matrix are obtained from data of lins. If there is no line between bus m and bus n, $connect(m,n)= connect(n,m)=0$; otherwise if line j exists between bus m and bus n,

$$connect(m,n) = connect(n,m) = \begin{cases} 1 & if \;\; X_{j,t} = 1 \\ 0 & if \;\; X_{j,t} = 0 \end{cases} \tag{1}$$

For example in the simple network:

$$connect(1,6) = 0, connect(15,13) = 1,$$
$$connect(7,10) = 1, connect(3,12) = 0, ...$$

In (1) variable $X_{j,t}$ indicate the presence (=1) or absence (=0) of line j in the network at year t. In a multi-stage planning problem, this is calculated on the value of corresponding decision variables.

- Matrix II: $bus\_level_{N_b \times 1}$

Each element of this matrix represents the level of corresponding bus, in other words the distance between the bus and the subtransmission substation. For example in the simple network of Fig. 1:

$$bus\_level(15) = 0, bus\_level(1) = 1,$$
$$bus\_level(6) = 4, bus\_level(12) = 3, ...$$

To determine the elements of this matrix, first the elements corresponding to substation buses are set to zero (zero-level buses). Then the elements corresponding to buses that are connected to zero-level buses are set to one (level-one buses) and so on. So, this matrix can be constructed using a graph traversal algorithm (such as BFS [14]) considering the data of matrix *connect*.

- Matrix III: $com\_feed_{N_{lb} \times 1}$

This matrix specifies the load points that are fed from a common feeder. The value of element corresponding to each bus would be equal to the number of level-one bus of the supplying feeder. For example in the simple network of Fig. 1:

$$com\_feed(1) = ... = com\_feed(6) = 1$$
$$com\_feed(7) = ... = com\_feed(12) = 7$$
$$com\_feed(13) = com\_feed(14) = 13$$

To construct this matrix, first the elements corresponding to level-one buses are set to the bus number. Then by using BFS algorithm and considering the matrices *connect* and *bus_level*, the load points that are connected to a common feeder is specified and their corresponding elements are set to the number of level-one bus.

- Matrix IV: $com\_sub_{N_{lb} \times 1}$

This matrix specifies the load points that are fed from a common substation. For example in the simple network of Fig. 1, all elements of this matrix would be equal to 15, because all load points are supplied from the subtransmission substation at bus 15. To construct this matrix, the elements corresponding to the load points of feeders that are supplied from a common substation are set to bus number of that substation. Therefore these elements can be calculated as in (2) by using the data of matrices *connect* and *com_feed*.

$$\begin{aligned} &\forall j \in \Omega_{lb} \;\&\; \forall m \in \Omega_{sb} : \\ &com\_sub(j) = m \quad \text{if } connect(m, com\_feed(j)) = 1 \end{aligned} \tag{2}$$

Where, Ω_{lb} and Ω_{sb} are set of load buses and substation buses, respectively.

- Matrix V: $feed\_rout_{N_{lb} \times N_f}$

This matrix specifies the route of supplying a load point. If line j is not on the feeding route of bus m, $feed\_rout(m,j)=0$, else if line j is the kth line in the supplying route of load point m, then $feed\_rout(m,j)=k$. For example in the simple network for bus 4:

$$feed\_rout(4,1) = 1$$
$$feed\_rout(4,2) = 2$$
$$feed\_rout(4,4) = 3$$

Other elements of row 4 of this matrix are zero, because the corresponding lines do not exist in the feeding route of bus 4.

The elements of *feed_rout* can be obtained using a recursive algorithm from the data of matrices *connect* and *bus_level*. For this purpose, first it is searched for a bus (bus n) so that it is connected to bus m and one level lower than this bus ($connect(m,n)=1$ and $bus\_level(n)=bus\_level(m)-1$). It is obvious that the line between these two buses (line j) is the last line in the feeding route of bus m, so:

$$feed\_rout(m,j) = bus\_level(m) \tag{3}$$

By repeating this process for bus n, the next line of the feeding route of bus m is determined and this process is continued until the subtransmission substation is reached. In this stage all lines of the feeding route of bus m is determined and mth row of matrix *feed_rout* is completed.

After constructing these matrices the identification process can be accomplished. It can be shown that the network configuration is uniquely identifiable by having two matrices *com_sub* and *feed_rout*. For example if these two matrices for

an unknown network is as in (4), the configuration of the network can be uniquely shown as in Fig. 2.

Therefore the necessary and sufficient condition to identify the configuration of the network is that two matrices *com_sub* and *feed_rout* is calculated using three matrices *connect*, *bus_level* and *com_feed*.

$$feed\_rout = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 2 & 0 & 0 & 0 & 0 \\ 1 & 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 2 & 0 \\ 0 & 0 & 0 & 1 & 2 & 3 \end{bmatrix} \qquad com\_sub = \begin{bmatrix} 7 \\ 7 \\ 7 \\ 7 \\ 7 \\ 7 \end{bmatrix} \tag{4}$$

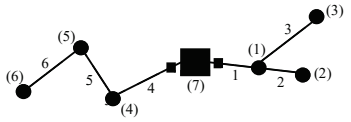

Fig. 2. The structure of network defined by (4)

B. Reliability Evaluation

After identifying the network structure, reliability evaluation process starts with the definition of matrix $u_{(N_f+N_{sb})\times N_{lb}}$. Each element $u(j,m)$ of this matrix represents the outage time of load point m due to failure of element j. To assess the reliability of primary distribution network, it is assumed that the outage of the load points is only due to the failure of/fault on the substations and distribution lines.

1) Failure of Subtransmission Substation

Detail of the substation reliability evaluation is not in the scope of this paper, so it is assumed that for each substation figures are calculated as its average failure rate and average repair time. Hence if a substation fails, service interruption will occur for all of the feeders which are fed from that substation. The outage time is equal to substation repair time, unless there is another subtransmission substation available in the network that can be used as back-up supply for the interrupted feeders. In latter case, the outage time of feeders that can be restored through reserve connection is reduced to time to perform the required switching actions. Of course in an automated distribution system this outage time will be negligible due to automatic and remote fault management procedure.

So matrix $feed\_restore_{N_{lb}\times 1}$ is defined as follows:

- *feed_restore*(m)=1 if the supplying feeder of load point m can be restored through reserve connection in the case of failure of main supplying substation.
- *feed_restore*(m)=0 if the supplying feeder of load point m cannot be restored in the case of failure of main supplying substation, thus its outage time is equal to substation repair time.

Considering above description, (5) calculates the elements of matrix u corresponding to subtransmission substations using matrix *feed_restore* and matrices defined in the identification process.

$$u(j,m) = \begin{cases} 0 & \text{if } com\_sub(m) \neq j \\ \lambda_j.(t_{sw}) & \text{if } com\_sub(m) = j \ \& feed\_restore(m) = 1 \\ \lambda_j.(t_{rp_j} + t_{sw}) & \text{if } com\_sub(m) = j \ \& feed\_restore(m) = 0 \end{cases} \tag{5}$$

2) Failure of/Fault on Lines

To assess the effect of failure of lines on load points, two matrices $flt\_effect_{N_f\times N_{lb}}$ and $bus\_restore_{N_f\times N_{lb}}$ are defined as follows:

For matrix *flt_effect*:

- *flt_effect*(j,m)=0: failure of/fault on line j has no effect on load point m, because line j and bus m are not in the same feeder.
- *flt_effect*(j,m)=1: failure of/fault on line j interrupts load point m, because line j is in the main supplying route of bus m.
- *flt_effect*(j,m)=2: failure of/fault on line j interrupts load point m, because line j or other related lines have no protection.
- *flt_effect*(j,m)=3/*flt_effect*(j,m)=4/*flt_effect*(j,m)=5: failure of/fault on line j does not interrupt load point m, because line j or related lines are protected with fuse/breaker/recloser and only in the case of failure of the protection device an interruption occurs.
- *flt_effect*(j,m)=6: failure of/fault on line j does not interrupt load point m, because there are more than one protection device between line j and load point m and the probability of simultaneous failure of two (or more) protection devices is considered negligible.

For matrix *bus_restore*:

- *bus_restore*(j,m)=0: line j and bus m are not in the same feeder, so failure of/fault on line j has no effect on load point m.
- *bus_restore*(j,m)=-1: following an interruption of load point m due to a fault on line j, this load point cannot be restored without repair of fault, so the outage time of this load point is equal to time required for fault detection, fault location, line repair and subsequent switching actions.
- *bus_restore*(j,m)=1: following an interruption of load point m due to a fault on line j, this load point can be restored through reserve connections, so the outage time is equal to time to perform the required switching actions.

For example in the simple network of Fig. 1, if all load points have in-switch and out-switch and lines 4 and 10 are protected with fuse:

$$flt\_effect(5,12) = 0 \qquad bus\_restore(5,12) = 0$$
$$flt\_effect(6,3) = 3 \quad bus\_restore(6,3) = 1$$
$$flt\_effect(7,11) = 1 \quad bus\_restore(7,11) = 1$$
$$flt\_effect(2,4) = 1 \quad bus\_restore(2,4) = -1$$

Considering above description, elements *flt_effect*(*j*,*m*) and *bus_restore*(*j*,*m*) can be calculated using matrices defined in the identification process. These two elements are equal to zero if line *j* and bus *m* are not in the same feeder. Otherwise, using BFS algorithm and choosing bus *m* as the root of graph, the graph is traversed until line *j* is reached. Therefore the number and type of the existing protection devices and other switches between line *j* and bus *m* is determined, then the elements can be calculated.

After constructing *flt_effect* and *bus_restore*, the elements of matrix *u* corresponding to lines can be calculated as in (6).

$$u(j,m)=\begin{cases} 0 & \text{if } flt\_effect(j,m)=0 \\ \lambda_j.\left(t_{fd}+t_{fl}+t_{rp_j}+t_{sw}\right) & \text{if } flt\_effect(j,m)=1 \\ & \&\ bus\_restore(j,m)=-1 \\ \lambda_j.\left(t_{fd}+t_{fl}+t_{sw}\right) & \text{if } flt\_effect(j,m)=1 \\ & \&\ bus\_restore(j,m)=1 \\ \lambda_j.\left(t_{fd}+t_{fl}+t_{rp_j}+t_{sw}\right) & \text{if } flt\_effect(j,m)=2 \\ & \&\ bus\_restore(j,m)=-1 \\ \lambda_j.\left(t_{fd}+t_{fl}+t_{sw}\right) & \text{if } flt\_effect(j,m)=2 \\ & \&\ bus\_restore(j,m)=1 \\ \lambda_j.\left(fail_{fuse}.(t_{fd}+t_{fl}+t_{rp_j}+t_{sw})\right) & \text{if } flt\_effect(j,m)=3 \\ & \&\ bus\_restore(j,m)=-1 \\ \lambda_j.\left(fail_{fuse}.(t_{fd}+t_{fl}+t_{sw})\right) & \text{if } flt\_effect(j,m)=3 \\ & \&\ bus\_restore(j,m)=1 \\ \lambda_j.\left(fail_{rcls}.(t_{fd}+t_{fl}+t_{rp_j}+t_{sw})\right) & \text{if } flt\_effect(j,m)=4 \\ & \&\ bus\_restore(j,m)=-1 \\ \lambda_j.\left(fail_{rcls}.(t_{fd}+t_{fl}+t_{sw})\right) & \text{if } flt\_effect(j,m)=4 \\ & \&\ bus\_restore(j,m)=1 \\ \lambda_j.\left(fail_{brk}.(t_{fd}+t_{fl}+t_{rp_j}+t_{sw})\right) & \text{if } flt\_effect(j,m)=5 \\ & \&\ bus\_restore(j,m)=-1 \\ \lambda_j.\left(fail_{brk}.(t_{fd}+t_{fl}+t_{sw})\right) & \text{if } flt\_effect(j,m)=5 \\ & \&\ bus\_restore(j,m)=1 \\ 0 & \text{if } flt\_effect(j,m)=6 \end{cases} \quad (6)$$

In (6), $fail_{fuse}$, $fail_{rcls}$ and $fail_{brk}$ are the probability of failure of fuses, reclosers and circuit breakers, respectively.

It should be noted that if the distribution system is equipped with full automation system, the time required for fault detection, location and switching actions will be negligible.

3) *Calculation of Reliability Indices*

After construction of matrix *u*, reliability indices of system and load points can be calculated. Indices *U* and *EENS* for load point *m* are calculated through (7) and (8), respectively.

$$U_m=\sum_j u(j,m) \quad \forall\ j\in\Omega_f\ \&\ \forall\ j\in\Omega_{sb} \quad (7)$$

$$EENS_m(t)=U_m(t).P_{D,m}(t).LF_m \quad (8)$$

Indices *SAIDI*, *EENS* and *AENS* for system at each year (*t*) are calculated using (9), (10) and (11). Also the service interruption cost ($Cost_{Int}$) is calculated using (12).

$$SAIDI(t)=\left(\sum_{m=1}^{N_{lb}}\omega_m.U_m(t).N_{cstmr,m}\right)/N_{cstmr} \quad (9)$$

$$EENS(t)=\sum_{m=1}^{N_{lb}}EENS_m(t) \quad (10)$$

$$AENS(t)=EENS(t)/\sum N_{cstmr,m} \quad (11)$$

$$Cost_{Int}(t)=\sum_{m=1}^{N_{lb}}\left(VOLL_m.EENS_m(t)\right) \quad (12)$$

In (7)-(12):

$P_{D,m}(t)$	Forecasted peak demand of load point *m* at year *t*.
LF_m	Load factor of load point *m*.
N_{cstmr}	Total number of customers.
$N_{cstmr,m}$	Number of customers fed from load point *m*.
$\omega_m(t)$	Presence (= 1) or absence (= 0) of load point *m* in the network at year *t*.

The flowchart of the proposed method is represented in Fig. 3.

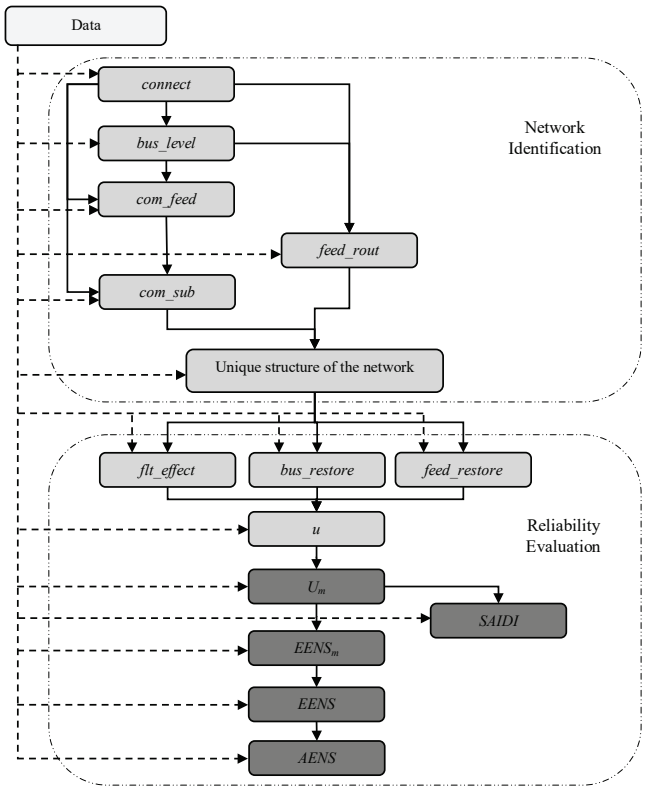

Fig. 3. Reliability evaluation of distribution systems in planning studies

IV. Numerical Results

As explained before, the proposed method can be implemented as the reliability evaluation subroutine in the comprehensive algorithm of distribution system design and planning. Therefore the numerical test of the proposed method should be performed during a planning study. So this section presents the results of the reliability evaluation using the proposed method obtained in the five-year planning study in [5] for the network shown in Fig. 4. Required data for reliability evaluation are shown in Table I. The data of *VOLL* and other related are as in [5].

Referring to [5], the developed plan for expansion of the existing network using max-profit model and considering

automation technologies (Case III [5]) is represented in Fig. 5. Table II presents the results of system reliability indices and the interruption cost at each year of the planning time horizon, which are calculated using the proposed method

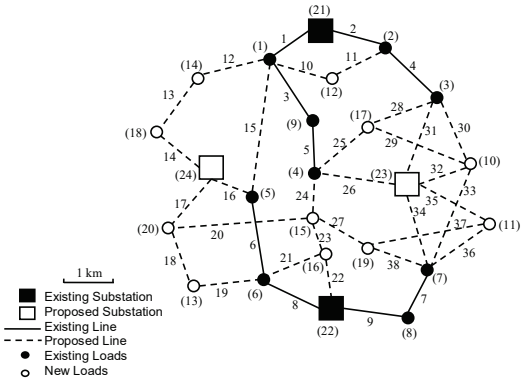

Fig. 4. 24-node test network under study [5]

TABLE I. REQUIRED DATA FOR RELIABILITY EVALUATION [5]

$\lambda_{overhead}$(occ./yr.km)	10	$t_{rp,overhead}$(hours)	2
λ_{cable}(occ./yr.km)	0.01	$t_{rp,cable}$(hours)	20
$\lambda_{substation}$(occ./yr)	0.015	$t_{rp,substation}$(hours)	150
t_{fd}(minutes)	5	t_{fl}(minutes)	45
$t_{sw,m}$(minutes)	30	$fail_{brk}$	0.04
$fail_{fuse}$	0.1	$fail_{rcls}$	0.04
$SAIDI_{th}$ (hr/yr.cstmr)	0.9	$AENS_{th}$ (kWh/yr.cstmr)	15

$SAIDI_{th}$ and $AENS_{th}$ are threshold values specified by regulator as a standard.

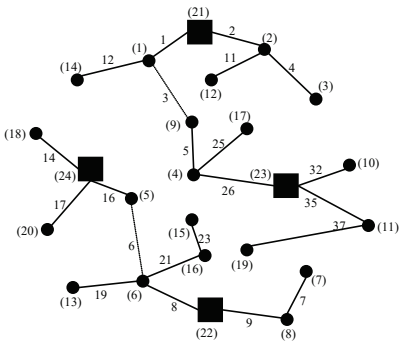

Fig. 5. The planned network [5]

TABLE II. RESULTS OF RELIABILITY EVALUATION

year	0	1	2	3	4	5
SAIDI	1.80	1.63	1.41	1.15	1.10	1.02
AENS	20.3	18.3	18.0	17.5	17.1	17.0
$Cost_{int}$ ($)	44,205	41,079	39,631	38,562	37,720	36,978

As the results show, the network expansion plan is contrived so that the reliability of the network is improved during planning time horizon and the indices become near to the standard range determined by the regulator.

V. CONCLUSION

Reliability of service has always been one of top priorities for DISCOs. So reliability evaluation is one of the studies must be performed through design and expansion planning of the distribution systems. However as explained in this paper, reliability evaluation of distribution systems during planning studies is faced with some difficulties due to frequent changes of configuration of the network in each iteration of the optimization algorithm. To solve these difficulties, this paper has proposed a systematic method to evaluate the reliability of the distribution network in planning studies. The presented algorithm can be implemented as a subprogram in the comprehensive software of distribution system planning and design.

In the proposed method, the configuration of the network with all related data must first be updated which is done with definition and construction of five matrices at the beginning of the algorithm. These five matrices uniquely determine the configuration of the network. Then in the next stage reliability indices are calculated with a novel approach.

The presented numerical results have been obtained using the proposed method through the five-year planning case study in [5]. Considering the developed multi-stage plan in [5], the accuracy and correctness of the results can be confirmed, if reliability evaluation is done on the planned network in each year with usual methods.

REFERENCES

[1] H. L. Willis, *Power Distribution Planning Reference Book*. 2nd Edition, New York: Marcel Dekker, 2004.

[2] T. Gonen and I. J. Ramirez-Rosado, "Review of Distribution System Planning Models: A Model for Optimal Multistage Planning," *Proc. Inst. Elect. Eng.*, vol. 133, no. 7, pp. 397-408, 1986.

[3] R. Billinton and S. Jonnavithula, "Optimal switching device placement in radial distribution systems," *IEEE Trans. Power Delivery*, vol. 11, no. 3, pp. 1646-1651, 1996.

[4] A. Shahsavari, S. M. Mazhari, A. Fereidunian, and H. Lesani, "Fault Indicator Deployment in Distribution Systems Considering Available Control and Protection Devices: A Multi-Objective Formulation Approach," *IEEE Trans. Power Systems*, vol. 29, no. 5, pp. 2359-2369, Sep. 2014.

[5] S. Heidari, M. Fotuhi-Firuzabad, and S. Kazemi, "Power Distribution Network Expansion Planning Considering Distribution Automation," *IEEE Trans. Power Systems*, vol. 33, no. 3, pp. 1261- 1269, Aug. 2014

[6] R. C. Lotero and J. Contreras, "Distribution System Planning with Reliability," *IEEE Trans. Power. Del.*, vol. 26, no. 4, pp. 2552-2562, 2011.

[7] A. M. Cossi, L. G. W. Da Silva, R. A. R. Lazaro, and J. R. S. Mantovani, "Primary Power Distribution Systems Planning taking into account Reliability, Operation and Expansion Costs," *IET Gener. Transm. Distrib.*, vol. 6, no. 2, pp. 274-284, 2012.

[8] B. R. P. Junior, A. M. Cossi, J. Contreras, and J. R. S. Mantovani, "Multiobjective multistage distribution system planning using tabu search," *IET Gener. Transm. Distrib.*, vol. 8, no. 1, pp. 35-45, 2014.

[9] N. C. Sahoo, S. Ganguly, and D. Das, "Multi-objective planning of electrical distribution systems incorporating sectionalizing switches and tie-lines using particle swarm optimization," *Swarm and Evolutionary Computation*, vol. 3, pp. 15-32, 2012.

[10] A. Samui, S. R. Samantaray, G. Panda, "Distribution system planning considering reliable feeder routing" *IET Gener. Transm. Distrib.*, vol. 6, no. 6, pp. 503-514, 2012.

[11] R. Billinton and R. N. Allan, *Reliability Evaluation of Power Systems*. New York: Plenum Press, 1996.

[12] R. J. Millar, M. Lehtonen, and E. Saarijärvi, "Switch and Reserve Connection Placement in a Distribution Network Planning Algorithm", *IEEE International Conference on Power System Technology (POWERCON)*, 2012.

[13] S. Kazemi, "Reliability Evaluation of Smart Distribution Grids," *Doctoral Dissertation*, Aalto University, 2011.

[14] S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*. 2nd Edition, Prentice Hall, 2003.