INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

# OPTIMAL POWER RESTORATION IN PRIMARY DISTRIBUTION NETWORK CONSIDERING OPTIMAL ALLOCATION OF REMOTE CONTROLLED SWITCHES.

Engineering

| | |
|---|---|
| **Ahmed R AbulWafa** | Ain Shams University, Cairo, Egypt. |
| **Doaa Adel Sabry*** | RAKA Design, Cairo, Egypt *Corresponding Author |
| **Hesham K.Temraz** | RAKA Design, Cairo, Egypt |

## ABSTRACT

This paper presents a novel modified method to identify the optimal power restoration on distribution system for improving the grid reliability. A popular strategy involves the placement of protective devices, switching devices, and its decision action plays a critical role in the distribution system restoration plan for improving reliability. In the proposed method, Remote control switches (RCS) are performed on a feeder scheme with proper placement to minimize the outage times. The main goal of this paper is solving restoration problem to restore a maximum load and minimize energy not supplied (ENS); Thereby, giving optimal allocations and least number of switching pairs necessary for system restoration. The priority for power restoration is provided to critical consumers such as hospitals, military services, call centers, water station plants, fire stations and largest pockets of customers. Power restoration steps are achieved according to progressive investment capability, from fault detection, fault isolation then power restoration. The objective of this paper is to analyze power restoration problem solved after a complete or partial blackout or after any planned outage and make sure that investment yields the most beneficial return. This paper describe a methodology simulation associated with RCS carried out on a part of benchmark medium voltage radial distribution models and a part of real MV distribution network developed in Dig-SILENT Power Factory software (DSL). The simulation focus on two different scenarios for each simulated network. The first using manual switches, the second scenario using RCS. Several case studies and the simulation results are discussed and demonstrated. It was concluded that the use of RCS with optimal number and location improve reliability performance by reducing the duration of interruptions and energy not supplied (ENS). It is clear that implementation of remote control switches is the key solutions to fast power restoration and improving network reliability.

## KEYWORDS

Restoration, Distribution network, Reliability Indices, Remote controlled switches.

## INTRODUCTION

The distribution system is a very important network as it represents the direct supply to end-users; therefore, any blackout is not accepted. Several blackouts occurred worldwide, e.g., North America in 2003 which caused great loss and the restoration persisted for almost two weeks, European power outage in 2006 affected 10 million consumers and continues up to 2 hours, Brazil and Paraguay experienced an extensive blackout in 2009, Fukushima nuclear power plant was shut down after the earthquake and tsunami in 2011, and the largest power outage in India about 50 GW of load, affected 670 million people and continued for two days in 2012.

Power system restoration is a very important and complex process. The reliability of the distribution network has measured the ability of the power system to deliver the electric power to the load continually. Moreover, the true power quality is the high power system reliability. The main objective of an electrical power system is to supply large customers or even small ones with electrical energy as economically and as reliably as possible. Consequently, the fast power restoration after an outage is a very significant procedure to enhance the distribution network reliability. The proper restoration plan can mitigate the negative impact on the consumers, the economy and the power system. The power quality is ordinarily measured by its ability to provide an adequate, secure power supply. Moreover, reducing the probability of customers being disconnected and keeps the value of the voltage or harmonic RMS same as the standard value.

The distribution network contains a number of normally closed switches (sectional switches) and normally open switches (Tie line switches). If these switches are remotely controlled then, the customers between two RCS are isolated from the rest of the distribution grid. The SAIDI is improved with a better outage management during a power failure. The installations of remote controlled switches improve the quality of service and isolate the fault for persistent faults in order to quicken the work of linemen. The optimal allocation of the switches to open or close to restore energy is the key to solve the restoration problem and improve the performance of the distribution network. In [23], RCS allocation strategies with fixed switching pair and with flexible switching pair are considered. When the switching pair is fixed, it may not be sufficient for certain fault conditions due to operating one pair alone. Severe challenges are observed in large systems. The complexity increases with growth of distribution system size. Therefore, the fixed switching pair is not a viable option. It was clarified in [23-24] that if the switching pair is flexible, the restoration plan can cover all fault conditions and maintaining radial network structure. However, when the search space is the whole system, it can take a long processing time to find the global optimal solution.

During the last decade, several researches have been conducted and great progress has been achieved towards power restoration for improving the reliability of the distribution network [3-19]. With the development of computer intelligence program, several algorithms are applied to distribution network to solve the optimal placement of protective devices, such as artificial neural networks [3], genetic algorithms [4], and fuzzy logic [5]. Graph theory with Petri nets [6] is also employed, but the constraints and reduction of uncertainties both need improvement. Based on the regional distribution characteristics in space, multi-agent technologies [7, 8] are developed with the potential prospect. As a functional extension of expert systems and heuristic rules, decision support systems [9] have been demonstrated efficiently. After the isolation of the faulty region, the power supply must be restored in whole or in part through the network reconfiguration [10]. This task is known as restoration [11] and can be achieved following several scheduled decisions comprising switching actions and load curtailment strategies, if necessary, with the main purpose of maximizing the supplied Loads and minimizing the customer interruption duration [12]. [17-18] have used a combined method, the switch exchange (SEM) and sequential switch opening method (SSOM), for reconfiguration of the network for loss reduction. Broadwater and Khan [19] have suggested a reconfiguration algorithm which calculates switch patterns as a function of time. Either seasonal or daily time studies may be performed. Both manual and automatic switches are used to reconfigure the system for seasonal studies whereas only automatic switches are considered for daily studies.

In this paper, A comprehensive planning of distribution network to make the power as safely, quickly restored and reliably as possible. Installing RCS with optimum allocation considering the failure is presented. The energy not supplied is minimized. The maximum amount of restored power in a minimized restoration time and the investment cost are compared between two scenarios subject to system operational constraints. The validity of this method is examined through part of MV benchmark distribution models and part of real distribution network. Moreover, the distribution networks are simulated with two different scenarios. The first scenario used manual switches and the other scenario using RCS. The simulations are carried out in dig-silent power factory [20].

## POWER RESTORATION

A major problem facing the operators in case of an outage is to establish overall information about the whole status of the power system. Currently, the SCADA (Supervisory Control And Data Acquisition) system plays an important role to help the operators. Consequently, remote controlled switches (RCS) actuate time are1-3 minutes to bring back power supply with cost-effective way. By contrast, in past decades circuits having manual restoration may take on an average 2-3 hours for being restored after the power outage is reported. The study focuses on the implementation of the restoration process using remote-controlled switches to improve the reliability of the network and decrease the number of switches action required to restore a total amount of power. The power restoration process is achieved through the following five steps [22]:

1. Fault Location Detection: the feeder fault detectors are responsible to detect the fault sector and recognize it with the faulted network element using appropriate methods. These methods take into account all equipment in the distribution system for fault detection and location.
2. Fault Isolation: the switch action 'on or off' which isolate the fault section, locating the part of the feeder with the faulted element using remotely controlled switching devices. This step is used for feeders without any equipment such as fault indicators and fault measurements.
3. Service Restoration: Re-supplying and reconfiguration of the distribution network by restoring the maximum and available consumers in the un-faulted area.
4. Check the entire network overload and voltage violation.
5. Return to Normal State: The network returned to the state before the fault occurred.

## REMOTE CONTROLLED SWITCHES

The flexible switching pair strategy limits the loop that was formed by closing the tie-line switch after isolating a fault instead of the whole system. Once a tie-line switch is selected it can be considered as the best switching allocation. Hence, an improved switching pair operation can be performed under two conditions: (1) if the fault isolation is within the loop, no more action needs to be opened when the tie-line closes, and (2) otherwise, a line segment within the loop needs to open after the tie-line switch closes. The installation of such switches makes it possible to restore power in a short time to most customers during an electric outage, which enables to enhance the SAIDI; Moreover reducing energy not supplied and the failure cost. Consequently, enhancing the SAIDI involves large investments especially for burying all MV lines. The reliability indices improved with a better outage management during a power failure.

After an outage in the network, the electrical network can be divided into two main areas the separated area and the restorable area. In this paper, RCS actuate time is 1 minute which isolate the fault "faulted area" between two remote-controlled switches and connect the other uninterrupted area "restored area". Figure 1.a shows that RCS is integrated into the (MV/LV) substations, which are directly placed on the main lines [24]. Figure 1.b shows only the main lines of the feeder and the customers between two RCS can be isolated from the rest of the distribution grid due to the RCS location. The types or RCS are different based on the purpose action and the location. The type used in this study are MV remote controlled switches which are different from circuit breaker as they required additional external action for the trigger and different from disconnects as they can automatically close and break under voltage circuit.

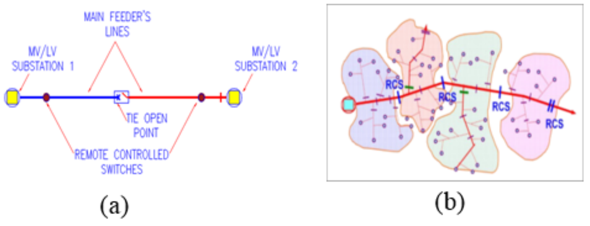


**Figure 1: One line schematic for RCS locations of a primary substation and a feeder**

In this paper, the main objective is to optimize power restoration after fault occurrence in a power distribution network considering optimum allocation of RCS. The outcome is to restore the faulted area using RCS, minimizing restoration time and the energy not supplied.

$$\min \; ENS = \sum_i (\sum \lambda_k * \mu_k * f_{i,k})*(P_{d_i} + P_{s_i})) \quad (1)$$

The biggest challenges have had optimization of the objective function or reducing the ENS depends on the optimum number and allocation of the RCS [25-30].

Where,

| | | |
|---|---|---|
| i | : | Load point |
| K | : | Contingency index |
| $\lambda_k$ | : | The frequency of interruption. |
| $\mu_k$ | : | The duration of the interruption. |
| $f_{i,k}$ | : | $f_{i,k} = \begin{cases} 0, & \text{in case of unsupplied load or for tot} \\ >0 \; and <1, & \text{in case of any parti} \end{cases}$ |
| $P_{di}$ | : | Average amount of disconnected power at load point *I*. |
| $P_{si}$ | : | Average amount of restored power at load point *I*. |

**Subject to operational constraints:**

Bus voltage limitation.

Feeder capacity constraints.

The optimum allocation of RCS analysis methodology is illustrated by flowchart shown in Figure 2. The methodology acts to find the optimal allocation of RCS that will maximize the electrical power restoration to consumers in the MV distribution network after fault isolation, without violating the operational constraints. The objective is closely related to decrease the number of RCS to maintain the annual cost within the required reduction and decrease the energy not supplied. The analysis requires obtaining the global solution with the lowest cost. The restoration time process after any short circuit occurs can be classified as follows

Time of circuit breaker T=0s, once short circuit occurs on a secondary MV line the circuit breaker located at the primary side of the substation will be opened automatically and all the customer at this feeder will be disconnected [3].

Time of remote control switch TRCS= 2 min, this time will be taken by the RCS to isolate the faulted area and power restoration. In the previous decades, this time can reach 12 hr taking by maintenance team going along the MV cables to accurately locate and identify the faulted section all this time the customers are waiting for the line to be repaired.

Time of short circuit TIND. = 30min, maintenance team checks any overload on

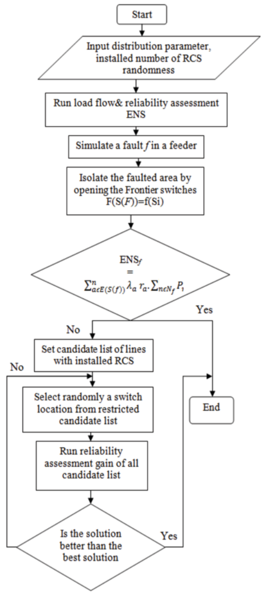


**Figure 2: Flowchart representing the optimum allocation of RCS methodology using in dig-silent software.**

**POWER RESTORATION ANALYSIS METHEDOLOGY**

The restoration problem can be solved using mathematical programming approaches. Either optimization technique or linear graph theory can be used in mathematical programming. In the optimization technique, the execution time required to solve the restoration problem increases exponentially; while in the graph theory time increases linearly. In this paper dig-silent power factory optimization technique are used as per the flowchart in figure 3. The DSL software has its programming algorithm which carried out the decisions for mitigation contingency using input all appropriate data.

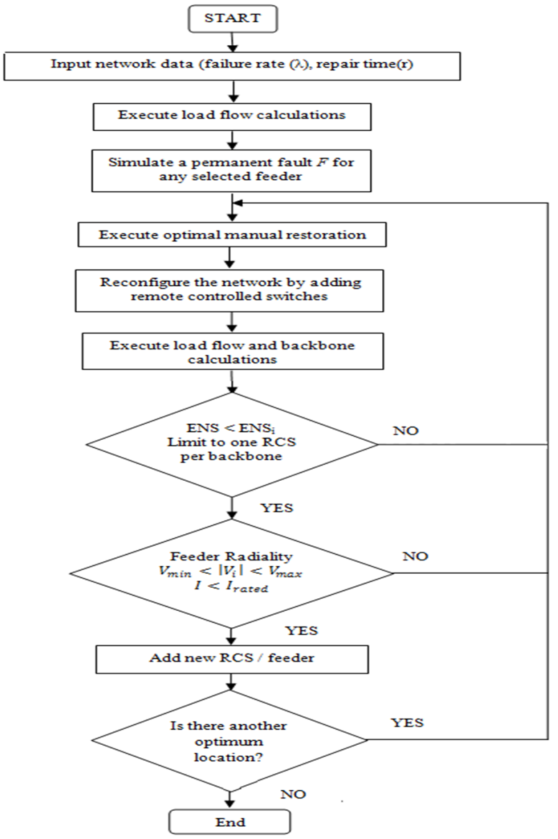


**Figure 3: Flowchart for the restoration methodology algorithm using in power factory software.**

For estimating the cost of blackouts, the Lawrence Berkeley National Laboratory has published many reports and a free web-based tool, the Interruption Cost Estimation (ICE) Calculator [21].

Simulation and Discussion of a benchmark distribution network The benchmark model is taking from dig-silent standard distribution network. Figure 4 represent the electrical distribution system by a graphic representation single line diagram (SLD). These diagrams depict information corresponding to equipments such as:

- Circuit breakers and disconnectors,
- Tie open points,
- Transformers 33/11KV, 10MVA.
- Power cables.
- Loads.

The model consists of six substations with 130 MVA capacity serving a large area with different types of residential, industrial and commercial loads. All network data are described in [20]. Simulated fault location is defined at line number 44. The impact of this fault will be on three substations (1, 2, and 6). Two scenarios has been considered as follow:

Scenario 1: benchmark model with two manual switches.
Scenario 2: benchmark model with two pair of RCS at the tie open point.

Reliability indices calculated for each simulated scenario before and after the installation of (RCS) and the results had been compared. Tables 1 and 2 describe the output results for both scenarios. Comparison for both scenarios is displayed in Table 3.

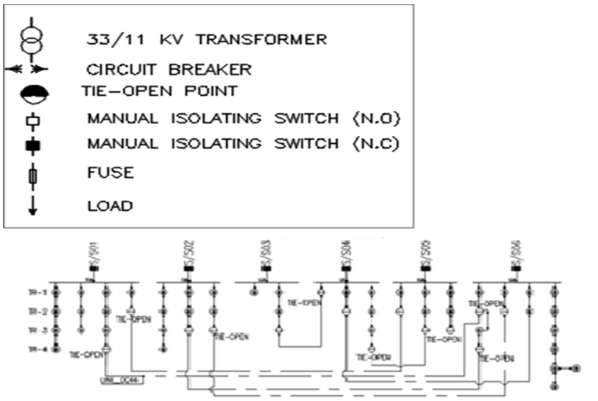


**Figure 4: Benchmark mode - 33/11kv diagram**

**Table -1Results of the benchmark model - scenario 1: With two manual switch**

Contingency: n-1

Fault location (n-1)
Component: LN_0044 Line
Network: 11kV System

Ideal component. Repair duration and failure frequency are unknown.

Summary of failure effects

| | Power | Customers |
|---|---|---|
| Interrupted: | 749.5 kW | 40 |
| Restored: | 749.5 kW (100.0 %) | 40 (100.0 %) |
| Energy not supplied | 374.7 kWh | |
| | 1/failure | |
| Interruption costs: | 862.8 k$ | |

| Time [min] | Step | Action | Device | Station: |
|---|---|---|---|---|
| 0:00 | Protection | Open | SW_0928 | SUBSTAT_06 |
| 30:00 | Short Circuit Indicator | Open | SW_0467 | TRFSTA11_4 |
| 30:00 | | Open | SW_0468 | TRFSTA11_4 |
| 30:00 | | Open | SW_0469 | TRFSTA11_4 |
| 30:00 | | Open | SW_0470 | TRFSTA11_4 |
| 30:00 | | Open | SW_0471 | TRFSTA11_4 |
| 30:00 | | Open | SW_0472 | TRFSTA11_4 |
| 30:00 | | Open | SW_0474 | TRFSTA11_4 |
| 30:00 | | Close | SW_0708 | TRFSTA11_3 |
| 30:00 | | Close | SW_0709 | TRFSTA11_3 |
| 30:00 | | Close | SW_0710 | TRFSTA11_3 |
| 30:00 | | Close | SW_0711 | TRFSTA11_3 |
| 30:00 | | Close | SW_0712 | TRFSTA11_3 |
| 30:00 | | Close | SW_0713 | TRFSTA11_3 |
| 30:00 | | Close | SW_0714 | TRFSTA11_3 |
| 30:00 | | Close | SW_0716 | TRFSTA11_3 |
| 30:00 | | Close | SW_0717 | TRFSTA11_3 |
| 30:00 | | Close | SW_0718 | TRFSTA11_3 |
| 30:00 | | Close | SW_0719 | TRFSTA11_3 |
| 30:00 | | Close | SW_0721 | TRFSTA11_3 |
| 30:00 | | Close | SW_0722 | TRFSTA11_3 |
| 30:00 | | Close | SW_0723 | TRFSTA11_3 |
| 30:00 | | Close | SW_0928 | SUBSTAT_06 |

Interrupted: 749.5 kW

| | |
|---|---|
| Interrupted: | 0.0 kW |
| Restored Power: | 749.5 kW (100.0 %) |
| Restored Customers: | 40 (100.0 %) |
| Totally Restored Power: | 749.5 kW (100.0 %) |
| Totally Restored Customers: | 40 (100.0 %) |
| ENS:(0:00 - 30:00) | 374.7 kWh |
| Total ENS: | 374.7 kWh |

**Table -2 Results of the benchmark model – scenario2: With 1 pair of remote controlled switch at the tie open point**

Contingency: n-1

Fault location (n-1)
Component: LN_0044 Line
Network: 11kV System

Ideal component. Repair duration and failure frequency are unknown.

Summary of failure effects

| | Power | Customers |
|---|---|---|
| Interrupted: | 746.6 kW | 40 |
| Restored: | 746.6 kW (100.0 %) | 40 (100.0 %) |
| Energy not supplied | 51.6 kWh | |
| | 1/failure | |
| Interruption costs: | 118.8 k$ | |

| Time [min] | Step | Action | Device | Station: | |
|---|---|---|---|---|---|
| 0:00 | Protection | Open | SW_0928 | SUBSTAT_06 | Interrupted: 746.6 kW |
| 1:00<br>1:00<br>1:00<br>1:00 | Remote Controlled<br><br>Short Circuit Indicator | Open<br>Open<br>Open<br>Close | SW_0464<br>SW_0564<br>SW_0578<br>SW_0040 | TRFSTA11_4<br>TRFSTA23_1<br>TRFSTA23_1<br>TRFSTA09_1 | Interrupted: 443.5 kW<br>Restored Power: 303.1 kW ( 40.6 %)<br>Restored Customers: 6 ( 15.0 %)<br>Totally Restored Power: 303.1 kW ( 40.6 %)<br>Totally Restored Customers: 6 ( 15.0 %)<br>ENS:(0:00 - 1:00) 12.4 kWh<br>Total ENS: 12.4 kWh |
| 5:00 | | Close | SW_0463 | TRFSTA11_4 | Interrupted: 57.6 kW<br>Restored Power: 385.9 kW ( 51.7 %)<br>Restored Customers: 15 ( 37.5 %)<br>Totally Restored Power: 689.0 kW ( 92.3 %)<br>Totally Restored Customers: 21 ( 52.5 %)<br>ENS:(1:00 - 5:00) 29.6 kWh<br>Total ENS: 42.0 kWh |
| 15:00 | Manual | Close | SW_0928 | SUBSTAT_06 | Interrupted: 0.0 kW<br>Restored Power: 57.6 kW ( 7.7 %)<br>Restored Customers: 19 ( 47.5 %)<br>Totally Restored Power: 746.6 kW (100.0 %)<br>Totally Restored Customers: 40 (100.0 %)<br>ENS:(5:00 - 15:00) 9.6 kWh<br>Total ENS: 51.6 kWh |

**Table -3 Results comparison of benchmark model reliability indices**

| Reliability Indices | Scenario 1 | Scenario 2 | Reduction percentage % |
|---|---|---|---|
| ENS (MWh/a) | 373 | 186.7 | 50% |
| Interruption cost (k$) | 859.4 | 429.9 | 50% |
| Total annual costs (k$/a) | 171.8 | 35.75 | 79 |
| SAIFI (1/Ca) | 12.542 | 2.906 | 77% |
| SAIDI (h/Ca) | 15.187 | 7.384 | 51% |
| CAIDI (h) | 3.092 | 1.446 | 53% |

Table-3 illustrates the reduction value of ENS about 50% and that is also for the interruption cost enhanced by 50% but this value compared with the cost value of the RCS which are added to the network, the cost of RCS is about 12 K$ [5], even after the addition of RCS the cost of case 2 is enhanced by about 48%. The value can be increased in the modern society which considers the penalty value.

**Simulation and discussion of Al Sherouk distribution network - 66/22kv Substation.**

The restoration process is implemented, using dig-silent power factory software on Al sherouk Distribution network which is a part of the distribution network in Al Qahira distribution network. Network SLD is shown in Figure 5. The network (66/22KV) consists of two interconnection lines, two spare line and two neighboring feeders, 4 x 66/22 KV main transformers each rated, 25 MVA, 66 KV, Over Head Transmission Line (OHTL) interconnection to the National Grid. Fault used in the test located at line 6. The estimated component data for the analyzed feeder as per Figure 6 depends on Global Positioning System (GPS) and global information system (GIS) [31].

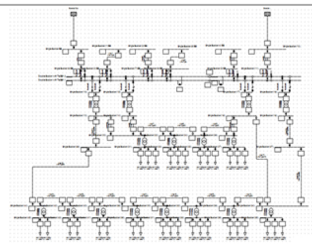

**Figure 5- Real Egypt Distribution Network (Al Qahira- Al SherouK)**

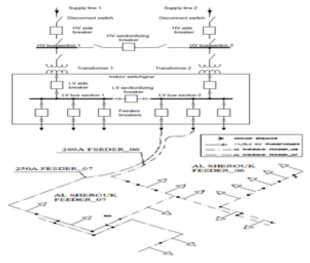

**Figure 6: One line diagram of fault occur at feeder_06**

Table 4 represent the initial results without installing RCS while Tables 5 represent the best ENS values within a few iterations and the corresponding number and location of RCS as obtained by DSL for Al Sherouk distribution system. Comparison for both scenarios is presented in Table 6.

**Table-4 Results of Al Sherouk -Scenario 1: With manual switches**

Contingency: n-1

Fault location (n-1)
Component: Line(6) Line
Network: Grid

Repair Duration: 6.00 h (360 min)
Failure frequency: 0.200 1/a

Summary of failure effects

| | Power | Customers | |
|---|---|---|---|
| Interrupted: | 3040.0 kW | 40 | |
| Restored: | 3040.0 kW (100.0 %) | 40 (100.0 %) | |
| Energy not supplied | 1520.0 kWh | | |
| | 1/failure | Yearly | Yearly (load state) |
| Interruption costs: | 60.8 k$ | 12.160 k$/a | *100.00 % = 12.160 k$/a |

| Time [min] | Step | Action | Device | Station: | |
|---|---|---|---|---|---|
| 0:00 | Protection | Open | CB2 | Single Bus | Interrupted: 3040.0 kW |
| 30:00<br>30:00<br>30:00<br>30:00<br>30:00<br>30:00<br>30:00<br>30:00<br>30:00<br>30:00 | Short Circuit Indicator<br><br><br>Manual | Open<br>Open<br>Open<br>Open<br>Open<br>Close<br>Close<br>Close<br>Close<br>Close | CB2<br>CB3<br>CB4<br>IS1.1<br>IS2.1<br>CB1<br>CB2<br>CB2<br>CB3<br>CB4 | Single Bus<br>Single Bus<br>Single Bus<br>Single Bus<br>Single Bus<br>Single Bus<br>Single Bus<br>Single Bus<br>Single Bus<br>Single Bus | Interrupted: 0.0 kW<br>Restored Power: 3040.0 kW (100.0 %)<br>Restored Customers: 40 (100.0 %)<br>Totally Restored Power: 3040.0 kW (100.0 %)<br>Totally Restored Customers: 40 (100.0 %)<br>ENS:(0:00 - 30:00) 1520.0 kWh<br>Total ENS: 1520.0 kWh |
| 360:00 | Repair: | | | | ENS:(30:00 - 360:00) 0.0 kWh<br>Total ENS: 1520.0 kWh |

**Table -5 Results of Al Sherouk -Scenario 2: With 1 pair of remote controlled switch at the tie open point**

```
Contingency:     n-1

Fault location (n-1)
   Component:        Line(6)            Line
   Network:          Grid

   Repair Duration:                     6.00 h    (360 min)
   Failure frequency:                   0.200 1/a

Summary of failure effects
                                 Power                        Customers
  Interrupted:                 3040.0 kW                        40
  Restored:                    3040.0 kW (100.0 %)              40 (100.0 %)
  Energy not supplied            50.7 kWh

                               1/failure                    Yearly          Yearly (load state)
  Interruption costs:             2.0 k$                    0.405 k$/a     *100.00 % = 0.405 k$/a
---------------------------------------------------------------------------------------------------
 Time [min]        Step          Action     Device      Station:       |
---------------------------------------------------------------------------------------------------
   0:00  Protection              Open       CB2         Single Bus     |
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | - - - - - - - - - - - - - -
                                                                       | Interrupted:            3040.0 kW
---------------------------------------------------------------------------------------------------
   1:00  Remote Controlled       Open       CB1         Single Bus     |
   1:00                          Close      CB3         Single Bus     |
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | - - - - - - - - - - - - - -
                                                                       | Interrupted:                 0.0 kW
                                                                       | Restored Power:           3040.0 kW (100.0 %)
                                                                       | Restored Customers:         40      (100.0 %)
                                                                       | Totally Restored Power:   3040.0 kW (100.0 %)
                                                                       | Totally Restored Customers: 40      (100.0 %)
                                                                       | ENS:(0:00 - 1:00)           50.7 kWh
                                                                       | Total ENS:                  50.7 kWh
---------------------------------------------------------------------------------------------------
  30:00  Manual                  Open       IS1.1       Single Bus     |
  30:00                          Open       IS2.1       Single Bus     |
  30:00                          Close      CB1         Single Bus     |
  30:00                          Close      CB2         Single Bus     |
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | - - - - - - - - - - - - - -
                                                                       | Interrupted:                 0.0 kW
                                                                       | Restored Power:              0.0 kW (  0.0 %)
                                                                       | Restored Customers:          0      (  0.0 %)
                                                                       | Totally Restored Power:   3040.0 kW (100.0 %)
                                                                       | Totally Restored Customers: 40      (100.0 %)
                                                                       | ENS:(1:00 - 30:00)           0.0 kWh
                                                                       | Total ENS:                  50.7 kWh
---------------------------------------------------------------------------------------------------
 360:00  Repair:                                                       |
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - | - - - - - - - - - - - - - -
                                                                       | ENS:(30:00 - 360:00)         0.0 kWh
                                                                       | Total ENS:                  50.7 kWh
```

**Table -6 Results comparison of Al Sherouk -66/22 KV Reliability indices**

| Reliability Indices | Scenario 1 | Scenario 2 | Reduction percentage % |
|---|---|---|---|
| ENS (MWh/a) | 1520 | 50.2 | 96% |
| Interruption cost (k$) | 60.8 | 2 | 90 |
| Total annual costs (k$/a) | 12.160 | 0.405 | 96 |
| SAIFI (1/Ca) | 20 | 2 | 90 |
| SAIDI (h/Ca) | 50 | 5 | 90 |
| CAIDI (h) | 20 | 2 | 90 |

## CONCLUSION

RCS are the most automated technique to be utilized for optimum number and allocation in the electric power distribution network to achieve optimum and safely power restoration. The opening and closing of RCS action has been done according to the switching optimization technique to restore power to consumers affected by the feeder outage. A system model and techniques are presented for evaluating the contribution of installing RCS in the overall system reliability and annual cost. The basic indices obtained from the process, and used as a measurement to compare between different scenarios, are the ENS and the annual cost. A methodology simulated in a computer using Dig-silent Power Factory software. The method has been applied to a benchmark model and real distribution network, each network simulated with two different scenarios and the obtained results were compared to clarify the effectiveness of using RCS in decreasing ENS and total annual cost. In this paper, the ENS reduction achieves 35%- 60% range of the base case and the annual cost reduction is 40%-90%.

## REFERENCES


[1] Allen EH, Stuart RB, Wiedoan TE (2014) No light in August: "power system restoration following the 2003 North American blackout". IEEE Power Energy Mag 12(1):24–33.

[2] Xue YS, Xiao SJ (2013) Generalized congestion of power systems:" insights from the massive blackouts in India". J Mod Power Syst Clean Energy 1(2):91–100. doi: 10.1007/s40565-013-0014-2.

[3] IEEE Guide for Electric Power Distribution Reliability Indices, IEEE Standard 1366-2012, pp. 1–43, 2012.

[4] Rajneesh K.Karn, Yogendra Kumar and Gayatri Agnihotri. (2013) "Multi-Objective Service Restoration Considering Primary Customers using Hybrid GA-ACO Algorithm", International Journal of Computer Applications, Vol. 64, No.3, February.

[5] Liu WJ, Lin ZZ, Wen FS et al (2012) "Intuitionist fuzzy Coquet integral operator-based approach for black-start decision-making". IET Gener Transm Distrib 6(5):378–386.

[6] Quirós-Tortós J, Panteli M, Wall P et al (2015) "Sectionalizing methodology for parallel system restoration based on graph theory". IET Gener Transm Distrib 8(11):1216–1225.

[7] Ye DY, Zhang MJ, Sutanto D (2011) "A hybrid multiagent framework with Q-learning for power grid systems restoration". IEEE Trans Power System 26(4):2434–2441.

[8] Wang HT, Liu YT, Qiu XZ et al (2006) "Multi-agent based on stackelberg decision for power system restoration". Autom Electr Power System 30(15):5–9.

[9] Hou YH, Liu CC, Sun K et al (2011) "Computation of milestones for decision support during system restoration". IEEE Trans Power System 26(3):1399–1409.

[10] Qiu F, Wang JH, Chen C et al (2016) "Optimal black start resource allocation". IEEE Trans Power System 31(3):2493–2494.

[11] Wang C, Vittal V, Sun K (2011) OBDD-"based sectionalizing strategies for parallel power system restoration". IEEE Trans Power System 26(3):1426–1433.

[12] Quirós-Tortós J, Wall P, Ding L et al (2014) "Determination of sectionalizing strategies for parallel power system restoration: a spectral clustering-based methodology". Electr Power System Res 116(1):381–390.

[13] Zhang C, Lin ZZ, Wen FS et al (2014) "Two-stage power network reconfiguration strategy considering node importance and restored generation capacity". IET Gener Transm Distrib 8(1):91–10.

[14] Sun W, Liu CC, Zhang L (2011) "Optimal generator start-up strategy for bulk power system restoration". IEEE Trans Power System 26(3):1357–1366.

[15] Mota AA, Mota MTM, Morelato A (2007) "Visualization of power system restoration plans using CPM/PERT graphs". IEEE Trans Power System 22(3):1322–1329.

[16] T. Taylor, D. Lubkeman, "Implementation of Heuristic Search Strategies for Distribution Feeder Reconfiguration", IEEE Transactions on Power Delivery, Vol. 5, No. 1, January 1990, pp. 239-246.

[17] G.J Peponis, M.P. Popadopoulos and N.D Hatziargyrion, "Distribution network reconfiguration for resistive line losses", IEEE Transactions on Power Delivery, Vol. 10, No. 3, 1995, pp. 1338-1342.

[18] R.P Broadwater, A.H. Khan, H.E Shalaan and R.E. Lee, "Time varying load analysis to reduce distribution losses through reconfiguration", IEEE Transactions on Power Delivery, Vol. 8, No. 1, 1993, pp. 294-300.

[19] A. Borghetti, M. Paolone and C.A. Nucci " A mixed integer linear programming approach to the Optimal configuration of electrical distribution Networks with embedded generators" 17th Power Systems Computation Conference, Stockholm Sweden - August 22-26, 2011.

[20] "Dig-silent Power factory analysis software", hppt://www.digsilent. De retrieved 11/03/2013.

[21] Lawrence Berkeley National Laboratory, "Interruption cost estimate calculator," U.S. Dept. Energy. [Online]. Available: http://www.icecalculator.com/

[22] Liu B., Kun S., Zou J., Duan X. and Zheng X., "Optimal feeder switches location scheme for high reliability and least costs in distribution system". In: Proceedings of the 6th IEEE congress on intelligent control and automation, June 2006, Dalian, China. Vol.2, pp, 7419–23, 2006.

[23] Y. Xu, C. C. Liu, K. P. Schneider, and D. T. Ton, "Placement of remote controlled switches to enhance distribution system restoration capability," IEEE Trans. Power Syst., vol. 31, no. 2, pp. 1139–1150, Mar. 2016.

[24] S. Khushalani, J.M. Solanki, and N.N .Schulz, "Optimized restoration of unbalanced distribution systems," IEEE Trans. Power Syst., vol.22, no.2, pp. 624–630, May 2007.

[25] SILVA, L.G.W.—PEREIRA, R.A.F.—ABBAD, J.R.—ANTOVANI, J.R.S.: "Optimized Placement of Control and Protective Devices in Electric Distribution Systems through Re-active Tabu Search Algorithm", Electric Power System Research78(Apr2008),372–381.

[26] Zhu HN, Liu YT (2014) "Multi-objective optimization of unit restoration during network reconstruction considering line restoration sequence". Autom Electr Power Syst 38(16):53–59.

[27] Sun PB, Liu YT, Qiu XZ et al (2015) "Hybrid multiple attribute group decision-making for power system restoration". Expert Syst Appl 42(19):6795–6805.

[28] Report on Black out in Turkey on 31st March2015. Available online: https://www.entsoe.eu/Documents/SOC%20documents/Regional_Groups_Continen Tal_Europe/20150921_Black_Out_Report_v10_w.pdf(accessedon13March2018).

[29] A.A. Chowdhury, D. O. Koval, T.E. Mcdermott and R.C. Dugan, 2009, "Power Distribution System Reliability; Practical Methods and applications", John Wiley & Sons, New Jersey.

[30] R. Billinton, R.N. Allon, (2009) "Reliability Evaluation of Power System", Plenum Press. New York.

[31] The Global Positioning System (GPS) and Geographic Information System (GIS).