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Research Article

Optimal Number and Locations of Smart RMUs for Self-Healing Distribution Networks

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Smart grids with self-healing (SH) capability provide an important intelligent feature to help in fast correction actions in case of network faults. SH architecture consists of modern communication systems, smart equipment, and intelligent sensors. With the high cost of SH components (especially smart ring main unit (SRMU)), optimization is required to achieve optimum performance with minimum cost. This study presents a proposed methodology to determine the optimum number and locations of SRMUs in electricity distribution networks considering various cost issues. The disconnection cost of on-grid photovoltaic (PV) plants is taken into consideration as an important factor in determining the locations of the SRMUs. The nonlinear programming (NLP) optimization technique is used to determine the required number of SRMUs, considering the cost/benefit analysis (cost of upgrading MRMUs to SRMUs/benefit due to interruption time reduction), which is the most important factor from DISCOs' perspective. The mixed integer linear programming (MILP) optimization technique is employed for selecting the optimal locations of the SRMUs considering the cost of losses, energy not supplied (ENS), and PV disconnection, which improves network operation cost. The methodology takes into consideration the cable failure rate and the interest rate. Moreover, the study introduces the Egyptian electrical distribution network and a pilot project for control centre development using SRMUs. The methodology is applied to a modified IEEE 37-node test feeder and a part of a specific district network in South Cairo consisting of 158 nodes; both systems include a number of PV distributed generation plants. Simulation results are presented to show the effectiveness of the proposed method.

1. Introduction

Due to recent challenges in traditional electrical distribution networks (EDNs), distribution companies (DISCOs) are looking for smart grid transformation to increase network capacity, mitigate the high penetration of renewables, reduce losses, improve power quality, and help distribution network operator (DNO) to take fast and right actions in case of network faults. With the development of smart grid, the restoration of the network after a fault will be automated; this is defined as self-healing (SH). The main steps of SH are as follows: collect data from smart sensors, detect fault location, do remote isolation of the fault, use optimization techniques for optimal reconfiguration, and send signals to smart equipment for quick action.

Monitoring the operation characteristics of system components is an important key for detecting component failures. A proposed method presented in [1] for smart distribution monitoring of substation is based on collected information analysis for equipment running status and environmental and security conditions. For distribution feeder monitoring, [2] developed a methodology to detect small ground faults and send data via cloud computing technology. For most sensor kinds in distribution network, [3] investigated the framework design of Internet of Things (IoT) monitoring devices which could be extended for engineering needs.

Abdalla et al. [4] proposed a strategy for faulted cable identification using signals from smart meters and Earth fault indicators. Then the optimal reconfiguration of distribution network with photovoltaic (PV) system is determined. Another way for fault detection is phasor measurement unit (PMU), which is time stamp dictated by the global positioning system (GPS). PMU measures the voltage at a bus and current at other buses related to the PMU's bus [5]. Main components and installation of PMU are well presented in [6]. Due to high cost of PMUs optimization techniques are used for the optimal placement as [5] presented a new binary semidefinite programming (BSDP) for fault location in power system and [7] developed hybrid method by coupling branch and bound method with sequential quadratic programming (SQP) to detect new solutions. For distribution network a micro PMU was presented in [8] with customized optimal μPMU placement algorithm to accelerate a solution for a large-scale system. A new minimization and low-cost μPMU device were designed in [9]. Objective functions of reconfiguration are defined in many researches [10–12]. Technical constraints (voltage and/or losses) may be violated due to reconfiguration after fault. Abdalla et al. [13] suggested using a battery energy storage system to overcome technical constraints violation.

There are different schemes for controlled switching implementation based on the switch location:

(1) Substation centralized scheme (controlled switches are for feeder inputs and feeder output in the substation) as in [14], which used a heuristic search technique to minimize the cost/benefit analysis. The same scheme was presented in [15] to maximize the reliability level and benefits.

(2) Sectionalized switching scheme (controlled switches are sectionalized switches) as in [16], which used genetic algorithm to minimize cost and improve system reliability. In [17], the same scheme was used but employing mixed integer nonlinear programming (MINLP) as an optimization technique for minimizing interruption cost and investment cost.

(3) Smart kiosk schemes (controlled switches are the ring main units (RMUs) in the kiosks) have been studied by many research studies: Xu et al. [18] used the greedy algorithm for minimizing the interruption cost. Other studies [19, 20] used the same objective function to minimize equipment cost and interruption cost. Maintenance cost was considered in [21, 22]. The mixed integer convex programming was presented in [23] for maximizing system reliability. Minimization of energy not supplied (ENS) was considered in [24] in addition to other objectives. Economic factors such as interest rate and equipment depreciation were considered in [25]. Investment cost uncertainty for the optimal number of controlled switch selection was considered in [26].

RMUs in kiosk are the most effective equipment to manage medium voltage (MV) networks by performing effective switching actions. Manual ring main units (MRMUs) could be upgraded to be smart ring main units (SRMUs) to facilitate better management and effective remote control. Remote control enables DNO commands to isolate the fault and reconfigure the network in a short time. The cost of upgrading traditional networks to effectively monitor and control smart grids should be optimized (especially SRMUs' number as SRMUs are the most expensive component for SH implementation) to encourage DISCOs for investment in improving network performance.

Renewable energy plays a crucial role in advancing progress on various sustainable development goals (SDGs) [27], in particular SDG7 as well as the global climate objectives set out in the 2015 Paris Agreement [28]. Coinciding with Russian-Ukraine war, the International Energy Agency (IEA) provides 10-Point Plans to the European Union for reducing reliance on Russian supplies by over a third while supporting European Green Deal. One of these points is "acceleration during the deployment of new wind and solar projects" [29]. PV plants are suitable to install in the distribution networks [30]. Therefore, a large spread of on-grid PV plants is expected in the coming years. The disconnection cost of these on-grid PV plants should be taken in consideration as an important factor in electricity interruption cost.

Most of research studies considered one or two objective functions to find the optimal placement of RMUs in smart kiosks as interruption cost, ENS, maintenance cost, and equipment cost. The objective of this study is to propose a methodology for the optimum number and locations of SRMUs, which gathers optimal cost/benefit ratio from DISCOs' perspective and optimal network operation cost. The first step of the methodology is based on the nonlinear programming (NLP) optimization technique for determining the optimum number of SRMUs considering cost/benefit ratio (cost of upgrading MRMUs to SRMUs/benefit due to interruption time reduction). The second step is to employ the mixed integer linear programming (MILP) optimization technique for determining the optimum locations of the SRMUs considering the cost of losses, ENS, and PV disconnection, thus leading to optimizing network operation costs. Effects of cable failure rate and interest rate are considered. Moreover, the study introduces the Egyptian EDN and a pilot project for control centre development using SRMUs.

2. Methodology of SRMUs' Number and Locations

The proposed methodology determines the number and locations of the required SRMUs by two steps: (i) determine the SRMUs number considering minimizing the cost/benefit (cost of upgrading MRMU to be SRMU/benefit due to decreasing both interruption time and ENS). While the interruption time decreases, the reliability index, system average interruption duration index (SAIDI), is improved; (ii) determine the locations of the SRMUs considering the minimization network losses cost, ENS cost, and PV disconnection cost. Figure 1 shows the flowchart of the methodology. The optimization techniques which have been used are as follows:

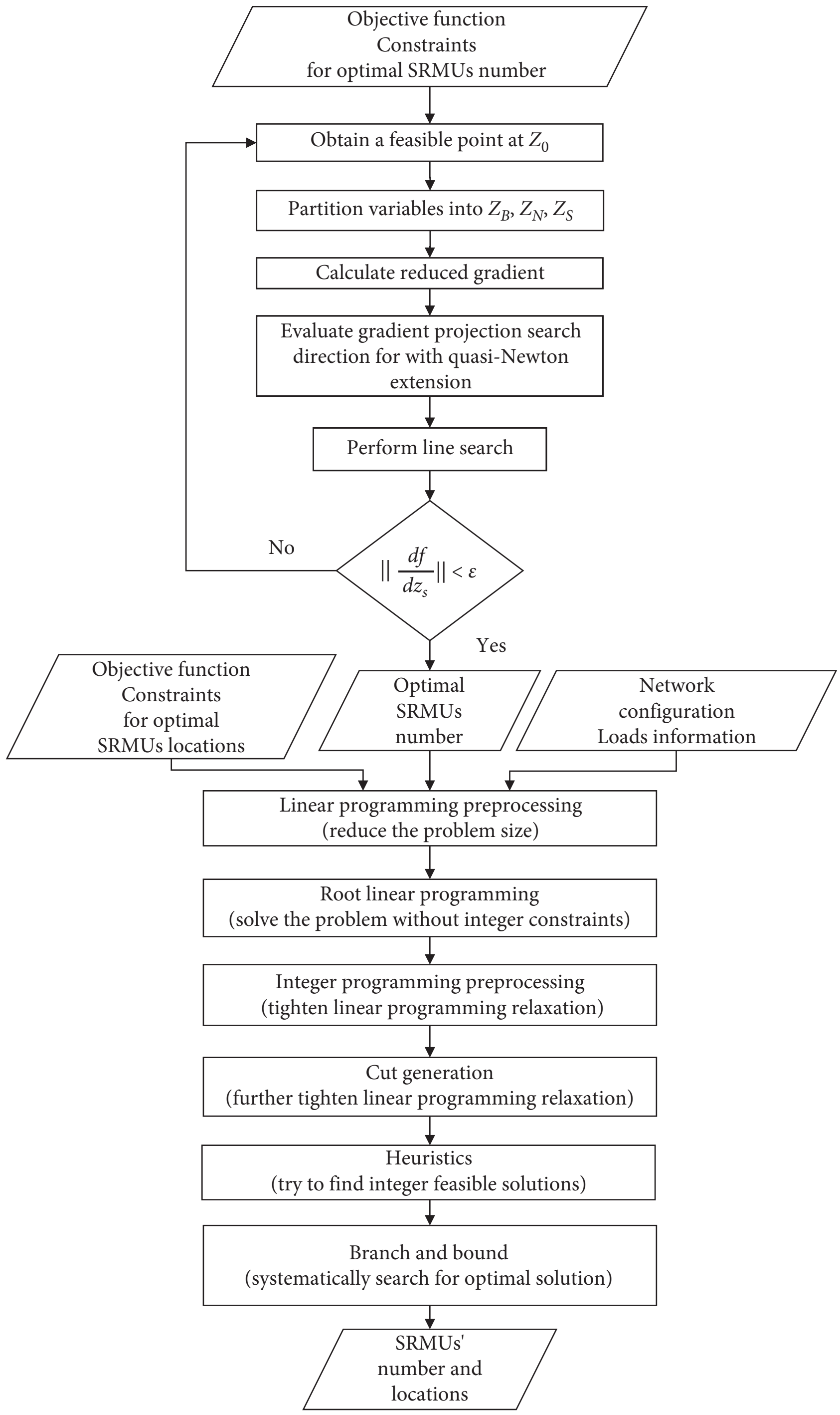

Figure 1: Methodology flowchart.

(1) Determine the number of SRMUs using the NLP optimization technique

(2) Determine the optimum locations of the SRMUs using the MILP optimization technique

2.1. Determining the SRMU Number. For the optimal number of SRMUs, the objective function is to minimize the cost/benefit.

$$f_1(x) = C_{\text{interruption}} + C_{\text{SRMU}}^{\text{capital}} + C_{\text{SRMU}}^{\text{maintenance}} + C_{\text{MRMU}}^{\text{capital}} + C_{\text{MRMU}}^{\text{maintenance}} + C_{\text{MRMU}}^{L\&V}, \quad (1)$$

where $f_1(x)$ is the objective function for the SRMUs number, $C_{\text{interruption}}$ is the interruption cost (the price of the electrical energy that is not consumed due to electricity interruption during reconfiguration after a fault), $C_{\text{SRMU}}^{\text{capital}}$ is the SRMUs capital cost, $C_{\text{SRMU}}^{\text{maintenance}}$ is the SRMUs maintenance cost, $C_{\text{MRMU}}^{\text{capital}}$ is the MRMUs capital cost, $C_{\text{MRMU}}^{\text{maintenance}}$ is the MRMUs maintenance cost, and $C_{\text{MRMU}}^{L\&V}$ is the labour and vehicle costs for MRMUs.

$$C_{\text{interruption}} = \left[t_{\text{fault}} \times C_{\text{kWh}} \times P \times N_{\text{interruptions}}\right]_{\text{SRMU}} + \left[t_{\text{fault}} \times C_{\text{kWh}} \times P \times N_{\text{interruptions}}\right]_{\text{MRMU}}, \quad (2)$$

where $t_{\text{fault}}$is the time during fault, C_{kWh} is th price of kWh for MV customers, P is the total power, and $N_{\text{interruptions}}$ is the number of interruptions.

$$C_{\text{interruption}} = \left[t_{\text{out}-S} \times C_{\text{kWh}} \times \frac{P \times N_{\text{SRMU}}}{N_{\text{RMU}}} \times \frac{\lambda \times N_{\text{SRMU}}}{N_{\text{RMU}}}\right]_{\text{SRMU}} + \left[t_{\text{out}-M} \times C_{\text{kWh}} \times \frac{P \times N_{\text{MRMU}}}{N_{\text{RMU}}} \times \frac{\lambda \times N_{\text{MRMU}}}{N_{\text{RMU}}}\right]_{\text{MRMU}}, \quad (3)$$

where $t_{\text{out}-S}$ is the interruption time while using SRMUs, $t_{\text{out}-M}$ is the interruption time while using MRMUs, N_{SRMU} is the number of SMRUs, N_{MRMU} is the number of MMRUs,N_{RMU} is the total number of RMUs, and λ is the number of interruptions = failure rate of cables/km per year × total cable length (km).

Failure rate is different from district to another as it depends on cables' age and external factors such as road civil works and atmosphere.

$$C_{\text{interruption}} = \frac{P \times C_{\text{kWh}} \times \lambda}{N_{\text{RMU}}^2} \left\{\left[t_{\text{out}-S} \times N_{\text{SRMU}}^2\right] + \left[t_{\text{out}-M} \times N_{\text{MRMU}}^2\right]\right\}. \quad (4)$$

The objective function can be written as follows:

$$f_1(x) = \frac{P \times C_{\text{kWh}} \times \lambda}{\text{RMUs}^2} \times \left\{\left[t_{\text{out}-S} \times N_{\text{SRMU}}^2\right] + \left[t_{\text{out}-M} \times N_{\text{MRMU}}^2\right]\right\} + \left[N_{\text{SRMU}} \times \left(C_{\text{SRMU}}^{\text{capital}} + C_{\text{SRMU}}^{\text{maintenance}}\right)\right] + \left[N_{\text{MRMU}} \times \left(C_{\text{MRMU}}^{\text{capital}} + C_{\text{MRMU}}^{\text{maintenance}}\right)\right] + \left[\left(\frac{\lambda \times N_{\text{MRMU}}}{N_{\text{RMU}}} \times C_{\text{MRMU}}^{L\&V}\right)\right]. \quad (5)$$

$$N_{\text{SRMU}} + N_{\text{MRMU}} = N_{\text{RMU}}. \quad (6)$$

The optimization technique to find the optimal SRMU number is NLP, which involves minimizing the nonlinear objective function subject to bounded constraints.

NLP is adequate as the design variables (SRMUs and MRMUs) are integers. In addition, using NLP provides fast solution. Reference [31] showed that the NLP model is sufficient as the binary integer programming model for PMUs optimal locations. The solution algorithm is Generalized Reduced Gradient (GRG) and more details are shown in Appendix A.

2.2. Determining the SRMUs Locations. The optimal locations of the SRMUs are determined using the MILP, which exhibits global optimum with well-defined solution method. During the fault, many reconfiguration scenarios could be used. The best scenario is the one which achieves minimization of losses cost, energy not supplied cost, and PV disconnection cost. Therefore, the locations of SRMUs should be selected to implement the best scenario.

The objective function is to minimize the losses cost, ENS cost, and PV disconnection cost.

$$f_2(x) = \text{SC}_{\text{kWh}} \times \sum R \times I^2 + C_{\text{kWh}} \times t_{\text{out}} \times \sum L_{\text{dis}} + 0.4 \times P_{\text{PV-peak}} \times C_{\text{dis}} \times t_{\text{out}}, \quad (7)$$

where $f_2(x)$ is the objective function for SRMUs locations, SC_{kWh} is the service cost for the MV, t_{out} is the outage duration, $\sum L_{\text{dis}}$ is the total disconnected load, $P_{\text{PV-peak}}$ is the rated power of PV plant, and C_{dis} is the disconnection price (it is mentioned in the agreement between the PV station owner and the distribution company). It should be used as the PV connection scheme: feed-in-tariff (FIT) scheme or independent power producer (IPP) scheme.

3. Egyptian Electrical Distribution Networks

The Egyptian electricity law [32] allows the private sector to invest in distribution networks. The investor could distribute electricity to customers after getting a license from the Egyptian Electric Utility and Consumer Protection Regulatory Agency (EgyptERA). Normally, EgyptERA evaluates DISCOs' performance every year according to performance indictors to renew the license.

3.1. Electrical Distribution Networks Layout. EDNs have 6.6, 11, and 22 kV for MV according to the zone. MV networks are designed to distribute electrical energy over a distance of 10 m to more than 10 km, to MV customers and distribution transformers. MV customers can be supplied via a distribution network from 500 kW to 30 MW [33]. Customers of more than 30 MW are usually supplied from the transmission network directly. A schematic overview of MV network part is shown in Figure 2. The MV network starts from the substation output to the distributors, which have the same voltage level. Every distributor has two inputs from two different substations, which are linked by an open bus coupler for more reliability. The solid lines indicate connected underground cables and dotted lines indicate normally open underground cables for manoeuvres. Every black rectangle represents a kiosk, which contains a RMU. Typical RMU is as shown in Figure 3. A two-source RMU (connected with a solid line and dotted line as shown in Figure 2)

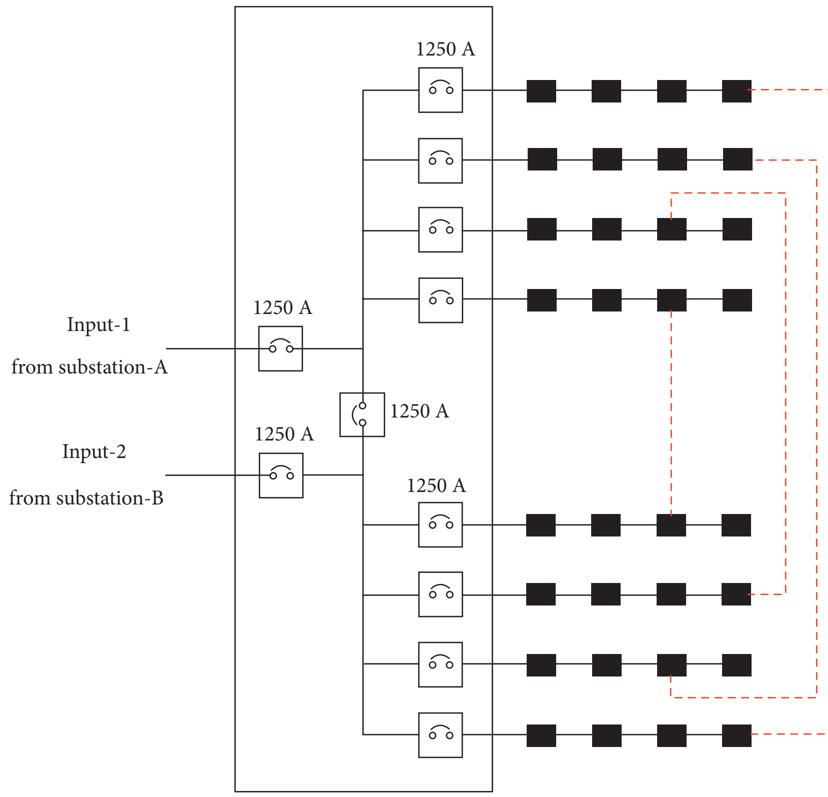

Figure 2: Part of the MV network.

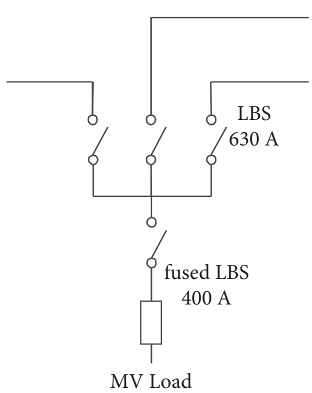

Figure 3: Typical ring main unit.

is a RMU with two different sources; one of them is energized and the other is standby. It can be used during faults to restore loads.

3.2. Fault Detection and Restoration. The current EDNs are traditional (i.e., nonautomated) and operated in radial form but designed to be ring-shaped layout. Therefore, it provides the possibility of rerouting electrical power during outages or maintenance. During a fault as shown in Figure 2, the circuit breaker (CB-14) in the distributor isolates all cable sections (from distributer to the first kiosk and between the four kiosks). Then the DNO deals with the interruption caused by that fault as shown in the flowchart in Figure 4. This procedure can take more than one hour, intensive

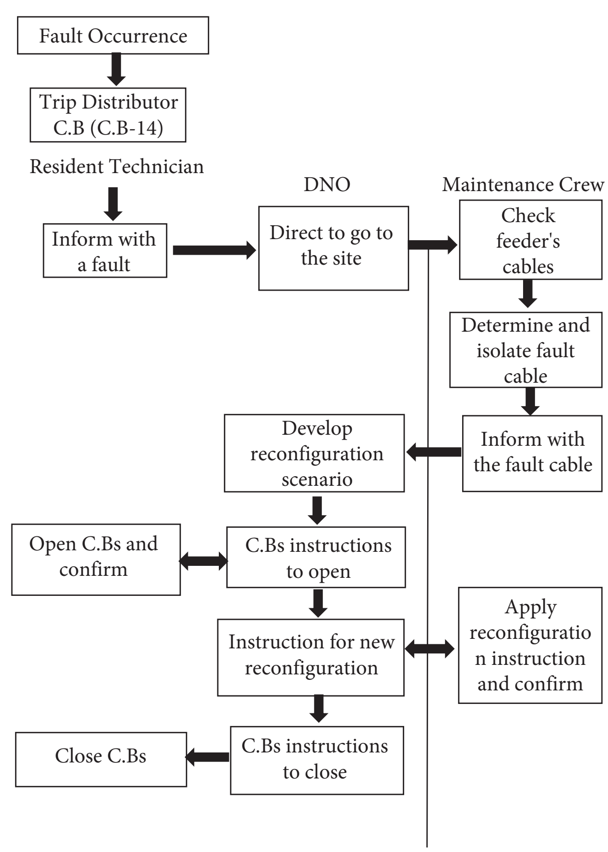

Figure 4: Fault detection and reconfiguration scheme.

efforts, and cost of labour and vehicles. One of the most important indicators for the quality and performance of a distribution network is its reliability. Reliability can be quantified and calculated in several ways looking at different aspects of what reliability is. The reliability level of EDN depends on the overall time of fault detection and load restoration. The reliability index SAIDI is the most used to indicate DISCOs' performance.

3.3. Renewable Energy. To encourage the private sector to produce electricity from renewable energy sources, Egypt adopted the Renewable Energy Law (Decree No 203/2014) in 2014 [34], which introduced four development schemes. The Supreme Council of Energy adopted the Egyptian Energy Strategy until 2035, which aims to reach the percentage of renewable energy contribution to 42% in 2035 (22% from PV). Until 2021, the total installed renewable capacity is 6305 MW (1642 MW from PV) [35]. Reference [36] used Strength, Weakness, Opportunities, and Threats (SWOT) method for analyzing the PV systems potential and prospects, which indicated a high opportunity for PV in Egypt.

The 27th session of the Conference of the Parties (COP 27) to the United Nations Framework Convention on Climate Change (UNFCCC) will be held in Sharm El-Sheikh, Egypt. Various steps have been taken in Egypt towards COP 27 including many projects such as installing PV plants in most of hotels, increasing the use of PV street lighting, and developing electric bus charging stations. In addition, the periodic book (6/2022) [37] is published by EgypERA to increase PV penetration in the distribution network by exempting PV plants up to 1 MW from integration fees.

4. Pilot Project for Control Centres Development in Egypt

Distribution networks are moving towards digitalization and smart use of energy and optimization are necessary to cope with new challenges such as higher PV penetration [38]. In Egypt, EDNs are being developed to improve the performance and upgrade the quality of electric supply through the establishment and development of 14 control centres. These centres will be at the DISCOs using the latest technology in control, monitoring, and communication systems for monitoring and controlling distributors, transformers, and the MV side of distribution stations in a safe and reliable manner. The project applied Fault Location, Isolation, and Service Restoration (FLISR) concept. The project is divided into two phases. The first phase: establishment of five control centres at three DISCOs (North Cairo, South Cairo, and Alexandria). The second phase: establishment of another nine dispatch centres with the rest of distribution companies following completion of the first phase [39]. In South Cairo DISCO, a project is being implemented in two districts, namely, Dokki and 6th October Cities through establishing two distribution control centres and 1580 SRMUs. The project aims to deploy the automation solution including SRMUs, communication systems, and analytical aid-for-decision tools (SE ADMS FLISR package).

4.1. Smart RMU. The SRMU consists of motorized load break switches (number of switches defined according to the configuration of the selected RMU), a circuit breaker (CB) to protect the distribution transformer, and a remote terminal unit (RTU) integrated in the low voltage (LV) cabinet. It allows for tele-controlling system voltage, current and power measurement, fault detection, broken conductor detection, switch/CB status, and thermal and environment monitoring [40].

4.2. Communication System. The communication system between the distribution control centre (DCC) and all distributors and kiosks employs dual communication media. The detailed communication scheme is shown in Figure 5. The main communication media of the distributor is radio frequency and 3 G/LTE for the backup. For the kiosk, the communication media is 3 G/LTE dual SIM one as the main and the second is the backup [40].

4.3. SE ADMS FLISR Package. In real-time operation, SE ADMS FLISR package provides on-demand appropriate switching sequence to help in FLISR automatic operation. It provides serval functions [41]:

(1) Fault localization: it provides an estimation of the distance from the substation to the faulted area. The fault location is shown in the dynamic diagram and geographical view, which is determined based on the fault impedance (resulting from voltage and current measurements available at the feeder's CB), information from the fault passage indicator (available in the RTU), and geographical coordinates from the geographic information system.
(2) Fault isolation: it proposes a switching sequence to isolate the faulted zone. The switching sequence includes the control on or off covers automatic operation only.
(3) Service restoration: it proposes a switching sequence to restore the healthy parts of another feeder considering the actual operating conditions to avoid overloading or causing large voltage droop.

According to the financial perspective, only 20% of the installed RMUs will be automated. The project contractor used internal specific analytical tools for optimal SRMU placement. The mathematical programming-based optimization algorithm defines the best locations for SRMU to maximize the selected objectives (reliability indices, system recovery).

5. Results and Discussion

The following data are used in the case studies:

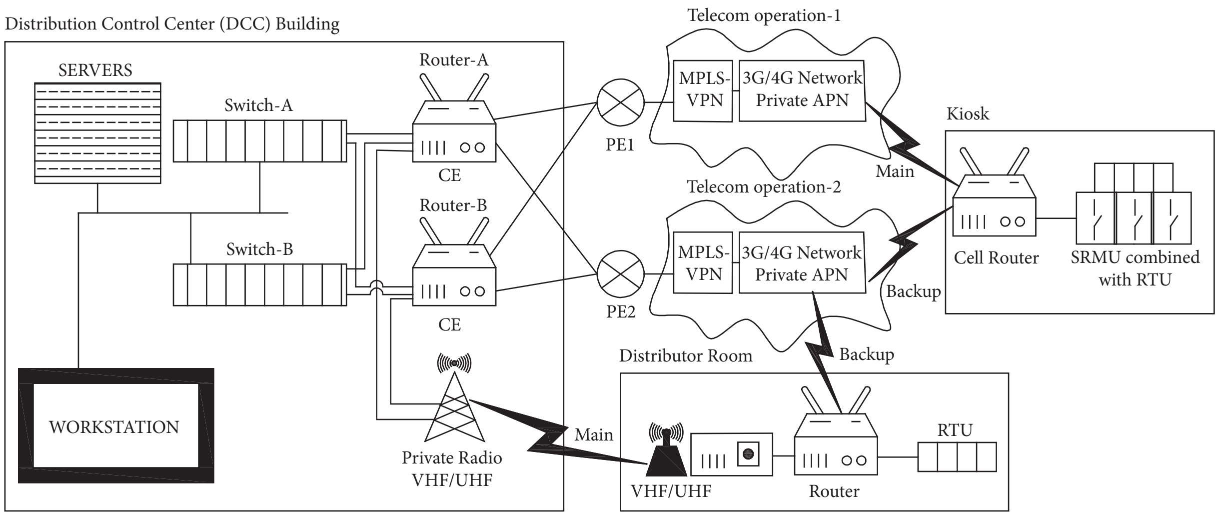

Figure 5: Communication scheme.

(1) Labour and vehicle cost for determining a fault cable = 6000 LE

(2) As per the EgyptERA, tariff for 2020/2021 [42]: the value of C_{kWh} = 1.15 LE/kWh and the cost of producing and transporting electricity services for 2019/2020, SC_{kWh} = 0.991 LE/kWh.

(3) From the FIT scheme phase-1:

$$C_{dis} = 0.4 \times P_{PV-peak} \times C_{FIT}, \quad (8)$$

where C_{dis} is the disconnection price, $P_{PV-peak}$ is the rated power of the PV plant, and C_{FIT} is the feed in tariff price.

5.1. IEEE 37-Node Test Feeder. In this case study, a modified IEEE 37-node test feeder is used. To implement the reconfiguration for this test feeder [43], it is modified by adding four normally open underground cables and two external grids; the rating of each one is 2500 kVA at 4.8 kV. For studying the PV impact, three medium scale PV (MSPV) stations, each one being 1000 kWp, are introduced. The modified IEEE 37-node test feeder is shown in Figure 6. Load data and cable lengths are listed in Appendix B. The modified elements are shown in red and open cables are dotted with red lines.

Total cable length = 6.6 km

Total power = 9.890 kW

Number of RMU = 35

5.1.1. Step-1: Number of SRMUs Is Determined as a Function of Failure Rate. Determination of the optimal number of SRMUs is based on equations (1)–(6). Tables 1 and 2 provide the results with various interruption rates at two different interest rates 0% and 12.75%. The latter is as per [44]. As cable failure rate increases, the number of SRMUs increases to minimize the interruption cost so the benefit increases. This is clearly given in Tables 1 and 2. Figure 7 shows a comparison of the effect of interest rate on the number of the resulting SRMUs at different failure rates. The number of the SRMUs significantly decreases with the higher interest rate of 12.75%.

5.1.2. Step-2: SRMUs' Locations Are Determined by the Node Number. SRMUs' locations are determined by using equations (7) and (8). The locations of SRMUs should be suitable to apply the best scenario, which achieves minimization of losses cost, energy not supplied cost, and PV disconnection cost. For example, if the faulted cable is cable number (4), there are two scenarios; (scenario-1 closing cable-40 and scenario-2 closing cable-3 and cable-6) for network reconfiguration as given in Table 3.

The total cost of scenario-2 is lower than scenario-1. The PV disconnection cost in scenario-1 is 2400 LE., while it is 0 in scenario-2. Therefore, the most suitable SRMUs are at nodes (702, 703, 713, and 730), which are used to implement scenario-2.

More examples are as follows:

(1) For failure rate 1.36 and interest rate 12.75%, Table 2 will be used. The optimal number of SRMUs is (6). The locations of SRMUs are at nodes (702, 703, 713, 725, 730, and 731).

(2) For failure rate 0.76 and interest rate 0%, Table 1 will be used. The optimal number of SRMUs is (13). The locations of these SRMUs are at nodes (702, 703, 705, 708, 713, 725, 729, 730, 731, 732, 737, 741, and 742).

(3) For failure rate 1.82 and interest rate 12.75%, Table 2 will be used. The optimal number of SRMUs is (15). The locations of these SRMUs are at nodes (702, 703, 705, 708, 713, 725, 729, 730, 731, 732, 733, 734, 737, 741, and 742).

5.2. Part of a Specific District in South Cairo Consists of 158 Nodes. This case study is a part of a specific district in South Cairo EDN consisting of 158 nodes shown in Figure 8. This

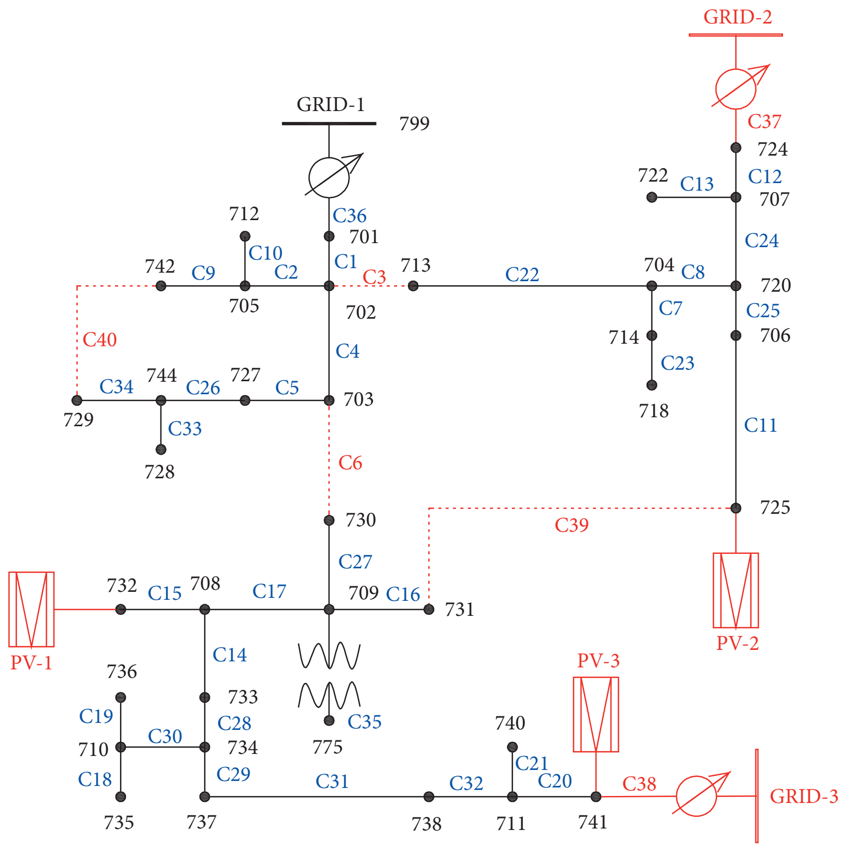

Figure 6: Modified IEEE 37-node test feeder: dotted red lines are opened cables.

Table 1: Optimal number of SRMUs with interest rate = 0%.

Number of interruptions (λ)	Failure rate	SRMUs	MRMUs	Number of SRMUs%
1	0.15	0	36	0%
2	0.30	0	36	0%
3	0.46	0	36	0%
4	0.66	6	30	17%
5	0.76	13	23	36%
6	0.91	18	18	50%
7	1.06	22	14	61%
8	1.21	24	12	67%
9	1.36	28	8	78%
10	1.52	28	8	78%
11	1.67	29	7	81%
12	1.82	30	6	83%

Table 2: Optimal number of SRMUs with interest rate = 12.75%.

Number of interruptions (λ)	Failure rate	SRMUs	MRMUs	Number of SRMUs%
1	0.15	0	36	0%
2	0.30	0	36	0%
3	0.46	0	36	0%
4	0.66	0	36	0%
5	0.76	0	36	0%
6	0.91	0	36	0%
7	1.06	0	36	0%
8	1.21	1	35	3%
9	1.36	6	30	17%
10	1.52	10	26	28%
11	1.67	13	23	36%
12	1.82	15	21	42%

Table 3: Network reconfiguration scenarios' cost (costs are in LE).

Scenario number	Scenario-1	Scenario-2
Reconfiguration structure	Close cable-40	Close cable-3 and cable-6
SRMUs' nodes	729 and 742	702, 703, 713, and 730
Losses cost	129	160
ENS cost	0	0
PV disconnection cost	2400	0
Total cost	2529	160

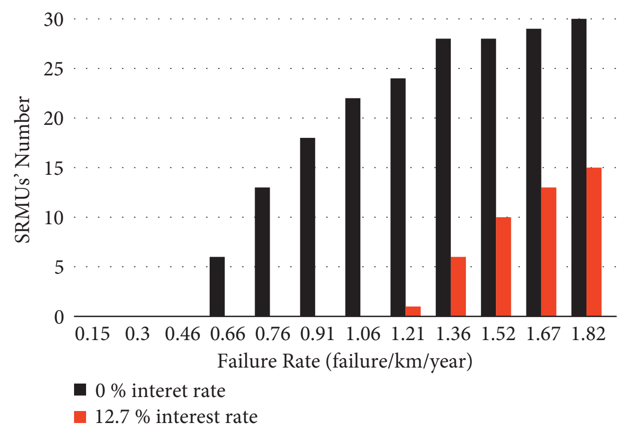

Figure 7: SRMUs number with 0% and 12.75% interest rates.

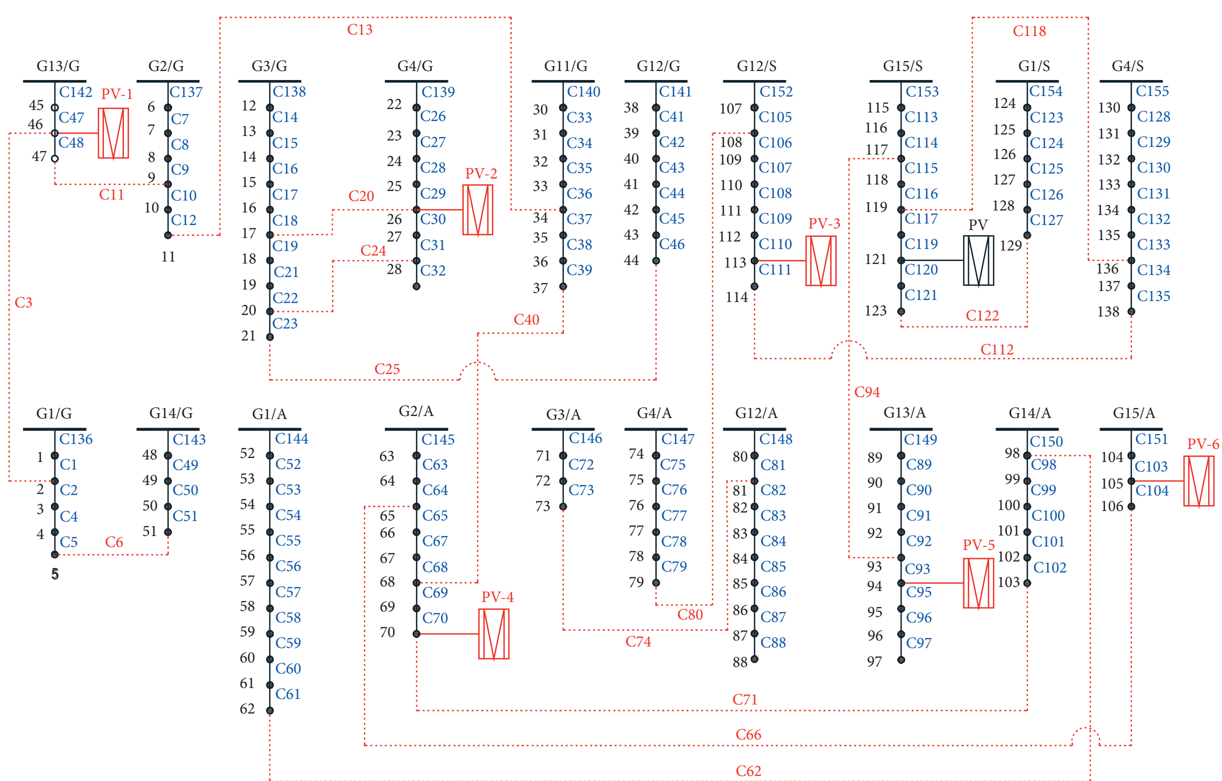

Figure 8: A part of a specific district in South Cairo.

part is an actual urban, underground 22 kV cable system with open-ring configuration. Some cables can be connected to each other through two normally opened RMUs at both ends of the cable. Loads and cable lengths are listed in Appendix C. Due to decreasing of PV prices, increasing of electricity tariff, and exemption of PV plants up to 1 MW

Table 4: Cable failure rate for a specific district in the South Cairo distribution network.

Year	Failure rate (failure/km/year)	Interruption percentage due to road civil works (%)
2015	0.15	65
2016	0.13	64
2017	0.11	51
2018	0.10	50
2019	0.09	48
2020	0.12	55
2021	0.13	66

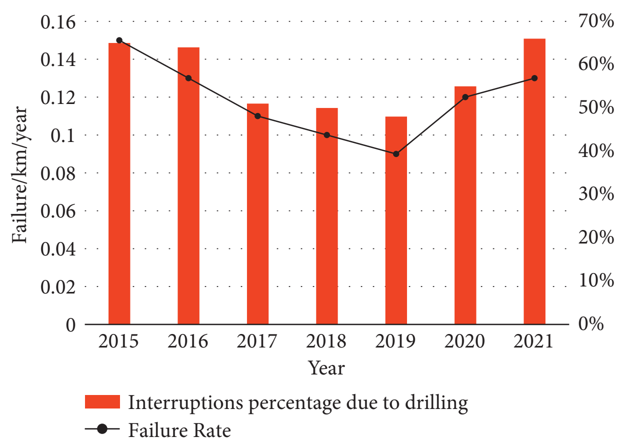

Figure 9: Historical failure rate and percentage interruptions due to road civil works.

Table 5: SAIDI and total cost for the pilot project and the methodology result (costs are in LE).

Option	SRMUs		SAIDI	Cost of interruption	Cost of upgrading MRMUs to SRMUs	Cost of labour and vehicles	Total cost
	Number	%					
1	0	0%	3043	15,292,955	0	7,835,220	23,128,175
2	32	20%	2476	11,354,668	4,838,400	6,391,889	22,584,957
3	56	35.44%	2051	7,622,518	8,467,200	5,428,740	21,518,458
4	158	100%	243	1,274,412	23,889,600	0	25,164,012

Table 6: Loads in (MW), power factor of all loads is 0.92 lag.

Node	Load	Node	Load	Node	Load	Node	Load	Node	Load	Node	Load
701	0.50	707	0.28	713	0.28	725	0.14	732	0.14	738	0.42
702	0.28	708	0.28	714	0.12	727	0.14	733	0.28	740	0.28
703	0.28	709	0.28	718	0.28	728	0.14	734	0.14	741	0.14
704	0.28	710	0.28	720	0.28	729	0.14	735	0.28	742	0.14
705	0.28	711	0.28	722	0.53	730	0.28	736	0.14	744	0.14
706	0.28	712	0.28	724	0.14	731	0.28	737	0.46	775	0.00

Table 7: Cable lengths (km) for the modified IEEE 37-node test feeder.

Cable	Length	Cable	Length	Cable	Length	Cable	Length	Cable	Length
1	0.29	9	0.10	17	0.10	25	0.18	33	0.06
2	0.12	10	0.07	18	0.06	26	0.09	34	0.09
3	0.11	11	0.09	19	0.39	27	0.06	35	0.06
4	0.40	12	0.23	20	0.12	28	0.17	36	0.56
5	0.07	13	0.04	21	0.06	29	0.20	37	0.56
6	0.18	14	0.10	22	0.16	30	0.16	38	0.56
7	0.02	15	0.10	23	0.16	31	0.12	39	0.18
8	0.24	16	0.18	24	0.28	32	0.12	40	0,11

Table 8: Loads in MW, power factor of all loads is 0.92 lag.

Node	Load	Node	Load	Node	Load	Node	Load	Node	Load	Node	Load
1	0.80	24	0.25	47	0.80	70	0.75	93	0.80	116	0.80
2	0.80	25	0.30	48	0.80	71	0.75	94	0.80	117	1.50
3	0.80	26	0.80	49	0.80	72	1.80	95	0.75	118	0.80
4	0.80	27	0.30	50	0.30	73	0.75	96	0.75	119	1.25
5	0.80	28	0.30	51	0.80	74	0.45	97	0.75	120	0.80
6	0.80	29	0.30	52	1.45	75	0.40	98	2.00	121	0.80
7	0.80	30	0.80	53	0.40	76	0.75	99	1.45	122	1.50
8	0.80	31	0.80	54	0.75	77	0.70	100	1.10	123	1.25
9	0.80	32	0.80	55	0.75	78	0.75	101	0.75	124	0.80
10	0.80	33	0.80	56	0.05	79	2.20	102	1.45	125	1.50
11	0.80	34	0.80	57	3.00	80	1.45	103	1.45	126	0.80
12	0.30	35	0.80	58	0.75	81	0.75	104	1.45	127	0.45
13	0.30	36	0.80	59	0.15	82	0.75	105	0.75	128	1.50
14	0.80	37	1.50	60	1.20	83	0.75	106	0.75	129	0.80
15	0.35	38	0.80	61	0.80	84	0.40	107	0.80	130	0.80
16	0.80	39	0.40	62	0.75	85	0.40	108	0.80	131	0.80
17	0.80	40	0.80	63	1.45	86	0.75	109	0.45	132	0.80
18	0.80	41	0.80	64	0.75	87	1.10	110	0.80	133	0.80
19	0.80	42	0.80	65	0.75	88	0.75	111	0.80	134	0.80
20	0.80	43	0.30	66	0.75	89	0.75	112	0.34	135	0.80
21	0.80	44	0.80	67	0.75	90	0.75	113	0.80	136	1.50
22	0.30	45	0.80	68	0.75	91	0.75	114	1.50	137	1.50
23	0.80	46	0.80	69	0.20	92	2.20	115	0.80	138	0.80

Table 9: Cable length (L) in (km).

Cable	Length	Cable	Length	Cable	Length	Cable	Length	Cable	Length
1	0.19	32	0.25	63	0.07	94	0.40	125	0.09
2	0.22	33	0.24	64	0.25	95	0.25	126	0.14
3	0.30	34	0.10	65	0.33	96	0.07	127	0.15
4	0.18	35	0.07	66	0.90	97	0.38	128	0.37
5	0.26	36	0.30	67	0.17	98	0.06	129	0.26
6	0.22	37	0.20	68	0.32	99	0.08	130	0.20
7	1.32	38	0.72	69	0.95	100	0.10	131	0.22
8	1.32	39	0.22	70	0.22	101	0.40	132	0.02
9	0.13	40	0.12	71	0.18	102	1.30	133	0.45
10	0.38	41	0.12	72	1.30	103	0.90	134	0.10
11	0.51	42	0.08	73	0.45	104	0.15	135	0.09
12	0.08	43	0.35	74	1.10	105	0.15	136	0.33
13	0.20	44	0.25	75	0.25	106	0.94	137	0.78
14	0.41	45	0.22	76	0.50	107	0.93	138	0.45
15	0.12	46	0.08	77	0.33	108	0.23	139	1.80
16	0.18	47	0.13	78	0.35	109	0.04	140	0.91
17	0.09	48	0.21	79	0.33	110	0.10	141	0.27
18	0.07	49	0.10	80	0.08	111	0.41	142	0.57
19	0.06	50	0.50	81	1.50	112	1.99	143	0.56
20	0.22	51	0.10	82	0.21	113	1.95	144	0.45
21	0.10	52	0.76	83	0.38	114	0.48	145	0.23
22	0.14	53	0.50	84	0.15	115	0.08	146	0.08
23	0.33	54	0.20	85	0.13	116	0.38	147	0.63
24	0.15	55	0.20	86	0.13	117	0.27	148	0.18
25	0.29	56	0.30	87	0.15	118	0.35	149	0.33
26	0.22	57	0.50	88	0.57	119	0.22	150	0.21
27	0.25	58	0.10	89	0.43	120	0.83	151	0.47
28	0.11	59	0.24	90	0.06	121	0.29	152	0.55
29	0.34	60	0.28	91	0.30	122	0.12	153	0.95
30	0.10	61	0.22	92	2.05	123	0.70	154	1.30
31	0.29	62	0.33	93	0.33	124	0.87	155	0.12

from integration fees as per the Egyptian regulations, it is expected that higher spread of PV plants will be witnessed soon. Therefore, six PV plants with 1 MW capacity are added (shown in red in Figure 8) to analyze their effect in determining the locations of the SRMUs.

Total cable length = 59.75 km

Total power = 77340 kW

RMUs number = 158

Table 4 provides the cable failure historical data (2015–2021) for a specific district in the South Cairo distribution network. From the historical data, the interruptions due to road civil works are more than 50%. The lowest failure rate was in 2019, as there were not much infrastructure developments. For 2020 and 2021, there were many infrastructure developments. That means there is a relation between infrastructure development, road works, and failure rate as shown in Figure 9. The planning engineer could analyze the historical data of failure rates and may use the minimum failure rate, average failure rate, or maximum failure rate according to the probable infrastructure development.

5.2.1. Step-1: Number of SRMUs Is Determined as a Function of Failure Rate. Using the average failure rate of 0.12 and interest rate of 12.75% as per the Central Bank of Egypt [44], the optimal number of SRMUs is 56 (35.44%). Table 5 provides a comparison between the results of the following four options:

(1) No SRMUs (all RMUs are manual)

(2) Pilot project (20% SRMUs)

(3) Optimal number of SRMUs (proposed in this study)

(4) All RMUs are upgraded to SRMUs (100% SRMUs)

SAIDI is calculated over one year. All costs are calculated for 20 years (SRMU lifetime) considering increasing of kWh price, maintenance cost, and labour and vehicle cost. Option 3 (using the proposed methodology presented in this study) results in minimum total cost with improved SAIDI compared to options 1 and 2. Significant improvement in SAIDI can be achieved by upgrading all MRMUs to SRMUs, option 4, but with the highest total cost compared to other options.

According to the SAIDI and the total cost given in Table 5, it is recommended to increase the ratio of the SRMUs for the specific district in South Cairo distribution network to be 35.44%. If the budget for the SRMUs is less than the cost of calculated SRMUs' number, DISCO's plan could start with the available number and use them in the most important locations. When additional budget is available, the number of SRMUs should be increased to reach the calculated optimal SRMUs' number to achieve the best cost/benefit analysis and better SAIDI.

5.2.2. Step-2: SRMUs' Locations Are Determined by the Node Number. According to step-2 of the proposed methodology, the locations of the 56 SRMUs are at the nodes (1, 2, 3, 5, 6, 7, 9, 10, 11, 17, 18, 20, 21, 23, 26, 27, 28, 30, 33, 34, 37, 42, 43, 44, 46, 47, 51, 62, 65, 68, 70, 73, 79, 81, 87, 92, 93, 96, 98, 99, 103, 106, 108, 109, 114, 116, 117, 118, 119, 123, 125, 129, 131, 136, 137, and 138).

6. Conclusions

The study has suggested a methodology to determine the optimal number and locations of the SRMUs in distribution networks with increasing penetration of PV solar plants. The methodology considered both failure rate and interest rate. The effect of the interest rate decreases the SRMUs due to its high capital cost, which is shown in the result section. The first step of the methodology was based on NLP optimization technique for determining the optimum number of SRMUs as the design variables (number of SRMUs and MRMUs) should be integer. The NLP optimization technique considered the cost/benefit analysis. For the second step of the methodology, MILP optimization technique was used for determining the optimum locations of the SRMUs considering the cost of losses, ENS, and PV disconnection. The capacity and location of PV significantly affect the SRMUs' location due to its disconnection cost. In addition, the study introduced the Egyptian electrical distribution network and a pilot project for control centre development using SRMUs. The methodology has been applied to a modified IEEE 37-node test feeder and a part of a specific district in South Cairo distribution network consisting of 158 nodes and seven PV plants with 1 MW each. For the average failure rate, the optimum number of SRMUs is more than the percentage in the pilot project.

It is recommended to increase the SRMUs to 35.44% in this specific district network in the South Cairo region to achieve the best cost/benefit analysis. A detailed comparison between the results of four options (No SRMUs, (all RMUs are manual), the Egyptian pilot project (20% SRMUs), optimal number of SRMUs (proposed in the study), and all RMUs are upgraded to SRMUs (100% SRMUs)) were presented. Finally, the optimal locations of SRMUs were identified by node numbers.

Appendix

A. Generalized Reduced Gradient (GRG)

The main idea of GRG method is to solve the nonlinear problem dealing with active inequalities. The variables are separated into a set of basic (Z_B) variables, nonbasic (Z_N) variables, and superbasic (Z_S) variables. Then, the reduced gradient is computed in order to find the minimum in the search direction. This process is repeated until the convergence is obtained. Steps for GRG algorithm are as follows:

(1) Initialize problem and obtain a feasible point at Z_0
(2) At feasible point Z^k, partition variables Z into Z_B, Z_N, and Z_S. Z_N variables are temporarily fixed.
(3) Calculate reduced gradient $((\mathrm{d}f/\mathrm{d}Z_S))$
(4) Evaluate gradient projection search direction for Z_S, with quasi-Newton extension
(5) Perform a line search
  (i) Find $\alpha \in (0, 1)$ with $Z_S\ (\alpha)$
  (ii) Solve for $c\ (Z_S\ (\alpha),\ Z_B) = 0$
  (iii) If $f\,(Z_S(\alpha), Z_B) < f\,(Z_S^k, Z_B)$, set $Z_S^{k+1} = Z_S\ (\alpha)$
(6) If $\|(\mathrm{d}f/\mathrm{d}Z_S)\| < \varepsilon =$ stop. Else go to 2.

$$\frac{\mathrm{d}f}{\mathrm{d}Z_S} = \nabla_S f(z) - \nabla_S C\left[\nabla_B C\right]^{-1}\nabla_B f(z). \tag{A.1}$$

Let $Z_S = N_{\mathrm{SRMU}} = x_1$ and $Z_B = N_{\mathrm{MRMU}} = x_2$

$$\begin{aligned} f(x) = {} & \frac{P \times C_{\mathrm{kWh}} \times \lambda}{\mathrm{RMUs}^2} \times \left\{\left[t_{\mathrm{out}-S} \times x_1^2\right] + \left[t_{\mathrm{out}-M} \times x_2^2\right]\right\} + \left[x_1 \times (\mathrm{SRMU's\ capital\ cost\ +\ maintenance\ cost})\right] \\ & + \left[x_2 \times (\mathrm{MRMU's\ capital\ cost\ +\ maintenance\ cost})\right] + \left[\left(\frac{\lambda \times x_2}{N_{\mathrm{RMU}}} \times \mathrm{Labor\ and\ vehicle\ cost}\right)\right]. \end{aligned} \tag{A.2}$$

S. T. $C = x_1 + x_2 = N_{\mathrm{RMU}}$.

B. Data of the Modified IEEE 37-Node Test Feeder

The loads and cable lengths are given in Tables 6 and 7

C. Data of the 158-Node System

The loads and cable lengths are given in Tables 8 and 9.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

References

[1] M. Zhang, J. Fang, W. Mo et al., "Development of the monitoring system in the smart distribution substation in Guangzhou, China," in *Proceedings of the 2020 International Conference on Wireless Communications and Smart Grid (ICWCSG)*, pp. 159–162, Qingdao, China, June 2020.

[2] H. Guanghui, C. Mingjia, and L. Haixuan, "Research and application of monitoring method of small current grounding fault in distribution line based on cloud computing," in *Proceedings of the 2018 China International Conference on Electricity Distribution (CICED)*, pp. 1363–1369, Tianjin, China, September 2018.

[3] L. Chen, M. M Jia, X. D. Yuan, L. J Zhao, and Y. L He, "A robust framework design of IoT monitoring device for power distribution network," in *Proceedings of the IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, pp. 1–4, Macao, China, December 2019.

[4] O. H. Abdalla, G. Abdel-Salam, and A. A. A. Mostafa, "Optimal reconfiguration strategy for distribution networks with PV connected systems," in *Proceedings of the CIRED 2021-The 26th International Conference and Exhibition on Electricity Distribution*, pp. 1869–1873, Geneva, Switzerland, September 2021.

[5] T. A. Alexopoulos, N. M. Manousakis, and G. N. Korres, "Fault location observability using phasor measurements units via semi definite programming," *IEEE Access*, vol. 4, pp. 5187–5195, 2016.

[6] N. M. Manousakis and T. C. Korres, G. N. Korres, Synchrophasor applications using conic optimization," in *Proceedings of the 2018 IEEE International Energy Conference (ENERGYCON)*, pp. 1–6, Limassol, Cyprusdoi, June 2018.

[7] N. P. Theodorakatos, "Fault location observability using phasor measurement units in a power network through deterministic and stochastic algorithms," *Electric Power Components and Systems*, vol. 47, no. 3, pp. 212–229, 2019.

[8] X. Chen, T. Chen, J. T. King, Y. Sun, and G. Amaratunga, "Customized optimal μPMU placement method for distribution networks," in *Proceedings of the 2016 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, pp. 135–140, Xi'an, China, October 2016.

[9] X. Wang, X. Xie, S. Zhang et al., "A novel micro PMU for distribution power lines," in *Proceedings of the CIRED 24th International Conference on Electricity Distribution*, Shanghai, China, June 2017.

[10] M. Mosbah, S. Arif, R. D. Mohammedi, and A. Hellal, "Optimum dynamic distribution network reconfiguration using minimum spanning tree algorithm," in *Proceedings of the 5th International Conference on Electrical Engineering (ICEE-B)*, pp. 1–6, Boumerdes, Algeria, October 2017.

[11] W. Deng, J. Yang, Y. Tian, Y. Li, J. Xiao, and Y. Cao, "A distribution network reconfiguration method based on the representative daily load curve," in *Proceedings of the IEEE 3rd Conference on Energy Internet and Energy System Integration (EI2)*, pp. 2811–2815, Changsha, China, November 2019.

[12] P. L. Cavalcante, J. F. Franco, A. V. Garcia, M. R. R. Malveira, L. L. Martins, and L. C. M. Direito, "Centralized self-healing scheme for electrical distribution systems," *IEEE Transactions on Smart Grid*, vol. 7, no. 1, pp. 145–155, 2016.

[13] O. H. Abdalla, G. Abdel-Salam, and A. Mostafa, "Multi-function battery energy storage system for distribution networks," *Energy Engineering*, vol. 119, no. 2, pp. 569–589, 2022.

[14] M. R. Elkadeem, M. A. Alaam, and A. M. Azmy, "Optimal automation level for reliability improvement and self-healing MV distribution networks," in *Proceedings of the 18th*

International Middle East Power Systems Conference (MEPCON), pp. 206–213, Cairo, Egypt, December 2016.

[15] M. R. Elkadeem, M. A. Alaam, and A. M. Azmy, "Improving performance of underground MV distribution networks using distribution automation system: a case study," *Ain Shams University Production and Hosting*, vol. 9, 2016.

[16] J. Masimula and K. Awodele, "Optimal distribution automation devices placement for reliability improvement of a real distribution network with sub-feeders considering customer interruption cost," in *Proceedings of the Southern African Universities Power Engineering Conference/Robotics and Mechatronics/Pattern Recognition Association of South Africa (SAUPEC/RobMech/PRASA)*, pp. 732–737, Bloemfontein, South Africa, January 2019.

[17] A. Heidari, M. Kia, J. Aghaei, M. Shafie-Khah, and J. P. S. Catalao, "Reliability optimization of automated distribution networks with probability customer interruption cost model in the presence of DG units," *IEEE Transactions on Smart Grid*, vol. 8, no. 1, pp. 305–315, 2017.

[18] Y. Xu, C. Schneider, and K. P. Ton, "Placement of remote-controlled switches to enhance distribution system restoration capability," *IEEE Transactions on Power Systems*, vol. 31, no. 2, pp. 1139–1150, 2016.

[19] M. Izadi, M. Farajollahi, A. Safdarian, and M. F. Firuzabad, "A multistage MILP-based model for integration of remote control switch into distribution networks," in *Proceedings of the International Conference on Probabilistic Methods Applied to Power Systems (PMAPS)*, pp. 1–6, Beijing, China, October 2016.

[20] M. Izadi, A. Moeini-Aghtaie, and M. Lehtonen, "Optimal placement of protective and controlling devices in electric power distribution systems: a mip model," *IEEE Access*, vol. 7, 2019.

[21] J. N. Ahour, M. Rostami, V. T. Majd, M. Rashidbeygi, and H. Moazen, "Optimal switch placement with revised genetic algorithm in distribution system," in *Proceedings of the 2016 21st Conference on Electrical Power Distribution Networks Conference (EPDC)*, pp. 54–59, Karaj, Iran, April 2016.

[22] M. Izadi, M. Safdarian, and A. Safdarian, "Optimal deployment of remote-controlled switches in distribution networks considering laterals," *IET Generation, Transmission & Distribution*, vol. 13, no. 15, pp. 3264–3271, 2019.

[23] S. Lei, J. Hou, and Y. Hou, "Remote-controlled switch allocation enabling prompt restoration of distribution systems," *IEEE Transactions on Power Systems*, vol. 33, no. 3, pp. 3129–3142, 2018.

[24] N. Sabeel, A. Alam, and M. Zaid, "Feeder automation based strategy for reliability enhancement of radial distribution systems," in *Proceedings of the International Conference on Power Electronics, Control and Automation (ICPECA)*, pp. 1–6, New Delhi, India, November 2019.

[25] M. Mosaed and S. Hasan, "A new analytical approach of cost benefit analysis for automated medium voltage closed ring distribution networks," in *Proceedings of the 21st International Middle East Power Systems Conference (MEPCON)*, pp. 1095–1100, Cairo, Egypt, December 2019.

[26] M. Safdarian, A. Safdarian, MIP model for risk constrained switch placement in distribution networks," *IEEE Transactions on Smart Grid*, vol. 10, no. 4, pp. 4543–4553, 2019.

[27] United Nations Development Programme, *Sustainable Development Goals*, Department of Economic And Social Affairs Sustainable Development, New York, NY, USA, 2015.

[28] The Annual Conference of Parties (COP), *2015 Paris Climate Conference*, United Nations Climate Change, New York, NY, USA, 2015.

[29] The International Energy Agency (IEA), *Renewables 2021, Analysis and Forecast to 2026*, International Energy Agency, Paris, France.

[30] O. H. Abdalla, "Technical design specifications and criteria for integrating PV systems into distribution networks in Egypt", keynote lecture, KL-REN-5," in *Proceedings of the 1st FUE International Conference on New Energy & Environmental Engineering*, pp. 11–13, Cairo, Egypt, April 2016.

[31] N. P. Theodorakatos, N. M. Manousakis, and G. N. Korres, "Optimal placement of phasor measurement units with linear and non-linear models," *Electric Power Components and Systems*, vol. 43, no. 4, pp. 357–373, 2015.

[32] "Egyptian electricity law (decree no 87/2015)," 2015, https://egyptera.org/ar/SidePages/img/works/pdf/SitePDF/law2015.pdf.

[33] Egyptian Electric Utility and Customer Protection Regulatory Agency, "Periodical book-8/2019," 2019, https://egyptera.org/ar/download/journal/2019/8_2019.pdf.

[34] "Renewable energy law (decree no 203/2014) Egypt," 2014, https://egyptera.org/ar/Downloads/Laws/RenewableLaw.pdf.

[35] New & Renewable eEnergy Authority (NREA), "Annual report," 2021, https://www.nrea.gov.eg/Media/Reports.

[36] O. H. Abdalla, K. Youssef, and A. A. A. Mostafa, "SWOT analysis of photovoltaic energy in Egypt," in *Proceedings of the Cigre Egypt 2019 Conference, The Future of Electricity Grids—Challenges and Opportunities*, Cairo, Egypt, March 2019.

[37] Egyptian Electric Utility and Customer Protection Regulatory Agency, *Periodical Book-6/2022*, https://egyptera.org/ar/Download/journal/2022/6_2022.pdf, 2022.

[38] O. H. Abdalla and A. A. Mostafa, *Technical Requirements for Connecting Solar Power Plants to Electricity Networks Book Chapter in "Innovation in Energy Systems—New Technologies for Changing Paradigms*, Intech Open, London, UK, 2019.

[39] Egyptian Electricity Holding Company, "Annual report 2018/2019 Egypt," 2019, https://www.eehc.gov.eg/eehcportal/eng/YearlyReport/finalEnglish.pdf.

[40] Egyptian Electricity Holding Company, *Technical Specification for 24 kV Automated Smart RMU*, Ministry of Electricity and Renewable Energy, Cairo, Egypt, 2021.

[41] R. J. W. de Groot, *Optimal Placement and Operation of Novel Grid Technologies in Distribution Grids*, Eindhoven University of Technology, Eindhoven, Netherlands, 2017.

[42] Egyptian Electric Utility and Customer Protection Regulatory Agency, "Electricity tariff 2020/2021," 2020, https://egyptera.org/ar/Tarrif2020.a.

[43] IEEE PES Distribution System Analysis Subcommittee's Distribution Test Feeder Working Group Distribution Test Feeders, "Institute of electrical and electronics engineers," https://www.ewh.ieee.org/soc/pes/dsacom/testfeeders/index.html.

[44] Central Bank of Egypt, "Annual report 2019/2018," 2018, https://www.cbe.org.eg/ar/EconomicResearch/Publications/Pages/AnnualReport.aspx.