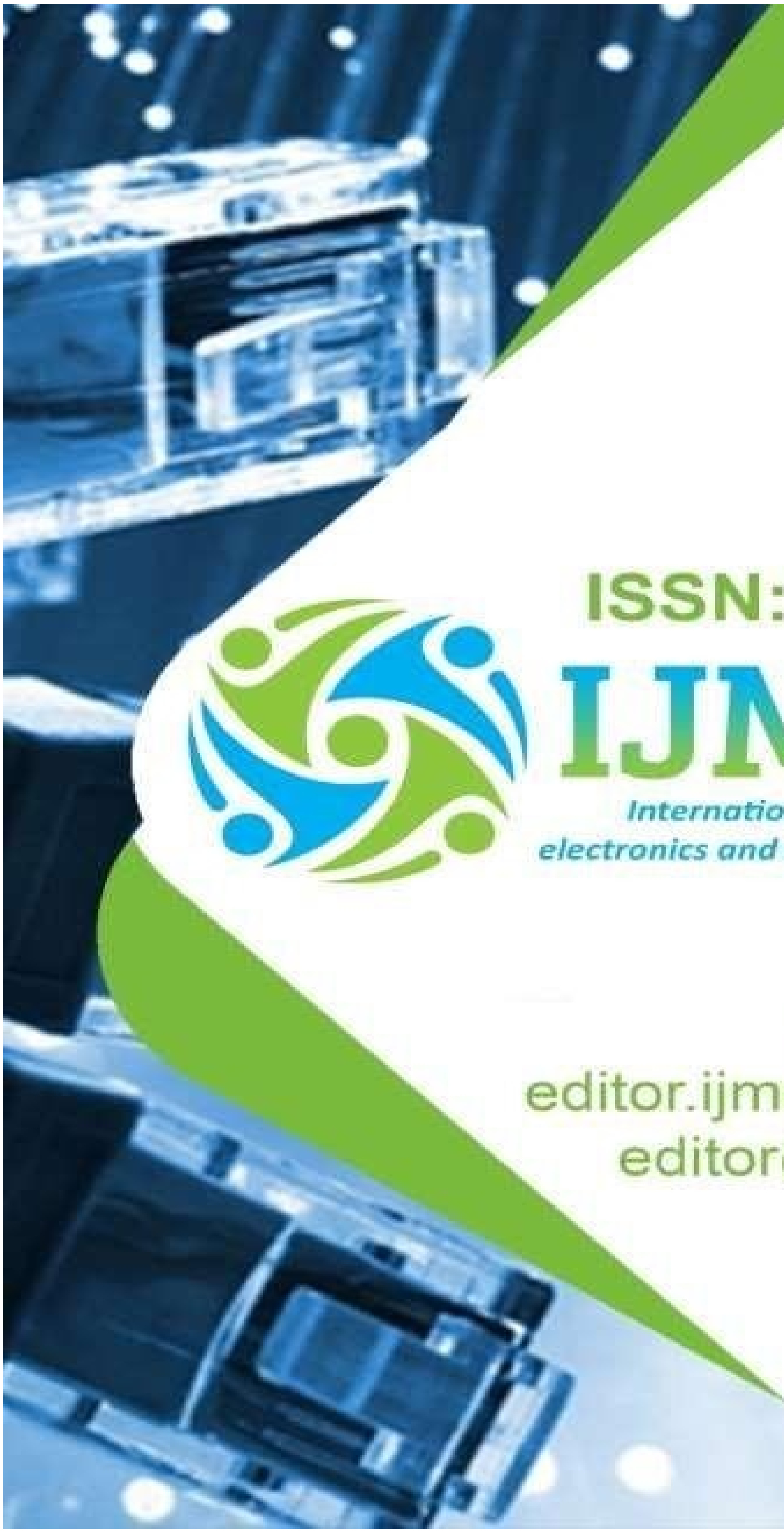

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Efficient Distribution Network Reconfiguration for Enhanced Reliability and Reduced Losses

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***Abstract*— Distribution networks are typically designed with a loop structure but are operated as radial networks to prevent circulating currents and improve stability. The placement of Normally Open (NO) switches plays a crucial role in achieving optimal operation, traditionally focusing on either minimizing real power losses or maximizing reliability. However, a more effective approach considers both objectives simultaneously. This paper presents a mathematical model to determine the optimal configuration of NO switches, balancing network losses and service reliability. The proposed multi-objective model employs a weighted sum approach to combine these objectives into a single-objective optimization problem. Formulated as a Mixed Integer Quadratically Constrained Programming (MIQCP) problem, the model ensures efficient and accurate solutions. Its effectiveness is demonstrated through various scenarios and sensitivity analyses conducted on a real Finnish distribution network, highlighting its practical applicability and robustness.**

***Keywords*— Distribution network; reconfiguration; reliability;network loss; switch deployment**

I. INTRODUCTION (*HEADING 1*)

Optimal distribution network reconfiguration is modeled as a combinatorial optimization problem, aiming to transform a loop-structured network into a radial configuration. Various objective functions have been explored in the literature, including minimizing active power losses, improving voltage profiles, and enhancing reliability. Numerous heuristic algorithms and mathematical approaches have been applied to tackle this problem. For example, [1] employed the Harmony Search Algorithm (HSA) to identify the optimal switching configuration, achieving reduced network losses and improved voltage profiles. In [2], two approximated power flow methods were used to derive general solutions for reconfiguration, targeting loss reduction and load balancing. [3] introduced a heuristic algorithm leveraging convex relaxation of AC Optimal Power Flow (OPF) to minimize network losses. Meanwhile, [4] proposed a distributed control strategy to manage the open and closed states of tie-switches for network reconfiguration.

In [5], a modified Simulated Annealing (SA) technique was employed to address the reconfiguration problem, minimizing network losses calculated using approximated line flow equations. Similarly, [6] introduced the Variable Scaling Hybrid Differential Evolution (VSHDE) algorithm to solve the reconfiguration problem, aiming to minimize network losses and improve the voltage profile. A fuzzy multi-objective algorithm was proposed in [7], considering objectives such as load balancing, network loss minimization, and voltage profile improvement. In [8], Artificial Neural Networks (ANN) were utilized to solve the problem with a focus on minimizing network losses.

A Mixed Integer Nonlinear Programming (MINLP) model was introduced in [9] to optimize the open/closed status of switches for network loss reduction. In [10], a two-stage robust optimization model was proposed, with the first stage reconfiguring the network into radial feeders and the second stage determining the optimal AC power flow for the reconfigured network. A heuristic two-stage method was also presented in [11], using loss sensitivity relative to candidate branch impedance to minimize network losses.

In [12], meta-heuristic Harmony Search was applied to reconfigure distribution networks with distributed generation (DG), reducing network losses and improving voltage profiles. Transformer utilization in a two-transformer substation was enhanced in [13] by incorporating reconfiguration under a single contingency policy (SCP). The value of real-time reconfiguration in the presence of renewable energy resources was explored in [14].

Additionally, [15]-[16] implemented an enhanced genetic algorithm and a clonal selection algorithm, respectively, to identify radial configurations that balance network losses and reliability. Lastly, [17]-[18] tackled the reconfiguration problem using a multi-objective Improved Shuffled Frog Leaping Algorithm (ISFLA) and Binary Particle Swarm Optimization (BPSO), demonstrating their efficacy in optimizing network configurations. In [19], the authors proposed a Mixed Integer Linear Programming (MILP) model to optimally integrate Remote Controlled Switches (RCSs) into distribution networks. Building on this, [20] examined the financial risks associated with RCS placement, accounting for uncertainties in system parameters. Furthermore, [21]-[22] analyzed the effects of RCS malfunctions on overall system reliability.

While these studies offer valuable approaches to address the reconfiguration problem, no mathematical model has been developed that achieves a global optimum while simultaneously considering both reliability and network losses. To address this gap, this paper introduces a Mixed

Integer Quadratically Constrained Programming (MIQCP) model for optimal distribution network configuration. The proposed model determines the optimal placement of Normally Open (NO) switches to maximize reliability and minimize network losses. Reliability is quantified using the Expected Energy Not Supplied (EENS) index, a widely accepted and practical metric for reliability evaluation. The two objectives were integrated into a single objective using the weighted sum algorithm, allowing distribution companies to prioritize between reliability and loss reduction based on their operational goals. The inclusion of a weighting factor provides flexibility in assigning relative importance to each objective. Notably, the proposed model is computationally efficient and can be solved within an effective runtime.

II. Problem Description

Reconfiguration in distribution networks is a critical challenge faced by operators. The need for radial operation in loop-structured distribution networks necessitates the strategic placement of Normally Open (NO) switches to address various objectives. Since distribution network losses are substantial, operators typically position NO switches to minimize these losses. However, network configuration also significantly impacts service reliability. Therefore, optimizing network configuration requires a careful consideration of both key performance indices: network losses and service reliability.

In such scenarios, distribution companies must strike a tradeoff between these objectives. The prioritization of loss reduction versus reliability enhancement varies across networks and is influenced by factors such as the types of customers served, their sensitivity to service interruptions, voltage levels, and feeder lengths, all of which affect network losses. Focusing solely on loss reduction in reconfiguration may lead to reliability compromises, while optimizing for reliability without addressing losses can result in increased operational costs due to higher losses. Balancing these objectives is essential for efficient and reliable network operation.

III. Mathematical Model

This section presents the mathematical model for optimal NO switch allocation in distribution networks. First, a representative distribution network is introduced to provide context for the model. Next, the mathematical formulations for evaluating the objective functions—namely service reliability and network losses—are outlined. Finally, the methodology for determining the optimal location of NO switches is described.

To ensure clarity, a representative loop-structured distribution network is depicted in Fig. 1. In loop-structured networks, each load point can be fed from two sources—in this case, Substation 1 and Substation 2. To convert the loop-structured network into two radial feeders, a NO switch must be installed in one of the odd-numbered sections.

A. Service Reliability Evaluation

In this paper, the Expected Energy Not Supplied (EENS) is chosen as the reliability index. EENS quantifies the amount of energy (in MWhr/year) not delivered to consumers due to potential contingencies. It is widely recognized as a practical and effective metric for assessing reliability in distribution networks. The Index can be formulated as follows:

$$EENS = \sum_i \sum_j \lambda_i \, r_i \, L_j \qquad (1)$$

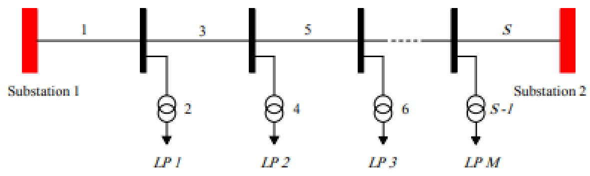

Fig. 1. A typical loop-structured distribution network

Where λi and ri represent the failure rate (occurrences per year) and repair time (in hours) of section i, respectively. It is important to note that in the method proposed in this paper, faults can occur not only in the lines between nodes but also in transformers within the lateral sections that supply load points.

The load level of load point j, denoted as Lj, is measured in megawatts (MW). If section i and load point j are physically connected, the impact of a failure in section i must be accounted for when calculating the Expected Energy Not Supplied (EENS) for load point j.

B. Network Losses Evaluation

To formulate network losses, highly nonlinear AC power flow equations are typically required. However, to simplify the computation and avoid these complexities, the power demands at load points are modeled as constant-current, constant-power-factor loads. Under this assumption, the current at each load point can be calculated using the following expression:

$$I_j = \frac{D_j}{V_j} \qquad (2)$$

Where Vj represents the voltage at load point j and Dj and Ij represent the load level and current at load point j, respectively. With the load points absorbing current, the active power losses in the network can be calculated by summing the active losses across all sections, as expressed in the following formula:

$$Network\ Loss = 3 \sum_{i=1|Odd} R_i \, {I_i^{line}}^2 + 3 \sum_{i=1|Even} R_i \, {I_i^{line}}^2 \qquad (3)$$

Where Ri and Ii represent the resistance (in ohms) and current (in amperes) of line i, respectively. The first term in equation (3) represents the effective active power loss in the main feeder, which varies depending on the location of the NO switch. The second term in equation (3) accounts for the loss in the laterals, which is a constant term and does not change with the NO switch location. Since the second term is constant and does not affect the optimization solution, it is excluded from the main optimization process. Therefore, for the remainder of the manuscript, only the first term of equation (3) is considered as the network loss.

C. Proposed Methodology

As shown in Fig. 1, the sections are numbered from 1 to S, with odd numbers assigned to the main sections and even numbers allocated to the lateral sections. Additionally, all parameters related to network data (such as failure rate, repair time, load point, section resistance, etc.) and variables (such as the location of NO switches) are defined for both the forward and backward directions.

The forward direction starts from Substation 1 and ends at Substation 2, while the backward direction begins at Substation 2 and ends at Substation 1. Therefore, the first value of any parameter defined in the forward direction is equal to the last value of the same parameter in the backward direction.

These relationships can be mathematically expressed as follows:

$$\lambda_i^f = \lambda_{S-i+1}^b \quad (4)$$

$$r_i^f = r_{S-i+1}^b \quad (5)$$

$$R_i^f = R_{S-i+1}^b \quad (6)$$

$$L_j^f = L_{M-j+1}^b \quad (7)$$

$$I_j^f = I_{M-j+1}^b \quad (8)$$

Where λ_i^f and λ_i^b represent the failure rates in the forward and backward directions, respectively. r_i^f and r_i^b are the repair times in the forward and backward directions, while R_i^f and R_i^b denote the resistance of the main section i in the forward and backward directions. Similarly, L_j^f and L_j^b represent the load levels at load point j in the forward and backward directions. I_j^f and I_j^b indicate the current at load point j in the forward and backward directions, respectively.

Using these parameters, the reliability index can be formulated as follows

$$EENS = \sum_i \sum_j b_{i,j}^f \lambda_i^f r_i^f L_j^f + \sum_i \sum_j b_{i,j}^b \lambda_i^b r_i^b L_j^b \quad (9)$$

subject to::

$$b_{i+1,j}^f \le b_{i,j}^f \quad \forall i \le S-1 \quad (10)$$

$$b_{i+1,j}^b \le b_{i,j}^b \quad \forall i \le S-1 \quad (11)$$

$$b_{i,j+1}^f \le b_{i,j}^f \quad \forall j \le M-1 \quad (12)$$

$$b_{i,j+1}^b \le b_{i,j}^b \quad \forall j \le M-1 \quad (13)$$

$$\sum_i \sum_j b_{i,j}^f + b_{i,j}^b = M \quad \forall j \le M-1 \quad (14)$$

The power loss in the network can be formulated as follows:

$$Loss = 3 \sum_{i=1|Odd}^{S} R_i^f \Big(\sum_{j=\frac{i+1}{2}}^{M} b_{i,j}^f I_j^f \Big)^2 + 3 \sum_{i=1|Odd}^{S} R_i^b \Big(\sum_{j=\frac{i+1}{2}}^{M} b_{i,j}^b I_j^b \Big)^2 \quad (15)$$

Where Loss represents the total active loss over the main feeder. Equation (15) is equivalent to equation (3), considering the influence of the NO switches. This expression consists of two terms: the first term calculates the loss for the sections fed by Substation 1, while the second term calculates the loss for the sections fed by Substation 2.

Finally, the objective function of the proposed model can be formulated as follows:

$$Min \;\; OF = \beta \times \frac{EENS}{EENS_{\max}} + (1-\beta) \times \frac{Loss}{Loss_{\max}} \quad (16)$$

Where β is defined as a weighting factor that allows the distribution operator to establish a tradeoff between the two objectives. This parameter can take any value between 0 and 1. β specifies the relative importance of service reliability compared to network losses from the operator's perspective. When β=1, reliability improvement is prioritized, while β=0 places full importance on minimizing network losses. Any value between 0 and 1 represents a compromise between the two objectives. The values of $EENS_{\max}$ and $Loss_{\max}$ are determined by equation (16) when β=0 and β=1, respectively.

The proposed model solves the NO switch allocation problem by using equation (16) as the objective function, subject to constraints (9)–(14) and (15).

IV. Results and Discussions

A part of an urban Finnish distribution network [23], shown in the single-line diagram in Fig. 2, is selected as the case study in this paper. As illustrated, the test system is a loop-structured network with 22 load points, all fed through a medium-voltage (MV) substation. Additionally, failures can occur in low-voltage (LV) substations due to issues in the secondary distribution network. As a result, the system consists of 45 sections that are susceptible to failure, including 23 main sections and 22 LV substations.

The aim of the proposed method is to determine the optimal location for a Normally Open (NO) switch, taking both service reliability and network losses into account simultaneously. To convert the network into two radial feeders, a NO switch must be placed between the LV substations.

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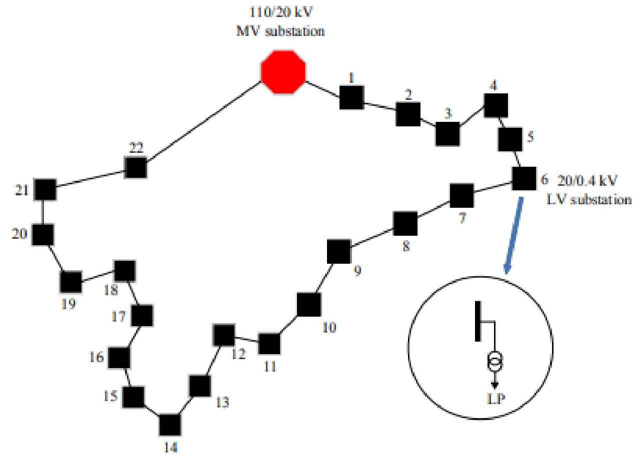

Fig. 2. Single line diagram of the test system

The proposed method can be investigated in the following three scenarios:

Scenario 1 (SC1): In this scenario, the location of the NO switch is determined to minimize network losses, with no consideration given to reliability. To achieve this, β is set to 0, and the problem is solved accordingly. The results, as shown in Table I, indicate that the NO switch is installed between load points 11 and 12.

TABLE I. EENS, LOSS AND NO SWITCH LOCATION UNDER SC_1

Scenario	β	*EENS (MWhr/yr)*	*Network Losses (kW)*	*NO switch location*
SC_1	0.0	2.510	5.315	11-12

Scenario 2 (SC2): In this scenario, the problem is solved by maximizing service reliability, with network losses neglected. To do this, β is set to 1. The scenario is simulated, and the results are presented in Table II. According to the results, the optimal location for the NO switch is between load points 9 and 10.

TABLE II. EENS, LOSS AND NO SWITCH LOCATION UNDER SC_2

Scenario	β	*EENS (MWhr/yr)*	*Network Losses (kW)*	*NO switch location*
SC_2	1.0	2.453	6.117	9-10

Scenario 3 (SC3): In this scenario, a tradeoff is established between network losses and service reliability. To achieve this, β is set to 0.7. The results are presented in Table III. Simulation of this scenario shows that the optimal location for the NO switch is between load points 10 and 11.

TABLE III. EENS, LOSS AND NO SWITCH LOCATION UNDER SC_3

Scenario	β	*EENS (MWhr/yr)*	*Network Losses (kW)*	*NO switch location*
SC_3	0.7	2.460	5.511	10-11

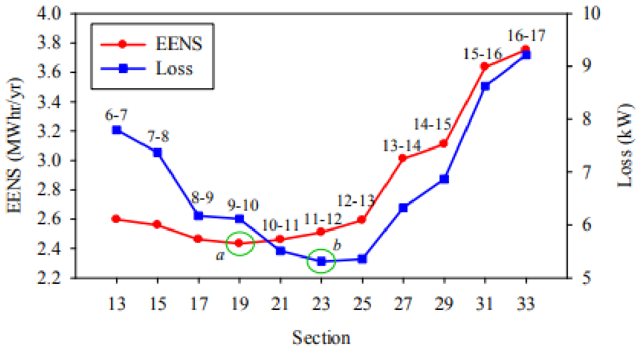

Fig. 3. EENS and Loss in various NO switch locations

Tables I-III present the simulation results for the three scenarios. As shown, increasing the weighting factor significantly increases network losses, while only slightly decreasing service reliability. Specifically, network losses in SC1 are about 15% higher compared to SC2, while EENS in SC1 is reduced by approximately 2.3% compared to SC2. Service reliability improves when the NO switch is placed between load points 9 and 10, while the minimum network losses occur when the switch is located between load points 11 and 12. In SC3, network losses are 3.7% higher than the minimum losses in SC1, and EENS is only 0.3% higher than the minimum EENS in SC2.

To further validate the accuracy of the proposed method, the NO switch placement was simulated for sections 13 to 33, and the resulting EENS and Loss values are shown in Fig. 3. As depicted in Fig. 3, the minimum EENS and Loss are achieved by placing the NO switch in sections 19 and 23 (a and b), respectively. These locations correspond to the sections between load points 9 and 10 for minimizing EENS, and between load points 11 and 12 for minimizing Loss. A comparison of the results from Table I and Fig. 3 confirms the accuracy and effectiveness of the proposed method.

V. CONCLUSIONS

Distribution networks are generally designed as loop-structured systems but are operated in a radial configuration. The optimal deployment of Normally Open (NO) switches plays a crucial role in managing these networks, as it directly affects both reliability and network losses. This paper introduces a mathematical model that simultaneously addresses both reliability and loss optimization. The proposed method allows the power system operator to prioritize either reliability or loss reduction when determining the placement of NO switches. The model optimizes these two objectives such as reliability and losswhich can be solved either independently or together. The model is formulated as a Mixed Integer Quadratically Constrained Programming (MIQCP) problem, which can be efficiently solved using widely available solvers.

REFERENCES

[1] R. Srinivasa Rao, S. V. L. Narasimham, M. Ramalinga Raju and A. Srinivasa Rao, "Optimal network reconfiguration of large-scale distribution system using harmony search algorithm," IEEE Trans. Power Syst., vol. 26, no. 3, pp. 1080-1088, Aug. 2011.

ISSN 2321-2152
www.ijmece.com
Vol 6, Issue 4, 2018

[2] M. E. Baran and F. F. Wu, “Network reconfiguration in distribution systems for loss reduction and load balancing,” IEEE Trans. Power Del., vol. 4, no. 2, pp. 1401-1407, Apr. 1989.

[3] Q. Peng, Y. Tang and S. H. Low, “Feeder reconfiguration in distribution networks based on convex relaxation of OPF,” IEEE Trans. Power Syst., vol. 30, no. 4, pp. 1793-1804, Jul. 2015.

[4] A. Augugliaro, L. Dusonchet, M. G. Ippolito and E. R. Sanseverino, “Minimum losses reconfiguration of MV distribution networks through local control of tie-switches,” IEEE Trans. Power Del., vol. 18, no. 3, pp. 762-771, Jul. 2003.

[5] Hong-Chan Chang, Cheng-Chien Kuo, “Network reconfiguration in distribution systems using simulated annealing”, Elect. Power Syst.Research, vol. 29, no. 3, pp. 227-238, 1994.

[6] Ji-Pyng Chiou, Chung-Fu Chang and Ching-Tzong Su, “Variable scaling hybrid differential evolution for solving network reconfiguration of distribution systems,” IEEE Trans. Power Syst., vol. 20, no. 2, pp. 668-674, May 2005.

[7] D. Das, “A fuzzy multiobjective approach for network reconfiguration of distribution systems,” IEEE Trans. Power Del., vol. 21, no. 1, pp. 202-209, Jan. 2006.

[8] H. Salazar, R. Gallego and R. Romero, “Artificial neural networks and clustering techniques applied in the reconfiguration of distribution systems,” IEEE Trans. Power Del., vol. 21, no. 3, pp. 1735-1742, Jul. 2006.

[9] H. P. Schmidt, N. Ida, N. Kagan and J. C. Guaraldo, “Fast reconfiguration of distribution systems considering loss minimization,” IEEE Trans. Power Syst., vol. 20, no. 3, pp. 1311-1319, Aug. 2005.

[10] C. Lee, C. Liu, S. Mehrotra and Z. Bie, “Robust distribution network reconfiguration,” IEEE Trans. Smart Grid, vol. 6, no. 2, pp. 836-842, Mar. 2015.

[11] G. K. V. Raju and P. R. Bijwe, “An efficient algorithm for minimum loss reconfiguration of distribution system based on sensitivity and heuristics,” IEEE Trans. Power Syst., vol. 23, no. 3, pp. 1280-1287, Aug. 2008.

[12] R. S. Rao, K. Ravindra, K. Satish and S. V. L. Narasimham, “Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation,” IEEE Trans. Power Syst, vol. 28, no. 1, pp. 317-325, Feb. 2013.

[13] M. R. Dorostkar-Ghamsari, M. Fotuhi-Firuzabad, A. Safdarian, A. S.Hoshyarzade and M. Lehtonen, “Improve capacity utilization of substation transformers via distribution network reconfiguraion and load transfer,” 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, pp. 1-6, 2016.

[14] M. R. Dorostkar-Ghamsari, M. Fotuhi-Firuzabad, M. Lehtonen and A. Safdarian, “Value of distribution network reconfiguration in presence of renewable energy resources,” IEEE Trans. Power Syst, vol. 31, no. 3, pp. 1879-1888, May 2016.

[15] Dong-Li Duan, Xiao-Dong Ling, Xiao-Yue Wu, Bin Zhong, “Reconfiguration of distribution network for loss reduction and reliability improvement based on an enhanced genetic algorithm”, Int. Journ. Elec. Power Energy Syst., vol. 64, pp. 88-95, 2015.

[16] A. Kavousi-Fard and T. Niknam, “Optimal distribution feeder reconfiguration for reliability improvement considering uncertainty,” IEEE Trans. Power Del., vol. 29, no. 3, pp. 1344-1353, June 2014.

[17] Abdollah Kavousi-Fard, Mohammad-Reza Akbari-Zadeh, “Reliability enhancement using optimal distribution feeder reconfiguration,” Neurocomputing, vol. 106, pp. 1-11, 2013.

[18] B. Amanulla, S. Chakrabarti and S. N. Singh, “Reconfiguration of power distribution systems considering reliability and power loss,” IEEE Trans. Power Del., vol. 27, no. 2, pp. 918-926, Apr. 2012.

[19] M. Izadi, M. Farajollahi, A. Safdarian and M. Fotuhi-Firuzabad, “A multistage MILP-based model for integration of remote control switch into distribution networks,” 2016 International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Beijing, pp. 1-6, 2016.

[20] M. Izadi and A. Safdarian, “Financial risk constrained remote controlled switch deployment in distribution networks,” IET Gener. Transm. Distrib., 2017.

[21] A. Safdarian, M. Farajollahi and M. Fotuhi-Firuzabad, “Impacts of remote control switch malfunction on distribution system reliability,” IEEE Trans. Power Syst, vol. 32, no. 2, pp. 1572-1573, Mar. 2017.

[22] M. Farajollahi, M. Fotuhi-Firuzabad and A. Safdarian, “Optimal placement of sectionalizing switch considering switch malfunction probability,” IEEE Trans. Smart Grid, vol. PP, no. 99, pp. 1-1.

[23] S. Kazemi, “Reliability evaluation of smart distribution grids,” Ph.D. dissertation, Aalto Univ. publication series 69/2011, Espoo, Finland.G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*

[24] Sina Gharebaghi,” Optimal Network Configuration Considering Network Losses and Service Reliability”, 2017 Smart Grid Conference (SGC)