Network Reconfiguration to Improve Oman Distribution Network Parameters Using SCADA System and Fuzzy Clustering Technique

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Abstract

Electric utilities worldwide are going through a process aimed at load balancing, reducing technical losses and improving the power quality. Network reconfiguration is one of several methods or applications to achieve these goals. It is featured with no investment costs where it is carried out through identifying the best location of the open point in the network. For this purpose, this paper is focused on applying the fuzzy clustering technique (FCT) on real distribution network in Mazoon Electricity Network (MEN) as a part of Oman distribution network. Supervisory Control and Data Acquisition (SCADA) system is used for measurement the performance of MEN for minimizing the power losses and improving the voltage profile. The FCT is applied to classify the distribution nodes based on their belonging to their feeder branch. The output of this FCT application is to create different valid reconfiguration scenarios which are simulated by ETAP to extract the optimal scenario that achieves the optimal network operation in terms of power losses reduction and voltage profile improvement.

Research Article

Network Reconfiguration to Improve Oman Distribution Network Parameters Using SCADA System and Fuzzy Clustering Technique

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Introduction

Generally power system consists of generation, transmission, distribution and loads. The main task of the distribution sector to provide power demands to their individual consumers with their diversified types, from large and small, either residential, commercial or industrial customers. Electric distribution utilities facing many problems in operating their medium voltage networks, the most important is to reduce technical losses and improve the voltage profile. Distribution power system has mainly around 5-13% of the total power generation losses where the highest number of customer interruptions is occurred with approximately 80% of the total interruptions .

Distribution power system is used to supply power to individual customers and should be ready to meet affordable power demands by big and modest customers. Electrical utilities facing several issues in the operational of the distribution power network, most major is to decrease number of faults and minimize the outage time.

To overcome the network operation issues and increase its dependability, incessantly network observance and control ought to be applied. Power system automation depends on collection of data and taking actions by exploitation devices that providing the essential information from the network and within the same time it will control the network components. Distribution automation provides the capability for network reconfiguration, fault identification, fault isolation, services restoration and avoid overloading. In regard of the increasing use of supervisory control and data acquisition systems (SCADA), distribution system reconfiguration becomes a more viable alternative for loss reduction. Distribution systems equipped with SCADA system already possess the necessary automated switches and remote monitoring facilities. By availability of all required network data and measurements provided by SCADA system, selecting the feeders to apply the network reconfiguration on it become more easily plus the real time information availability support the dynamic network reconfiguration in case the switches automation functions exists. Distribution Automation could be a key ingredient for fulfilling those needs and developing new ways .

Distribution power system automation uses Supervisory Control and Data Acquisition system (SCADA) to achieve the automation principles and goals. SCADA is a system used on geographically wide area network that is suitable for the distribution power system. SCADA system could be a complete control system applied on the station level and the network level by exploitation communications system. It refers to the mixture of measurement and data acquisition. It commences with activity of measuring by specific devices within the field of application and picked up via intelligent electronic devices (IEDs), then transferring this information to a master station to implement the required process and control.

In electrical distribution systems, network reconfiguration is considered an important function in order to achieve the required goals in reducing the technical losses and improve the operation performance of the distribution network by improving the voltage profile.

The network reconfiguration concept is to modify the topology of the distribution network to minimize power losses and enhance voltage profile could be recognized as being cost efficient, and consequently of interest to efficiency conscious electric utilities.

In this paper, SCADA system is used for measurement the performance of MEN and the fuzzy clustering technique is developed to achieve the power losses reduction and enhance the voltage profile. Here introduce the paper. In the introduction, explain why you did it (motivation) and what you did (outcome). Potential readers are primarily interested in the motivation and outcome of your research. Do a thorough review and include a survey of the current literature available on this. Here, you need to introduce the main scientific publications on which your work is based, citing some original and important works. References must be listed at the end of the paper. Authors should ensure that every reference in the text appears in the list of references and vice versa.

Distribution Automation principles

Distribution automation is to gathering all necessary information from the network to control center via SCADA. The SCADA system is stands for Supervisory Control and Data Acquisition system that involve the follows:

- Collect the information from the field.
- Convert the information into transmissible type.
- Bundle the information into packets.
- Transmit the packets of information over the communication media.

- Receive the information at the control centre.
- Decrypt the information.
- Show the information at the suitable points on the show screens of the operator .

Data is that the basis of the control center that is giving the desired data to operator performs the correct call in network operation. For the present scrutiny of distribution network instrumentation supported manual input detection, there are issues like correctness and low potency .

Many types of information are transferred to control center, like components status and conditions, sequence of events and protection functions alarms. Another kind of information is that the measurements which are monitored instant like voltage, current, active power, reactive power and power factor. Transferring all measurements to the control center prevent engineer from site attending and provide all needed information for network study. After collection every type of data and keep within the control center, several applications obtainable within the SCADA system that are performing analysis and studies that facilitate the operator and planning engineer to take the correct selections for operating the network. One of the vital functions of SCADA is that provides the flexibility to control the various parts of the power network system that facilitate in quickly fault isolation and service restoration.

SCADA System Architecture

SCADA is an integrated control system consisting of a number of homogeneous stations connected by a communications network . Three main categorizes forms the architecture of the SCADA system: Substation Automation, Communication Network System and Master Station. Fig. 1 shows the SCADA System Architecture.

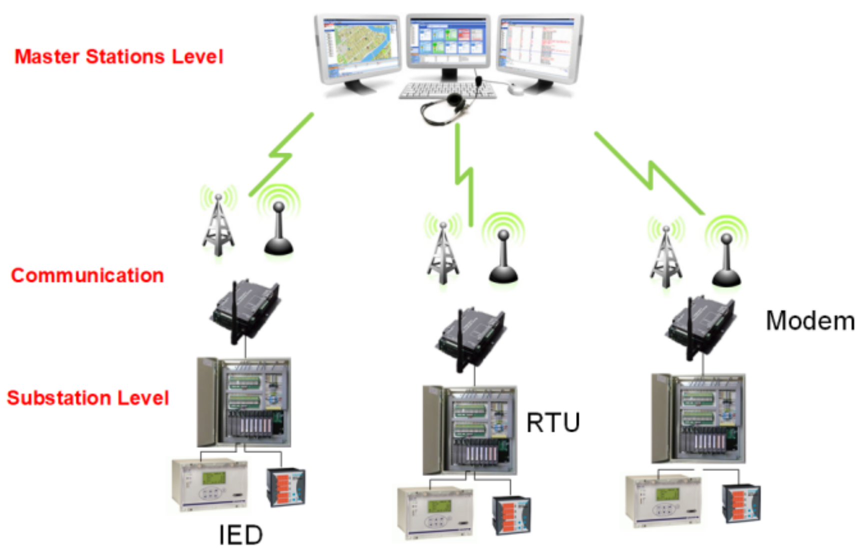

Figure 1 SCADA System Architecture

Substation Automation

Basically the substation automation level consists of sub-levels,

Level 1 (Field / Process):

This level contains the field equipments and switchgear, current transformers, voltage transformers, etc. Monitoring and measurement of system parameters are carried out at this layer.

Level 2 (Bay):

This level contains the protection and control equipment. Protective relays, Remote Terminal Units (RTU) and Intelligent Electronic Devices (IED) constitute this level. The collected information for level 1 is processed to this level.

Level 3 (Station):

This level contains the operator display and engineering workstation for executing the programs and monitoring & controlling the substation from central location.

There are two main types of automation for the substation. The first type is the RTU based solution. RTU is a device installed at a remote location that collects data, codes the data into a format that is transmittable and transmits the data back to the control center. RTUs are equipped with input channels for sensing, metering, indication or alarms and with output channels for control and communications ports.

This type is based on connecting the field signals through hardwire connection to the interface cards in the RTU plus connection through protocol to the protection relays for the protection signals and another connection to the Multi-Function Meter (MFM) for transferring the measurements. The RTU based solution is shown in Fig 2.

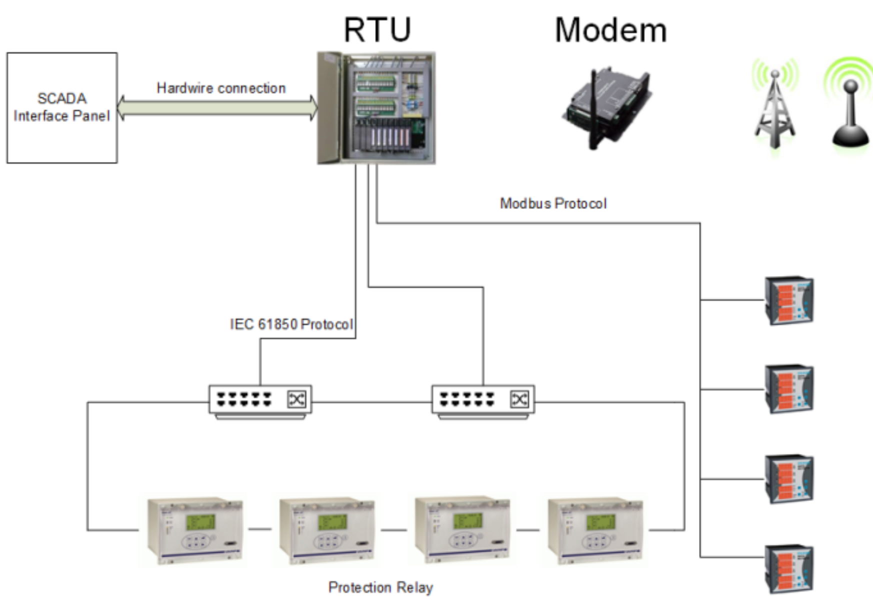

Figure 2 RTU Based Solution

The second type is the Substation Control System (SCS) which based on installing Bay Control Unit (BCU) gathering all signals types from a feeder and then all BCUs are connected through communication LAN to the central servers & gateways in the station. Fig. 3 shows the SCS based solution.

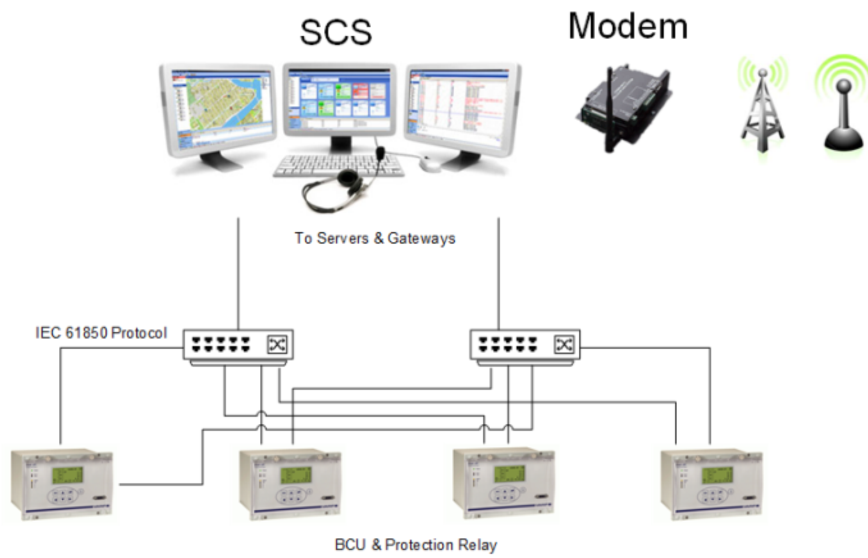

Figure 3 SCS Based Solution

Communication Network System

The nerve connecting all elements of the system is that the communication network. Without a properly designed and reliable communication network system, a SCADA system cannot survive. All supervisory control and data acquisition aspects of the SCADA system depend entirely on the communication system to provide a passage for flow of data between the supervisory controls, the data acquisition units, and any controllers that will be connected to the system.

The aim of a communications network among a SCADA system is to interface the remote terminal units (RTUs) / SCS Gateways with the SCADA Master Station. Two main types for the communication system which are:

- Wired: Many options for the wired communication system like, phone Line, Ethernet, power line Carrier, Fiber Optic and coaxial cable.
- Wireless Different types for the wireless communication system like, UHF, VHF, Wi-Fi, Microwave, Cellular and Satellite. Recently, the long term Evolution (LTE) wireless cellular network communication technology has been introduced and its diffusion is speedily increasing within the communication network for distribution automation .

Master Station

Master station forms the virtual brain of the power system automation system. The SCADA master station receives information and data from the field, decides what to do with it. Master station consists of multiple servers and software system applications. In trendy systems, the Master Station is usually a set of computers, peripherals, and appropriate input / output (I/0) subsystems that alter the dispatchers to monitor the state of the plant, say, power system and to control it. Master station equipment allows the dispatcher to monitor the system: visually, by sounding alarm, and by textual matter .

The SCADA master station consists of two parts:

- Servers Room: Location that housing all kinds of servers and devices like, Front-End servers, data engineering servers, SCADA servers, communication LAN, external disk storage and GPS. These devices

accountable for interfacing to the outstation through the communication cloud.
- Dispatcher Room: It is contains workstations with Human Machine Interface (HMI) that enable the control engineer to monitor and control the network. Operator workstation, system administration and training workstation, engineering workstation and printers are all devices available within the dispatcher room.

An important facet of each SCADA system is that the computer software system used within the system. The foremost obvious software system component is that the operator interface or HMI package. The software system computers process the data received from and sent to the RTU sites and present it to human operators in a very form that the operators will work with. The software system is programmed to inform the system what and when to monitor, what parameter ranges are acceptable, and what response to initiate once parameters modification outside acceptable values. SCADA System Master Stations are very important to safe, reliable, and economic operation of utility systems. Interruptions to the operation of the essential functions that they perform should so be as rare as potential. Moreover, whenever a failure happens, the system should be repaired in minimum time.

SCADA Applications

Based on data received from SCADA and to achieve the data acquisition goal for MEN, the Distribution Management System (DMS) are integrated with outage management systems (OMSs) and asset management systems (AMSs).

There are many considerations on how to control so much data. There is the centralized solution of DMS. A DMS is a real-time information system for all operational activities in a modern distribution control room . In power distribution systems, it is required to reduce outage time and provide more reliable delivery of electric power.

Distribution automation and SCADA system hinge on the information and data received from remote stations, based on that, the need to have devices in remote stations to send and transfer its data from field to control center is become essential for automation.

Distribution Management System is including multiple applications installed on the SCADA platform , like:

- Advanced alarms management.
- Network management.
- Fault management.
- Outage report.
- Switching orders.
- Network simulation.
- Distribution feeder optimization.
- Load flow analysis.
- Short-circuit calculation.
- Protection coordination.
- Automatic voltage regulator (AVR) application.
- Load forecast.
- Fault Location, Isolation and Service Restoration (FLISR).

The foundation of the monitoring system infrastructure is based on sensors, transducers and intelligent electronic devices (IED) collecting information throughout the distribution system . The most important element which is responsible to most of data received by control center is the intelligent Electronic Device (IED). There are many types of smart grid devices which install in the station based on the functions required, such as: Bay control units (BCU).

BCU is used for MEN for providing a wider range of control and automation capabilities at the individual bay. The BCU features a powerful user interface which will display single line diagrams, status, alarms and measurements. It's a key component among the versatile substation Automation System. In addition to the monitoring functions, BCU additionally support all control functions that are needed for operating the station. With integrated logic, the user will set, via a graphic interface, specific functions for the automation of switchgear or station. Functions are activated via function keys, binary input or via communication interface .

The BCUs and different smart devices using several communication protocols, IEC 61850 is widely used. IEC 61850 features a vital impact on all aspects of the smart Grid and is outlined as one of the key technologies for its development and implementation .

The proposed technique is tested on a part of Mazoon Distribution Electricity Company (MZEC) which generally is a part of Oman unified network. The selected part of study is a ring network from Al Ashkhara primary substation in Sharqiya region which is featured of high voltage drop problem.

Network Reconfiguration Definition

Electrical distribution networks are regularly configured as radial for appropriate protection coordination. To supply the loads, reduce power losses, increase power system security, and power quality improving, the reconfiguration of these networks may be diverse with manual or automatic switching operations. Network reconfiguration as well relieves the overloading of the network elements.

Modification in the topology of a distribution network for the sake of high efficiency operation of the system is results in network reconfiguration. Network reconfiguration would allow for the transfer of load from heavily loaded part of the power distribution system to locations that are relatively less loaded. This would not only improve the operation conditions but also allow the full utilization of system hardware capabilities. The network reconfiguration is performed during emergency for load restoration and in normal situation for loss reduction, load balancing and other goals .

However, the location of normally open switches represents a great challenge in searching for the best performance of the network operation. Network and feeder reconfiguration is finding the best location for the normally open switch in the network for each feeder.

One of the network reconfiguration types is the static distribution network reconfiguration which is providing optimal network structure based on constant load. Many techniques have been suggested for network reconfiguration and presented in different researches where, each technique handles various purposes like power losses reduction, voltage profile improvement, services restoration and load balancing.

Distribution system reconfiguration for loss reduction was proposed by Merlin and Back , which was based on power loss reduction using branch-and-bound type heuristic technique. Following this research, many methods and studies have been presented for system reconfiguration.

Challenges

In power distribution network, the feeder types are mainly two, radial and ring feeders. The first type and it is the simplest and with lower expensive in construction, but it has the disadvantage of no maintaining supply in the incident of a fault taking place in the feeder. The second type has more reliability with providing several possibilities to deliver the power by both pathways of the ring. In ring feeder arrangement, the open point is traditionally operated in manual manner and so the loss of supply restoration is done by manual switching which requires human intervention. Nowadays, both operations could be done automatically by SCADA if there is interface to control center which supports the modernized functions of the smart grids.

Therefore, the main challenge is how to choose the best location for the normally open point in the ring feeders that achieves the best network quality via searching for the Open/closed status of the switches. In this study, two objectives are considered for implementing the network reconfiguration which are reducing system losses and voltage profile improvement. It has been focused on applying the FCT to classify the distribution nodes based on their belonging to their feeder branch. Then, different valid reconfiguration scenarios are simulated by ETAP to extract the optimal scenario that achieves the optimal network operation in terms of power losses reduction and voltage profile improvement.

Proposed Technique

A distinct advantage of distribution system reconfiguration over the other numerous other methods of reducing line losses is the fact that it can be implemented at a minimal expense contrariwise of other methods which required big cost investment for enhancing the power quality .

In this study a clustering technique is firstly used to classify the distribution nodes based on their belonging to their feeder branch. Clustering techniques consider data as objects. They partition the objects into groups or clusters, so that the objects within a cluster are "similar" to one another and "dissimilar" to the objects in other clusters. Similarity is commonly defined in terms of how "close" the objects are in space, based on a distance function.

Clustering methods are used to identify groups of similar objects in a multivariate data sets collected from fields. There are different types of clustering methods, including:

- Partitioning methods
- Hierarchical clustering
- Fuzzy clustering
- Density-based clustering
- Model-based clustering

From the above mentioned types of clustering technique, the FCT used in this study, which is considered as soft clustering, where each element has a probability of belonging to each cluster. In other words, each element has a set of membership coefficients corresponding to the degree of being in a given cluster .

Clustering is a valuable unsupervised data mining technique which partitions the input space into K regions depending on some similarity/dissimilarity metric where the value of K may or may not be known a priori . The major objective of any clustering technique is to produce a K × n partition matrix U(X) of the given data set X, consisting of n patterns, X ={x1, x2, . . ., xn}. The partition matrix may be represented as U= [uk,j], k=1, . . ., K and j=1, . . ., n, where uk,j is the membership of pattern xj to the kth cluster. For fuzzy clustering of the data, 0 < uk,j < 1, i.e., uk,j denotes the degree of belongingness of pattern xj to the k th cluster. Evolving an appropriate U(X) is a complex optimization problem, requiring the application of advance optimization techniques.

This proposed method is applied to the studied network by utilizing the available input data which are:

- Transformer capacity on each node with MVA.
- Distance between each node and the feeder with KM.

Each node in the network will have electrical torque which formulated by calculating the product of transformer capacity and its distance from the supplied feeder. This data is formulated in a matrix form and the FCT is applied via MATLAB environment. Their output is many scenarios with different values where the higher values mean the higher evaluation. Then, the extracted scenarios are simulated in ETAP to show the best network operation performance.

Application

Test System Data

The network reconfiguration using the FCT for power losses reduction and voltage profile improvement applied and tested on a loop from Al Ashkhara primary substation in Sharqiya region as a part from MZN electrical network that is shown in Fig 1. It contains 2 main feeders and 29 transformers with different capacities. As stated in the proposed technique section, data model is obtained using SCADA system which is presented in Table 1. The collected data forms the matrix which is developed by MATLAP using the fuzzy cluster technique solution. Fig. 4 shows the single line diagram for MEN.

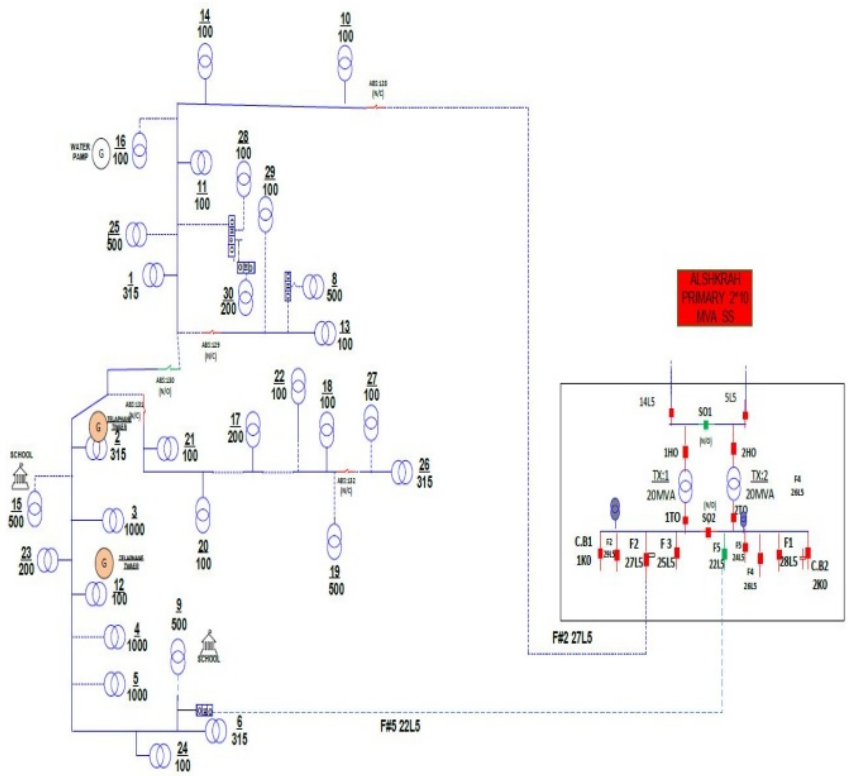

Figure 4 Single Line Diagram for MEN

Table 1 Calculated Data for Matrix Formulation

No.	Transformer Size (MVA)	Electrical Torque to F2	Electrical Torque to F5
10	0.2	2.396925	64.87546
14	0.1	69.495095	63.35826
16	1	69.9236	63.34986
11	0.1	71.55005	63.04956
28	0.1	85.41808	63.19356
30	0.1	88.31536	63.87996
25	0.5	98.17254	61.53756

No.	Transformer Size (MVA)	Electrical Torque to F2	Electrical Torque to F5
1	0.2	98.96427	60.78576
13	0.1	106.633335	61.13166
8	0.5	109.065405	59.95966
29	0.1	117.02318	62.29026
21	0.1	119.751695	62.38749
20	0.1	123.56229	67.02286
17	0.2	124.61955	61.13886
22	0.1	127.63897	69.19226
18	0.1	128.03279	61.02246
19	0.5	129.419015	60.36916
27	0.1	130.63621	71.61426
26	0.315	130.66141	64.613385
2	0.315	135.34996	58.40526
15	0.5	135.62815	58.22655
3	1	138.715315	55.63084
23	0.2	139.11985	52.32658
12	0.1	139.459375	51.44503
4	1	140.062165	51.24613
5	0.5	140.681935	46.8894
24	0.1	141.055255	42.91383
6	0.315	141.265525	40.79049
9	0.5	141.376525	38.8935

Results and comments

Before and after applying the network reconfiguration, the studied network is simulated using ETAP and its related results are tabulated in Table 2. From this simulation, there are some observed points as follows:

- There are many nodes which are operating under low voltage conditions (below 0.94 p.u.) with total number of 84 nodes.
- The minimum voltage is of 0.85 p.u. at node (006).
- The active power losses and the reactive power losses are 189 KW and 185 KVAr which represent a percentage of 7.2 % and 11.1% of the active and reactive total demand, respectively.

The network reconfiguration has been applied to the proposed network by formulating the matrix and developing it with FCT. The obtained results from MATLAB program show two possible scenarios to reconfigure the network by changing the open point. After simulating them, the best scenario is determined, and its related results is tabulated in Table 2. From this table, it is observed that there is significant reduction in both active and reactive power losses compared to the initial case. This reduction is reached to 32.8 % and 35.1 % for active and reactive power losses, respectively which represent a percentage of 4.8 % and 7.2% of the active and reactive total demand, respectively. In addition, the lowest bus voltage in the loop is enhanced. Added to that, the number of the buses that is operating under low voltage conditions is greatly reduced from 84 nodes to just 4 nodes which considered a recognized improvement of the voltage profile.

Table 2 Comparative results of Initial and optimal cases

	Initial Case	**After Network Reconfiguration**
Open Point	SW 244	SW 246
Active Power Losses	0.189 MW	0.127 MW

	Initial Case	After Network Reconfiguration
Active Power Losses Reduction Percentage	—-	32.8 %
Reactive Power Losses	0.185 MVAR	0.120 MVAR
Reactive Power Losses Reduction Percentage	—-	35.1 %
Minimum Voltage	0.85 p.u.	0.87 p.u.

Conclusions

In this paper, a proposed integrated method based on SCADA system, FCT and ETAP software has been applied on part of a real electrical network for applying the network reconfiguration. This proposed method is featured by very simple characteristics, easy and effective way, and great interactivity with the distribution operators. In addition, it is applicable for traditional and smart distribution systems. SCADA system has been used efficiently to obtain the performance measurement of MEN. However, SCADA system indicates that there are many performance of MEN need to improve. From the results, it can be observed that the proposed method gives better network performance by reducing the system power losses and improving the voltage profile.

Therefore, it can be recommended to thoroughly implement the network reconfiguration on the whole MEN by using the proposed technique based on the required goals to be achieved. Also, it can be recommended to automate selected switches even for critical feeders to enable dynamic network reconfiguration which will enhance the network reliability and reduce the fault restoration time.

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CONFLICT OF INTEREST

The author declares no potential conflict of interest.

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