Reliability Improvement and Loss Minimization by Optimal Distribution Network Reconfiguration

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***Abstract*—Reliability improvement is a fundamental aspect of modern power distribution systems and smart grids. The optimal distribution network reconfiguration (DNR) has been proven an effective and economic way to improve system's reliability. This paper overcomes the nonlinearity of the DNR problem constraints and thus presents a convex model for optimal DNR with the objective of 1) reliability indices improvement, and 2) power loss minimization. The proposed second-order cone programming based method is tested on a 69-bus distribution system examining different scenarios for the weighting coefficients of the objective function's terms. The obtained results demonstrate the effectiveness and usefulness of the proposed optimization model.**

Keywords—distribution network reconfiguration, mixed integer second-order cone programming, reliability improvement, power loss minimization

NOMENCLATURE

A. Sets

Ω_L	System branches
Ω_{LSW}	System branches with switches
Ω_N	System buses
Ω_{NS}	System substation buses
Ω_Z	System zones
Ω_{ZS}	System substation zones

B. Parameters

c_1, c_2, c_3, c_4	Weighting coefficients
ENS_{max}	Maximum value of ENS
M	Relatively large number
$P_{d,i} / Q_{d,i}$	Load demand at bus $i \in \Omega_N$
R_{ij} / X_{ij}	Impedance of branch $ij \in \Omega_L$
r_{ij} / r_z	Restoration time of branch $ij \in \Omega_L$ or zone $z \in \Omega_Z$
$SAIDI_{max}$	Maximum value of SAIDI
$SAIFI_{max}$	Maximum value of SAIFI
$S_{\max,ij}$	Thermal limit of branch $ij \in \Omega_L$
$TotP_{loss,\max}$	Maximum value of total active power losses
$V_{\min,i} / V_{\max,i}$	Voltage limits of bus $i \in \Omega_N$
$y_{z,k}^{D}$	Artificial demand at zone $z \in \Omega_Z$ for every bus $k \in \Omega_N$
λ_{ij} / λ_z	Annual failure rate of branch $ij \in \Omega_L$ or zone $z \in \Omega_Z$

C. Variables

$AuxV_i^{sqr}$	Voltage auxiliary variable of bus $i \in \Omega_N$
ENS	Energy Not Supplied
I_{ij}^{sqr}	Squared value of current magnitude of branch $ij \in \Omega_L$
λ_k	Annual failure rate of bus $k \in \Omega_N$
P_{ij} / Q_{ij}	Power flows of branch $ij \in \Omega_L$
$P_{loss,i} / Q_{loss,i}$	Power losses associated variable of bus $i \in \Omega_N$
$P_{ss,i} / Q_{ss,i}$	Apparent power supplied from substation bus $i \in \Omega_{NS}$
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
U_k	Annual duration of interruptions at bus $k \in \Omega_N$
V_i^{sqr}	Squared value of voltage magnitude of bus $i \in \Omega_N$
$y_{ij,k}$	Artificial flow through switch $ij \in \Omega_{LS}$ for every bus $k \in \Omega_N$
$y_{ij,k}^{+}, y_{ij,k}^{-}$	Artificial flow auxiliary variables
$y_{z,k}^{S}$	Artificial generation at substation zone $z \in \Omega_{ZS}$ for every bus $k \in \Omega_N$

D. Binary Variables

sw_{ij}	Status of system switches; it takes the value 1 if switch $ij \in \Omega_{LS}$ is closed and 0 if it is open
rd_{ij}	Variable associated with system radiality; it takes the value 1 if bus $i \in \Omega_N$ is parent of bus $j \in \Omega_N$ and 0 otherwise
$up_{z,k}$	Upstream path variable; it takes the value 1 if zone $z \in \Omega_Z$ is part of the upstream path of bus $k \in \Omega_N$ and 0 otherwise.

I. INTRODUCTION

In power distribution systems, active power losses and reliability are the major factors indicating the performance of the system. The reliability of a power system is described as the ability of the system to supply customers continuously with acceptable quality [1]. Since reliability is directly related to the level of customer satisfaction, reliability analysis of distribution systems is one of the prominent areas in electric power industry. Moreover, the level of power losses and number of failures are significantly high in the distribution networks. As a result, the main goal of distribution system operators is to reduce power losses and customer interruptions in order to achieve optimal utilization of the distribution network. To ensure system's sufficient performance, the accurate evaluation of appropriate reliability indices is critical.

Distribution network reconfiguration (DNR) plays a vital role to improve system's reliability without any extra cost. DNR can be defined as the procedure of changing the topology of the system by using the available switching devices. For each possible topology, all the operational constraints should be satisfied. Distribution networks are constructed as meshed networks but are operated in radial configuration to simplify their protection scheme and curtail short circuit current. Therefore, the goal of DNR is to find a radial topology that optimizes a specific objective function whilst satisfying operational constraints. Apart from preserving the bus voltages within acceptable limits and reducing the active power losses, adequate levels of reliability must also be ensured. For this reason, the objective function of the DNR problem should provide a balance between active power losses and system's reliability, since both of them are quite important for the distribution system operators. As a result, operational and reliability objectives, such as active power losses, system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI) and energy not supplied (ENS) should be included. The calculation of reliability indices (*SAIFI*, *SAIDI* and *ENS*) is based on the values of failure rate $\left(\lambda_{ij}\right)$ and restoration time $\left(r_{ij}\right)$ of system's branches, which are directly related to the network's topology. Therefore, DNR is considered as a critical strategy to improve reliability of power distribution systems.

Many researchers have adopted DNR strategy in order to achieve reliability improvement. However, most of the proposed optimization models implement heuristic or meta-heuristic algorithms, taking advantage of their simplicity in order to deal with the nonlinearity and complexity of the DNR problem. More specifically, evolutionary algorithms in [2]–[3], a fuzzy algorithm in [4], binary particle-swarm optimization in [5], quantum firefly algorithm in [6], binary gravitational search algorithm in [7], enhanced gravitational search algorithm in [8], clonal selection algorithm in [9], and genetic algorithms in [10]–[14] have been investigated. However, the aforementioned heuristic and meta-heuristic methods do not ensure optimality of the final solution. On the contrary, in case of convex mathematical programming models, convergence to optimality is guaranteed.

The present paper proposes a multi-objective optimization model for DNR, which simultaneously minimizes active power losses and improves system's reliability. A mixed-integer second-order cone programming (MISOCP) model is proposed, which transforms the original mixed integer nonlinear programming (MINLP) formulation of the optimal DNR problem into a convex optimization model. Therefore, the proposed model, the control variables of which are the statuses of the network's switches, can easily be solved by classic optimization techniques.

The main contributions of this paper are as follows:

- The use of a MISOCP formulation for the reconfiguration problem makes the proposed method flexible and precise, as well as it ensures optimality by using commercial optimization solvers.
- The multi-objective model allows investigating the trade-off between active power losses and reliability indices by considering various scenarios for the weighting coefficients of the objective function.

The rest of the paper is organized as follows. Section II presents the problem formulation, including the objective function, the operational and the reliability constraints. Section III presents the 69-bus test system and discusses the obtained results. Section IV concludes the paper.

II. PROBLEM FORMULATION

This section presents the objective function, as well as the operational and reliability constraints of the proposed method.

A. Objective function

The optimization model for both active power loss minimization and reliability indices improvement is formulated as follows:

$$min\, f = \sum_{t=1}^{4} f_t \tag{1}$$

where

$$f_1 = c_1 \cdot \frac{\sum_{i \in \Omega_N} P_{loss,i}}{TotP_{loss,max}} \tag{2}$$

$$f_2 = c_2 \cdot \frac{SAIFI}{SAIFI_{max}} \tag{3}$$

$$f_3 = c_3 \cdot \frac{SAIDI}{SAIDI_{max}} \tag{4}$$

$$f_4 = c_4 \cdot \frac{ENS}{ENS_{max}} \tag{5}$$

The objective function includes multiple objectives. The first objective reduces network's active power losses. The second and third objective minimizes *SAIFI* and *SAIDI*, respectively. The fourth objective minimizes *ENS*. The values of the weighting factors are selected according to the importance and hierarchy of each objective. The objectives are normalized so that their magnitudes become comparable. By varying the weighting coefficients c_1, c_2, c_3 and c_4, the objective function can be optimized with different priorities for total active power losses and reliability indices.

B. Operational constraints

The proposed optimization method is based on the convex relaxations of the *DistFlow* equations presented in [15]–[16]. The set of system's operational constraints is presented below:

$$\sum_{j \in \Omega_N} \left(P_{ji} - P_{ij}\right) + P_{ss,i} = P_{loss,i} + P_{d,i} \quad \forall i \in \Omega_N \tag{6}$$

$$\sum_{j \in \Omega_N} \left(Q_{ji} - Q_{ij}\right) + Q_{ss,i} = Q_{loss,i} + Q_{d,i} \quad \forall i \in \Omega_N \tag{7}$$

$$-M \cdot rd_{ij} \le P_{ij} \le M \cdot rd_{ij} \quad \forall ij \in \Omega_L \tag{8}$$

$$-M \cdot rd_{ij} \le Q_{ij} \le M \cdot rd_{ij} \quad \forall ij \in \Omega_L \tag{9}$$

$$V_i^{sqr} \le V_j^{sqr} - 2 \cdot \left(R_{ij} \cdot P_{ji} + X_{ij} \cdot Q_{ji}\right) - M \cdot \left(1 - rd_{ji}\right) \; \forall ij \in \Omega_L \tag{10}$$

$$V_i^{sqr} \ge V_j^{sqr} - 2 \cdot \left(R_{ij} \cdot P_{ji} + X_{ij} \cdot Q_{ji}\right) + M \cdot \left(1 - rd_{ji}\right) \; \forall ij \in \Omega_L \tag{11}$$

$$AuxV_i^{sqr} \cdot P_{loss,i} \geq R_{ij} \cdot \left(P_{ji}^2 + Q_{ji}^2\right) \ \forall ij \in \Omega_L \tag{12}$$

$$AuxV_i^{sqr} \cdot Q_{loss,i} \geq X_{ij} \cdot \left(P_{ji}^2 + Q_{ji}^2\right) \ \forall ij \in \Omega_L \tag{13}$$

$$AuxV_i^{sqr} \leq V_j^{sqr} + M \cdot \left(1 - rd_{ji}\right) \ \forall ij \in \Omega_L \tag{14}$$

$$AuxV_i^{sqr} \geq V_j^{sqr} - M \cdot \left(1 - rd_{ji}\right) \ \forall ij \in \Omega_L \tag{15}$$

$$V_{\min,i}^2 \leq V_i^{sqr} \leq V_{\max,i}^2 \ \ \forall i \in \Omega_N \tag{16}$$

$$P_{ss\min,i} \leq P_{ss,i} \leq P_{ss\max,i} \ \ \forall i \in \Omega_N \tag{17}$$

$$Q_{ss\min,i} \leq Q_{ss,i} \leq Q_{ss\max,i} \ \ \forall i \in \Omega_N \tag{18}$$

$$P_{ij}^2 + Q_{ij}^2 \leq S_{\max,ij} \ \ \forall ij \in \Omega_L \tag{19}$$

$$rd_{ij} + rd_{ji} = 1 \ \ \forall ij \in \Omega_L \setminus \Omega_{LSW} \tag{20}$$

$$rd_{ij} + rd_{ji} = sw_{ij} \ \ \forall ij \in \Omega_{LSW} \tag{21}$$

$$\sum_{j \in \Omega_N} rd_{ij} = 1 \ \ \forall i \in \Omega_N \setminus \Omega_{NS} \tag{22}$$

$$rd_{ji} = 0 \ \ \forall i \in \Omega_{NS} \tag{23}$$

Power balance equations for every bus are presented in (6) and (7). The variable rd_{ij} is associated with the network radiality condition. If bus *i* is the parent of bus *j*, then $rd_{ij} = 1$. Otherwise rd_{ij} is equal to 0, and so do the active and reactive power flows, as shown in (8) and (9). In case buses *i* and *j* are connected, equations (10) and (11) calculate the voltage drop between them. The combination of (12), (14) and (15) provides the active power loss on the branch connecting buses *i* and *j*, while (13)–(15) provide the reactive power loss, respectively. The voltage magnitude limits are given by (16). The capacity limits of the substation and the thermal limits of every branch are given by (17)–(19). The radiality of the network topology is guaranteed by (20)–(23). Equations (20) and (21) ensure that if branch *i–j* is part of the supplied network (either because there is no switch in that branch or there is switch which is closed, respectively) bus *i* will be the parent of bus *j* ($rd_{ij} = 1$) or the opposite ($rd_{ji} = 1$). Equations (22)–(23) guarantee that every bus has only one parent, except from the substation, which cannot have parents.

C. *Reliability constraints*

The formulation used to evaluate system's reliability is based on [17] and it is as follows:

$$\sum_{\substack{ji \in \Omega_{LSW} \\ z_i = z}} y_{ji,k} - \sum_{\substack{ij \in \Omega_{LSW} \\ z_i = z}} y_{ij,k} + y_{z,k}^S = y_{z,k}^D \ \ \forall k \in \Omega_N, \forall z \in \Omega_Z \tag{24}$$

$$| y_{ij,k} | \leq sw_{ij} \ \ \forall ij \in \Omega_{LSW}, \forall k \in \Omega_N \tag{25}$$

$$up_{z_j,k} \geq | y_{ij,k} | \ \forall ij \in \Omega_{LSW}, \forall k \in \Omega_N \tag{26}$$

$$up_{z_i,k} \geq | y_{ij,k} | \ \forall ij \in \Omega_{LSW}, \forall k \in \Omega_N \tag{27}$$

$$up_{z,k} \leq \sum_{\substack{ij \in \Omega_{LSW} \\ z_i = z}} \left| y_{ij,k} \right| + \sum_{\substack{ji \in \Omega_{LSW} \\ z_i = z}} \left| y_{ji,k} \right| \ \forall k \in \Omega_N, \forall z \in \Omega_Z \tag{28}$$

$$\lambda_k = \sum_{z \in \Omega_Z \setminus \Omega_{ZS}} \left(up_{z,k} \cdot \lambda_z \right) \ \forall k \in \Omega_N \setminus \Omega_{NS} \tag{29}$$

$$U_k = \sum_{z \in \Omega_Z \setminus \Omega_{ZS}} \left(up_{z,k} \cdot \lambda_z \cdot r_z \right) \ \forall k \in \Omega_N \setminus \Omega_{NS} \tag{30}$$

$$SAIFI = \frac{\sum_{k \in \Omega_N \setminus \Omega_{NS}} \left(N_k \cdot \lambda_k \right)}{\sum_{k \in \Omega_N \setminus \Omega_{NS}} N_k} \tag{31}$$

$$SAIDI = \frac{\sum_{k \in \Omega_N \setminus \Omega_{NS}} \left(N_k \cdot U_k \right)}{\sum_{k \in \Omega_N \setminus \Omega_{NS}} N_k} \tag{32}$$

$$ENS = \sum_{k \in \Omega_N \setminus \Omega_{NS}} \left(P_{d,k} \cdot U_k \right) \tag{33}$$

$$SAIFI \leq SAIFI_{\max} \tag{34}$$

$$SAIDI \leq SAIDI_{\max} \tag{35}$$

$$ENS \leq ENS_{\max} \tag{36}$$

The formulation that identifies the upstream path of each bus *k* by using an artificial flow between system zones and switches is presented in (24). Constraint (25) associates the artificial flow $y_{ij,k}$ to the status of the switch sw_{ij} . If switch *i–j* is open ($sw_{ij} = 0$), then $y_{ij,k} = 0$; otherwise, constraint (25) allows the artificial flow $y_{ij,k}$ to take nonzero value. Equations (26)–(28) determine the zones that form the upstream path of every bus *k* to the substation. If switch *i–j* is part of the upstream path of bus *k* ($y_{ij,k} \neq 0$), then $up_{z_i,k} = up_{z_j,k} = 1$. In constraints (24)–(28), $y_{ij,k}$ can be replaced by $y_{ij,k}^+ - y_{ij,k}^-$ and $\left| y_{ij,k} \right|$ by $y_{ij,k}^+ + y_{ij,k}^-$, so as to preserve the linearity of the equation system. The annual failure rate (λ_k) and the annual duration of interruptions (U_k) of each bus *k* are given by (29) and (30). Since λ_k and U_k have been evaluated, the reliability indices *SAIFI*, *SAIDI* and *ENS* can be calculated by (31)–(33). Constraints (34)–(36) should be added to the proposed model in order to ensure that *SAIFI*, *SAIDI* and *ENS* cannot violate their maximum values. Moreover, since a bus can possibly have multiple paths to the source, as the network size grows, the number of paths to be considered will become quite large. As a result, tight bounds on *SAIFI*, *SAIDI* and *ENS* can decrease the computational effort needed by excluding paths that violate the reliability indices limits.

The original optimal DNR model is a non-convex MINLP problem, which is difficult to be solved by most optimization tools. However, the proposed DNR model represented by (6)–(23) is convex. The system of reliability equations in (24)–(36) is a mixed-integer linear equation system. As a result, the new reliability-oriented DNR model represented by (6)–(36) is a MISOCP problem that can be solved by commercial solvers, such as CPLEX.

III. RESULTS AND DISCUSSION

The proposed methodology is applied to a 69-bus system, shown in Fig. 1. It is an 11 kV system, with one substation zone (Z1), 15 load zones (Z2–Z16), and 21 switching devices interconnecting all the different zones. The voltage limits of system buses are considered ±5% of the nominal voltage, the capacity of substation is 5 MVA and the thermal limit of each branch is 1 MVA. The parameter *M* is taken as 10. The average failure rate and restoration time of each branch are equal to 0.1 faults/year and 2 h, respectively.

A. Pre-processing procedure

Before applying the proposed method in the 69-bus distribution system, some parameters need to be evaluated, according to the following three steps:

1st: The set of zones in which the 69-bus system is divided must be defined (Ω_Z). The zones are determined as the parts of the network in which all bus are separated by the switching devices, as shown in Fig. 1.

2nd: The parameters of failure rate λ_z and restoration time r_z of all system load zones must be evaluated as follows:

$$\lambda_z = \sum_{ij\in\Omega_{L_z}} \lambda_{ij} \quad \forall z \in \Omega_Z \setminus \Omega_{ZS} \tag{37}$$

$$r_z = \frac{\sum_{ij\in\Omega_{L_z}} r_{ij}}{\left|\Omega_{L_z}\right|} \quad \forall z \in \Omega_Z \setminus \Omega_{ZS} \tag{38}$$

3rd: The maximum values $TotP_{loss,max}$, $SAIFI_{max}$, $SAIDI_{max}$, and ENS_{max} used in the objective function must be evaluated. $SAIFI_{max}$, $SAIDI_{max}$ and ENS_{max} are considered the values of *SAIFI*, *SAIDI* and *ENS*, respectively, as calculated by solving the optimization problem of (6)–(33) only with the objective of minimizing the active power losses. The optimization problem with the objective of minimizing any of *SAIFI*, *SAIDI* or *ENS* leads to the same system topology and as a result to the same values for both power losses and reliability indices. Therefore, $TotP_{loss,max}$ is considered as the value of total active power losses of the network, as calculated by solving the optimization problem of (6)–(33) with the objective of minimizing any of *SAIFI*, *SAIDI* and *ENS* separately.

Tables I and II present the values of the parameters that are calculated with the above three-step procedure.

TABLE I. AVERAGE FAILURE RATE AND RESTORATION TIME OF EACH LOAD ZONE

Load zone	λ_z (faults/year)	r_z (h)	Load zone	λ_z (faults/year)	r_z (h)
Z2	0.6	2	**Z10**	0.2	2
Z3	0.6	2	**Z11**	0.3	2
Z4	0.5	2	**Z12**	0.5	2
Z5	0.7	2	**Z13**	0.3	2
Z6	0.1	2	**Z14**	0.1	2
Z7	0.1	2	**Z15**	0.2	2
Z8	0.4	2	**Z16**	0.5	2
Z9	0.2	2			

TABLE II. MAXIMUM VALUES OF ACTIVE POWER LOSSES AND RELIABILITY INDICES

$TotP_{loss,max}$ (kW)	304.74
$SAIFI_{max}$ (faults/year)	2.08
$SAIDI_{max}$ (h/year)	4.17
ENS_{max} (kWh/year)	1852.17

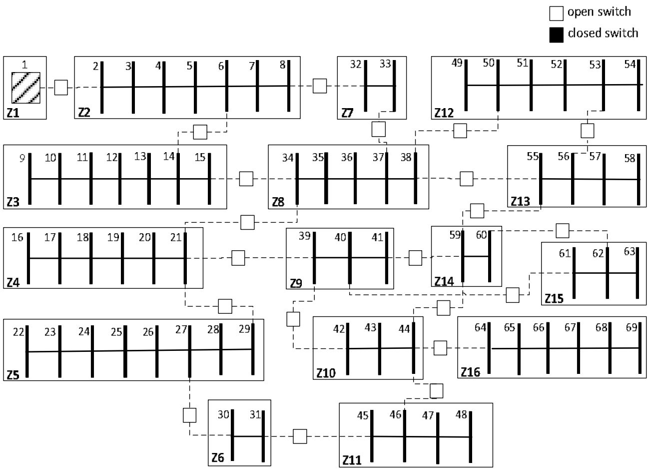

Fig. 1. Initial topology of 69-bus system

B. Results of the 69-bus system

In order to indicate the accuracy and usefulness of the proposed methodology, three scenarios for different values of weighting coefficients of objective function have been examined, as shown in Table III. Scenario A is considered as the base scenario, since all the weighting coefficients are equal to 1, and as a result no priority is given in any term of the objective function. In Scenario B, the weighting coefficient c_1 is equal to 100, while all the other weighting coefficients are equal to 1, in order to give higher priority to the first term of the objection function, which minimizes the active power losses. In Scenario C, the weighting coefficients c_2, c_3 and c_4 are equal to 100, while c_1 is equal to 1, and as a result priority is given to the second, third and fourth term of the objective function, which aim to the improvement of the reliability indices. The weighting coefficients of reliability indices (c_2, c_3 and c_4) are assumed to have the same values in all scenarios, since they are all referred to the reliability-oriented terms of the objective function. The values of the weighting coefficients are selected by the decision-makers based on their experience, by giving clear priority to the desired criterion in each case.

The results of the proposed method for the three scenarios considered are shown in Table IV. For each scenario, the appropriate switching actions and the upstream paths determined by the proposed method are presented. Moreover, the total active power losses of the 69-bus system, as well as the reliability indices of *SAIFI*, *SAIDI* and *ENS* for each scenario are calculated. In Fig. 2, the percentage difference of total active power losses and reliability indices for scenarios B and C, in compare with the base scenario A, are presented. The final topology of the 69-bus system for each scenario is presented in Figs. 3–5.

TABLE III. SCENARIOS CONSIDERED

Scenario	c_1	c_2	c_3	c_4
A	1	1	1	1
B	100	1	1	1
C	1	100	100	100

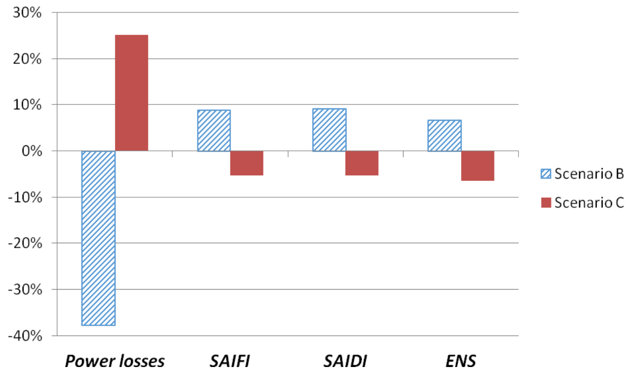

Fig. 2. Percentage difference of power losses and reliability indices of scenarios B and C in compare with base case scenario A

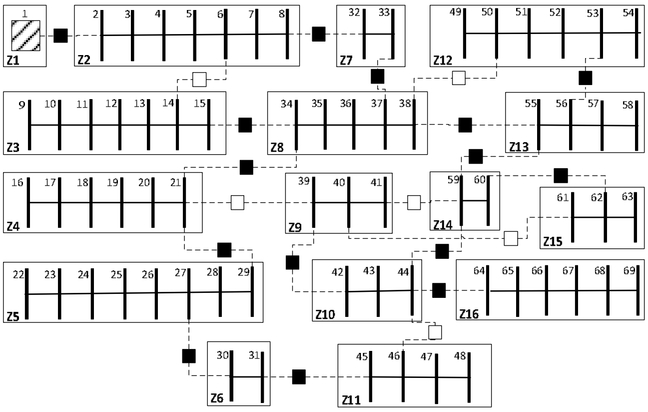

Fig. 3. Final topology of 69-bus system for scenario A

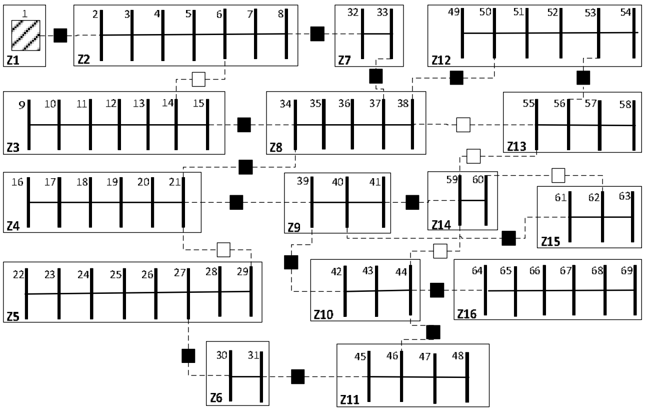

Fig. 4. Final topology of 69-bus system for scenario B

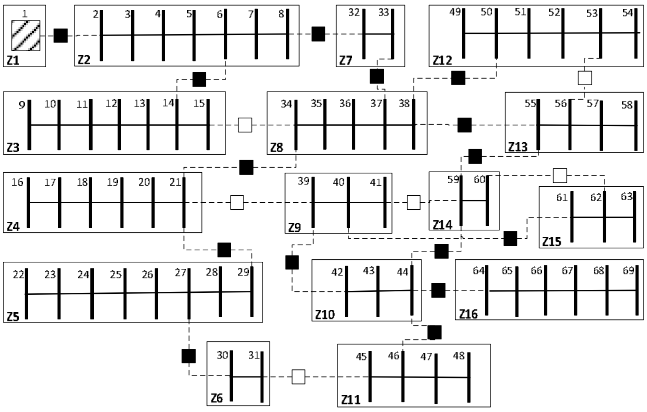

Fig. 5. Final topology of 69-bus system for scenario C

TABLE IV. RESULTS FOR THE THREE DIFFERENT SCENARIOS

Results	**Scenario**		
	A	**B**	**C**
Switches closed	1-2, 8-32, 21-34, 27-30, 33-37, 39-42, 44-64		
	15-34, 21-29, 31-45, 38-55, 44-59, 53-56, 55-59, 60-62	15-34, 21-39, 31-45, 38-50, 40-61, 41-59, 44-46, 53-56	6-14, 21-29, 38-50, 38-55, 40-61, 44-46, 44-59, 55-59
Upstream paths	Z1-Z2-Z7-Z8-Z3	Z1-Z2-Z7-Z8-Z3	Z1-Z2-Z3
	Z1-Z2-Z7-Z8-Z4-Z5-Z6-Z11-	Z1-Z2-Z7-Z8-Z4-Z9-Z10-Z11-Z6-Z5	Z1-Z2-Z7-Z8-Z4-Z5-Z6
	Z1-Z2-Z7-Z8-Z13-Z12	Z1-Z2-Z7-Z8-Z4-Z9-Z10-Z16	Z1-Z2-Z7-Z8-Z12
	Z1-Z2-Z7-Z8-Z13-Z14-Z10-Z9	Z1-Z2-Z7-Z8-Z4-Z9-Z14	Z1-Z2-Z7-Z8-Z13-Z14-Z10-Z9-Z15
	Z1-Z2-Z7-Z8-Z13-Z14-Z10-Z16	Z1-Z2-Z7-Z8-Z4-Z9-Z15	Z1-Z2-Z7-Z8-Z13-Z14-Z10-Z11
	Z1-Z2-Z7-Z8-Z13-Z14–Z15	Z1-Z2-Z7-Z8-Z12-Z13	Z1-Z2-Z7-Z8-Z13-Z14-Z10-Z16
$TotP_{loss}$ (kW)	79.63	49.63	99.63
***SAIFI* (faults/year)**	1.70	1.85	1.61
***SAIDI* (h/year)**	3.40	3.71	3.22
***ENS* (kWh/year)**	1500.09	1600.34	1402.45

C. Discussion

As is shown in Table IV, in all three scenarios, fifteen out of twenty-one switching devices of the 69-bus system are being closed in the final topology determined by the proposed model. Seven of them are the same in all three scenarios. The different final topology of the 69-bus system in each scenario is responsible for the minimization of total active power losses or the improvement of the reliability indices of the system. In all three scenarios, six upstream paths are determined by the proposed model, in which the calculation of the reliability indices is mainly based.

In scenario B, where the priority was given to the minimization of system's total active power losses, $TotP_{loss}$ was decreased from 79.63 kW to 49.63 kW, which is a 37.7% reduction in compare with the base scenario A, validating the sufficiency of the proposed method. On the other hand, the reliability indices of *SAIFI*, *SAIDI* and *ENS* were increased by 8.8%, 9.1% and 6.7%, respectively.

As far as scenario C is concerned, where the weighting coefficients of the reliability-oriented terms of the objective function were increased, the results demonstrate the effectiveness of the proposed method in the field of system's reliability improvement. More specifically, SAIFI was decreased from 1.7 faults/year to 1.61 faults/year; SAIDI was reduced from 3.4 h/year to 3.22 h/year; and ENS was decreased from 1500.09 kWh/year to 1402.45 kWh/year, in compare with the base scenario A. In other words, SAIFI, SAIDI and ENS were decreased by 5.3%, 5.3% and 6.5%, respectively. Moreover, in scenario C, the total active power losses of the 69-bus system were increased in compare with the base scenario by 25.1%.

As a result, the proposed method can provide the proper reconfiguration solution depending on if reliability or power losses or a trade-off between them is desired. Distribution system operators can choose the weighting coefficients in such a way in order to align with characteristics and priorities for specific distribution systems.

IV. CONCLUSION

The reliability issues of power systems are quite serious, especially in the context of deregulated electricity markets. High reliability levels both increase customer satisfaction and improve the economic benefits of electricity suppliers. The two aspects of power losses and reliability often conflict and present distribution system operators with a wide range of challenging problems. Therefore, it is vital in the distribution system operation to determine that network configuration that provides at the same time minimum power losses and adequate reliability level.

The present paper introduces a convex optimization model for DNR aiming to improve system's reliability and minimize total active power losses. The proposed MISOCP model is tested on a 69-bus system in order to indicate its usefulness and effectiveness. Different scenarios for the weighting coefficients of objective function terms are considered and the obtained results are discussed. The presented methodology is able to determine that network's topology, which satisfies most the term of the objective function to which more priority is given. The obtained results established that there is a trade-off condition between minimization of active power losses and reliability improvement. Therefore, the presented model can indicate to the decision maker the most desired system topology among a set of possible solutions according to his requirements. Taking into account that reliability is considered as practical operating constraints, the proposed reliability-oriented DNR method can play a vital role at the distribution management system.

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