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Reliability improvement of distribution networks: A case study of Duhok distribution network

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Abstract

Power system is considered one of the most complicated infrastructures. The main components of the system are generation, transmission and distribution. The main function of the system is to supply consumers with electricity as economically and reliably as possible. In order to provide uninterrupted power supply to the consumers, the reliability of distribution system needs to be improved. Several strategies are in place in order to enhance the reliability of the distribution networks. The distribution system could encounter the challenges of aging infrastructure, environmental factors, and the rising in demand power which can cause frequent power interruptions. This paper aims to enhance the reliability of distribution networks by utilizing network reconfiguration techniques to improve voltage profiles, reduce power losses, and restore power to interrupt sections as quickly as possible in the event of a failure. Additionally, the study incorporates the use of fault passage indicator devices installed along the lines. These devices are intended to swiftly identify fault locations, thereby minimizing outage durations and further improving network reliability. An investment in these measures, can obtain significant reliability improvements in the network which at the end lead to consumer satisfaction and huge economic advantages for the system operator.

Keywords: Reliability improvement, Reliability indices, SAIDI, SAIFI, distribution networks.

1. INTRODUCTION

The planning, operation and maintenance of power system are hard due to the facts that this system is complex in its construction, operation and maintenance. The criteria of designing the power system are to supply the power to the consumers ideally with no interruptions or very rare interruptions. The reliability of the power system is determined by the quality of power supply, number of interruptions and the duration of the interruptions. The continuous supply of the power is profitable for both utilities and the end users. Therefore, a sustainable and reliable power system is vital and the priority of the utilities.

The reliability of the power system is divided into the system adequacy and system security. The facilities of the power system are assessed by system adequacy and evaluated whether they have the ability to meet the demand load of the consumers. This evaluation includes ensuring that the system has sufficient generation system, enough transmission network to transmit the power and the required distribution network to transfer the power from the transmission system to the end users. This is the static assessment and do not include the disturbances that may occur frequently. On the other hand, the system capability to respond to the dynamic disturbances is evaluated under system security aspect. This evaluation includes the failure in major generation and transmission system in addition to the localised impacts. It is possible to improve the reliability of the electric power system considering any of the aspects separately. However, working on both aspects together will contribute to better reliability improvement of the system[1], [2].

The distribution systems usually have not been given the required consideration as they have a less capital cost compared to the transmission and generation system. It is obvious that the loss of some generation units or portions of transmission lines is more critical than a failure in a part of distribution system due to the fact that the failure in generation or transmission system will affect the entire power system. In past, the outages in distribution system were considered to have the localised impact. In spite of this, the inability to supply the end user with the power as a result of the fault in distribution system makes the sufficient of generation and transmission system impractical. Occurring of the faults in distribution system have the huge effect on power interruption leading the majority of the consumer outages[3]. The outages in distribution systems deprive the residential consumers from using the basic electrical equipment for lighting and cooking while the industrial and commercial consumers are stopped which have substantial financial impacts.

In modern societies, the electricity is considered as a social right rather than being used for luxury. Despite the high tariff which imposes the consumer to pay the increasing amount of the electricity, the electricity is utilised on a daily basis even with poor quality ranging from poor voltage supply to long duration of interruptions. Occurring of many interruptions leads to damage and failure of the electrical equipment and appliances. Even with the numerous numbers of issues in power system such as aging of infrastructure, unexpected weather, overload and thefts, the demand on the electricity is often increasing. Therefore, the power network is deteriorating continuously and right measures need to be taken[4].

2. RELATED WORKS

In last decades, several strategies are examined to improve the reliability of the distribution network. The main goal of reliability improvement is to minimize the interruption duration, increase the efficiency and meeting the relevant standards. The main strategies are fault detection mechanisms and isolation, redundancy, grid automation and restoration and, reconfiguration, integration of distributed generation and asset maintenance [6], [7]. Due to introducing the modern electrical grid and increasing the components of the system, the network is complicated and required enhancing the reliability. This subject has become an interested topic for many researchers as applying these measures and techniques, the disruptions can be reduced, optimized operation and accordingly enhanced the reliability of distribution networks. Another factor which is contributing to the regulate the power supply is applying the Service Quality Incentives (SQI) which is used to either reward of penalties the power providers based on their performance. As it is known, the economic constraints and the reliability of the network usually restrict each other, as a result some compromise is needed. Energy demand management is required and project that have maximum benefits with minimum costs to be selected by both the utility and customers which require thorough study and analysis in order to take the proper action.

Evaluating the reliability of the power distribution system is one of the effective measures to assess the performance of the distribution network as the results can provide a good insight on the weak points of the network and identify the components that need to be rectified. Simulation and modelling of the system can be conducted to assess and identify the possible measure theoretically and highlight their advantages prior to practical implementation. The aim of this research is to suggest practical and economical choices to the utility which are justifiable for the predictable future.

In order to study the reliability of the power system, various reliability indices are used to evaluate the degree of the system reliability. These indices indicate the status of the components, the protection provided and their coordination, the network topology and the maintenance strategies. Based on the study requirements, the appropriate indices are used. Main indices of reliability are[8],[10]:

1. System Average Interruption Frequency Index (SAIFI)
2. Momentary Average Interruption Frequency Index (MAIFI)
3. Customer Average Interruption Duration Index (CAIDI)
4. System Average Interruption Duration Index (SAIDI)

These indices indicate the quality of the network in terms of the number and duration of interruption allowing the utility operators to identify the weakest points of the distribution network and improve their reliability.

The protection devices include switches and reclosers which are used to disconnect the faulted segment of the network while maintaining the rest of the network energised. Switches are installed in strategic locations and reclosers need to be properly coordinated when multiple reclosers are connected. Reclosers can be used to clear the transient faults and restore the power to the network. The advantages of installing more switches and reclosers are outlined in this study[11][12].

Improving the reliability of the distribution system leads to an improvement of the entire system reliability and increases the power availability for the customers. A customer satisfaction is increased by reducing the number and duration of the interruptions. In addition, the associated maintenance and operation costs are decreased. With the availability of enhanced system security, there is always a power reserved to be used during the contingency and peak demand. Besides, improving the reliability reduces the losses which means more overall saving. The aim of this research work is addressing the following aspects:

1. The main causes of the interruptions.
2. The status of the distribution component reliability
3. Methods of improving the distribution system reliability
4. The impact of reconfiguration on the reliability
5. The impact of the reliability on thermal loading and voltage
6. The effect of the number and location of switches and reclosers on the reliability.
7. The impact of installing additional protection on distribution system and is it profitability.

One of the benefits of the assessing the reliability of the power system is allowing the utility operator to effectively plan and improve the network performance. The quality of the power supply is improved by reducing the frequency and the duration of the outages. There is an attempt from all utilities to comply with the international standard regarding the reliability. Therefore, several methodologies are in place around the world to improve the reliability and performance of the power system[13][14].

The main aim of this study is to improve the reliability of distribution network specifically for Duhok city which consists of long radial feeders and several equipment types. Based on the traditional methods of reliability improvement which include the upgrading of the existing equipment or installing redundant equipment, the capital investment is usually large[15]. By implementing the redundant networks, there is a possibility to move the consumers between the adjacent networks during the fault periods or regular maintenances. Redundant networks also allow the operational flexibility, loss reduction in income, and improve the key performance indicators of the electricity utility. In spite of the fact that the redundancy on the distribution network allow the customers to have an uninterrupted supply, the cost of building the infrastructure and maintaining the additional part of the network is high and also time consuming.

By using the Reliability Centred Maintenance method to rank and prioritise the maintenance operation, the reliability is improved. This is a cost-effective method as it practices regarding good utility operation. In order to achieve the maximum benefits, this method is used in conjunction with other methods of reliability improvement rather than being used as a standalone method[16]. The effect of failure can be reduced and the reliability can be improved using distribution automation and other technologies of the smart grid. Despite the fact that the mentioned methods are applicable, cost-effective and have several benefits such as identification of thefts and real time load management, the utility should dedicate large capital investment in order to implement the mentioned methods[17][18]. On the other hand, the certain amount of the loads can be injected by Distributed Generation (DG) in case of outages and system failures. One of the limitations of the DG, is that they can only supply the power to the specific number of customers. Another limitation is the DG is expensive and long installation procedure as well as the failure possibility, add more interruptions to customers[19], [20].

In 1975, the network reconfiguration was first implemented for the purpose of loss minimisation in the network[20] . Reconfiguration means changing the network topology and operating conditions which changes the losses and restoration time. There is no budget required in order to conduct the reconfiguration of the network[23].

The safety and the quality of the power supply can be improved by installing the switches and reclosers. During the permanent fault conditions, a certain part of the network can be disconnected while the power is restored to the rest section of the network in most of the cases using switches and reclosers. Adding more devices such as switches, reclosers and fuses is cost effective if the devices are installed in strategic locations[23][24]. The previous solution has a great long-term advantage which can be easily installed by the utility. The summary and main findings of several studies have been listed in Table 1.

Table 1. Summary and finding of conducted research

References	Summary	Main findings
[25]	This paper presents a method to improve the reliability of an electric power system by installing distributed generation using biomass-fuelled gas engines, which was found to improve the overall reliability of the electrical system when tested on the IEEE 14-bus Test System.	The reliability index of the electrical power system improves when distributed generation from biomass-fuelled gas engines is connected. - The interval containing the reliability index is reduced (i.e., the estimate becomes more precise) when the number of simulated contingencies is increased. Future research could include generators without voltage control, like small photovoltaic and wind generators, and optimize the placement and

References	Summary	Main findings
		sizing of a mix of generator types to improve reliability while considering other factors like losses and costs.
[26]	The paper discusses the integration of hybrid community mini-grids into power systems to improve the availability and reliability of electricity supply, as well as the lifetime of power grid equipment, and outlines the key system-wide effects of this integration.	Community mini-grids can reduce electricity prices for customers by 10-15% below annual inflation. Integrating community mini-grids into power systems can reduce SAIDI and SAIFI by 12% and 10% respectively. Community mini-grids can integrate up to 20% renewable electricity generation, or up to 25-30% with energy storage systems.
[27]	This paper presents a comprehensive survey on the reliability evaluation of electrical power systems, with a focus on the impacts of integrating renewable energy sources and the reliability analysis and improvement techniques for electrical power distribution systems and wind-integrated power systems.	The paper presents a comprehensive survey on the reliability evaluation of electrical power systems with the integration of renewable energy sources. The paper discusses the reliability improvements seen in electrical network planning and operation when renewable sources are incorporated into the main electrical power system. The paper describes the reliability impacts on reactive power, unit commitment, and protection systems in renewable-integrated power systems.
[28]	This paper provides a comprehensive review of power system reliability assessment, including the significance of reliability, various reliability indices, different reliability assessment techniques, and future research directions and challenges.	The present review work has explored various reliability assessment methods in detail to reliably fulfil power system requirements, with most reviews emphasizing historical assessment and analytical approaches. Probabilistic methods and performance analysis are commonly used to analyse

References	Summary	Main findings
		system availability, forced outage rate, and load point indices, while techniques like particle swarm optimization, stochastic programming, fuzzy chance-constrained programming, and risk analysis are being adopted to address power system challenges.
[29]	The paper evaluates and enhances the reliability of electrical distribution systems, particularly in the presence of distributed generation, and shows that the implementation of distributed generation can improve reliability indices	The introduction of distributed generation (DG) to the distribution system can have positive or negative impacts on power flow and voltage conditions, depending on the characteristics of the distribution system and the DG. Implementing DG in the distribution system can improve reliability metrics such as SAIFI, SAIDI, and AENS, with further improvements when DG is combined with storage systems.
[30]	The paper proposes methods to improve the reliability of the urban electric network in Dushanbe, Tajikistan, by identifying factors affecting damage and forecasting electricity consumption to regulate the parameters of the urban electrical grid.	The most damaged elements of the city electric network in Dushanbe are cable power lines and transformer substations, especially during the autumn-winter and winter-spring periods, due to increased electricity consumption and changes in climatic and meteorological conditions.
[31]	The paper discusses measures to improve the reliability of electrical power systems, including integration of the global electricity industry, new technologies like power electronics and energy storage systems, and the intellectualization of power systems through the "Smart Grid" concept	Integration of global electricity industry through interconnected power systems and markets is a key direction for improving power system reliability. New technologies like power electronics, FACTS devices, and energy storage systems can increase reliability and controllability of power transmission.

The concept and research contribution of recently conducted research about the methods of reliability improvements for distribution networks is shown in Table 2.

Table 2. Contribution of researches on reliability improvements

References	Concept	Research contribution
[32]	Integration of renewable energy distributed generation (DG)	The article analyses the impact of energy storage on distribution network reliability by evaluating storage size, initial state of charge, and DG penetration, aiming to optimize energy storage parameters for specific reliability targets.
[33]	automated reconfiguration	The study utilizes reliability graphs to assess the impact of automated reconfiguration on distribution grid reliability and resilience, demonstrating improvements in System Average Interruption Frequency Index (SAIFI) and resilience against high-impact events such as storms or earthquakes.
[34]	Using reclosers, automatic sectionalisers, and manual switches	The study compares the reliability enhancements achieved by using outdoor distribution devices like reclosers, automatic sectionalisers, and manual switches, addressing the challenges utilities face in improving reliability post-deregulation and the importance of reducing interruptions for sensitive loads.
[35]	implementation of Advanced Distribution Automation Systems (ADAS)	The study investigates the enhancement of power distribution system reliability using Advanced Distribution Automation Systems (ADAS), focusing on fault location, isolation, and service restoration (FLISR) for improved reliability and self-healing capabilities. It assesses the impact of a local-centralized-based FLISR architecture on an urban underground medium voltage distribution network, demonstrating substantial reliability enhancements and increased customer satisfaction.
[36]	voltage regulation	The study simulates network operation under various PV scenarios to assess impacts on reliability indices and bus voltages.
[37]	Network reconfiguration and optimal device placement	This document focuses on improving reliability in distribution systems through network reconfiguration and optimal device placement. It explores the significance of system adequacy and security in enhancing overall reliability, particularly in distribution networks.

Tables 1 and 2 clearly demonstrate that various strategies are available for evaluating and enhancing the reliability of distribution networks, with each strategy tailored to suit specific systems.

3. ORIGINALITY

The reliability of the existing distribution network needs to be improved as quickly as possible. The methods utilised in this study are:

1. The network can be reconfigured easily with almost with no cost. This method is considered a most effective way to enhance the reliability and performance of the distribution network.
2. Placing additional protection devices such as reclosers, switches and FPs which can contribute to enhance the reliability and performance of the distribution network further.

The distribution systems in Kurdistan region currently have several issues compared to previous decades because of increasing the demand for electricity continuously. Adding more loads to the existing network increase the loads on the lines and transformers and results in weaker systems and bad reliability due to the overloading the equipment as they have not been planned and installed to deliver the additional loads. With the new loads, the network is larger and more complicated in nature because of the long distances of the new loads from the power sources. The vast majority of the distribution line are overhead due to their low cost compared to underground lines despite the fact that the overhead lines are more expose to environmental conditions which result in more failures. Normally the overhead lines have higher SAIDI and SAIFI values. Due to the fact that all distribution feeders are in radial scheme, the consumers are suffering from long periods of power outages due to both planned and unplanned shutdowns[38].

All the components of the power system are expected to perform their function continuously if loaded according to their rating limit and based on the network design. However, unplanned interruption occurs due to the incidents and faults in the network.

There are several reasons for occurring the faults which could be due to[39]:

1. The technical issues such as failure in electrical components like conductors, insulators, transformer and structure.
2. The external condition such as bad weather conditions which lead to infrastructure damage.
3. The intervention of human, such as theft and vandalism.
4. Component aging
5. Design
6. Manufacture
7. Lack of maintenance

There are specific kinds of faults that occur more than other faults which require longer duration for repairing. The faults duration relies on many factors such as fault location, staff availability to repair the fault, availability of spare equipment and how easily the faulted equipment can be replaced. The faults can lead to equipment damage and disconnect the consumers from the network for the fault duration which have an adverse impact on the security and reliability of the system[40].

The growth of the country's economy is influenced by the power supply quality and reliability. In addition, the interruption affects the utility income as well as the reputation of the utility and the performance indicators. The goal of the power utility is to meet the customers' requirements with minimum costs. Therefore, it is essential to plan, design, operate and keep the power system as reliable as possible where interruptions adverse impact is reduced, the number and duration of the interruption are minimised and consumers are supplied with continuous power as far as possible[41].

A section of the 11kV distribution network in Duhok city is selected for this study. The frequency and duration of faults are analysed for various components, including overhead lines, transformers, fuses, cables, circuit breakers, and busbars.

Using data provided by the Duhok Electricity Distribution Directorate, the system's reliability is assessed prior to implementing any improvements. To enhance reliability and performance, a required measure including the installation of fault passage indicators and network reconfiguration are proposed. The impact of these improvements on system reliability is evaluated and compared with the system's performance before the enhancements. The primary objective is to improve system reliability, which helps reduce power losses, enhance voltage stability, and ultimately meet the needs of both the power supply and the customers.

4. SYSTEM DESIGN

The power system in Kurdistan region of Iraq consists of generation, transmission and distribution. Usually, the power is generated at voltages that need to be stepped up while transferring the power over long distances. The transmission system voltage is 400kV and 132kV while the distribution system voltage is 33kV, 11kV and 0.416kV.

The 33kV and 11kV supply industrial customers while 0.416kV supply commercial and residential customers. Figure 1 presents the block diagram of the Duhok city grid, highlighting its connection to the Turkish line via a transmission line with a voltage of 154kV. Additionally, the diagram illustrates the connections with other cities in Kurdistan and Iraq. However, it does not include the 33kV, 11kV, and 0.416kV lines due to the extensive size of the network.

This work concentrated on on 11kV distribution network of Duhok city which provides the power to various consumers. Due to the fact of demand rising and poor distribution infrastructure, investigating the capability and performance of the existing network is crucial. Network reconfiguration, which requires installing reclosers and switches and also installing fault passage indicators are the techniques used in this study to improve the reliability of the distribution network. This study will evaluate the reliability of the network and then propose the most appropriate solutions which will contribute to optimise the efficiency. The quality of the suggested solution will be measured through discussing and evaluating of the study results.

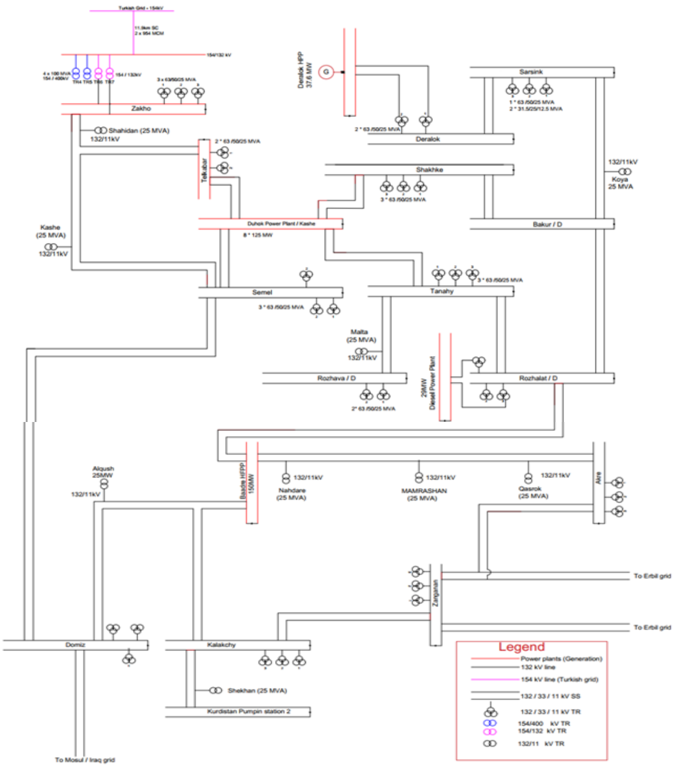

Figure 1. Block diagram of Duhok electric grid

The main goals of this study are:

1. Assessing the recorded fault data in order to investigate the main causes of the interruption and to identify the different reasons of the equipment failure
2. Examining the method of network reconfiguration to determine the impact on the reliability indices and network efficiency.
3. Proving the recommendation to the system operator regarding the best, economic and long-lasting solution for improving the reliability of the distribution network.

The main limitations of the study are:

1. The reliability of transmission and generation system is excluded and only the distribution system are considered.
2. Only a portion of the distribution network is considered which is 11kV feeder called F317.
3. The real implementation of the methodology or any hardware is excluded

4. The proposed location of the switches and reclosers are assumed to be applicable
5. The data, cost and standards are appropriate at the time of the study

The 11kV feeder, designated as F317, is chosen for this case study, with its topology illustrated in Figure 2. This feeder is supplied by the Segrka 33/11 kV substation, spans 2400 meters, and connects 25 transformers, each with a capacity of 250 kVA. The feeder topology is shown in Figure 3.

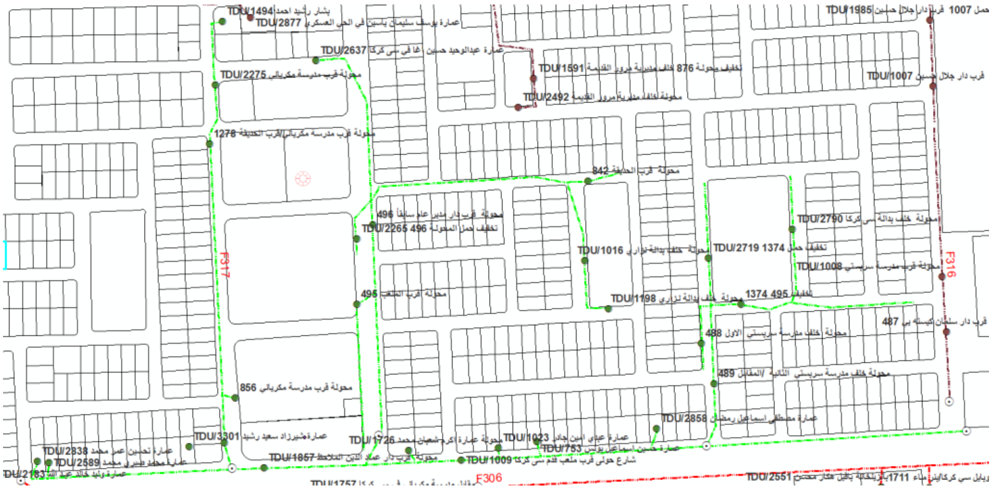

Figure 2. Topology of 11kV feeder (F317)

In order to show the components of the selected feeder, a single line diagram is shown in Figure 3.

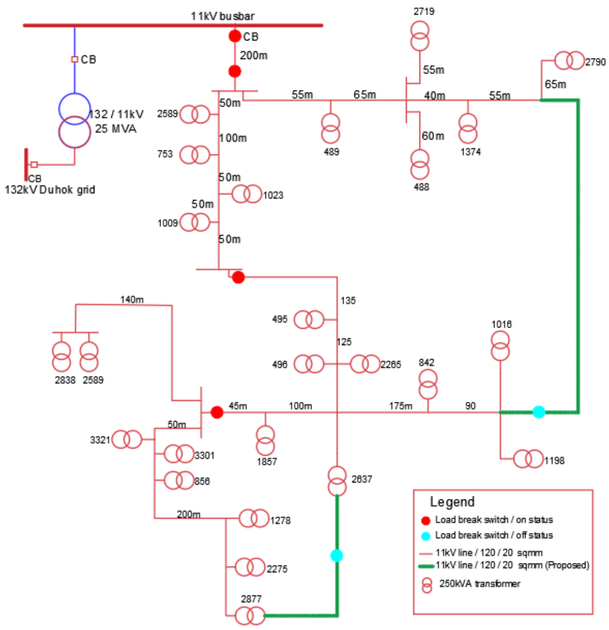

Figure 3. Single line diagram of 11kV feeder (F317)

The single-line diagram illustrates the path of the 11 kV overhead line, including branch lengths, transformer locations with identification numbers, and load break switches. On average, each 250 kVA transformer serves about 20 consumers. Consequently, the total number of consumers connected to this feeder is 500.

5. EXPERIMENT AND ANALYSIS

Reliability of supply is a measure of availability of supply to electricity consumers. Generally, consumers prefer to have continuous and uninterrupted supply. However, unplanned supply interruptions occur due to system faults or failure of network equipment. Such interruptions have undesirable impacts on the quality of life of people and well as on the economy.

Table 3. Feeder Outages data (F317)

Months 2023	Tripping (forced)		
	Number	Total Duration (hrs)	Number of affected customers
January	23	11.5	500
February	18	13.5	500
March	17	12.75	500
April	18	18	00
May	10	15	500
June	14	10.5	500
July	18	12	500
August	18	9	500
September	16	8	500
October	17	12.75	500
November	15	14	500
December	20	15	500
Totals	204	152	500

It should be noted that duration as well as frequency of interruptions affects the supply reliability. Even momentary interruptions caused by auto-reclosing operations may inconvenience consumers. For example, momentary supply interruptions may cause computer systems to shut down, equipment such as spilt units to be reset, certain industrial processes to be halted. Hence measure of supply reliability should include measurement of both frequency and duration of supply interruptions. Internationally used key reliability indices are defined below[19].

$$System\ Average\ Interruption\ Frequency\ Index\ (SAIFI) = \frac{Total\ number\ of\ customer\ interruptions}{Total\ number\ of\ customers\ served} \quad (1)$$

$SAIFI = \frac{Total\ number\ of\ customer\ interruptions}{Total\ number\ of\ customers\ served}$ *System Average Interruption Duration Index*

$$(SAIDI) = \frac{Total\ duration\ of\ customer\ interruptions}{Total\ number\ of\ customers\ served} \quad (2)$$

$$Customer\ Average\ Interruption\ Duration\ (CAIDI) = \frac{Total\ no.of\ customer\ interruptions\ duration}{Total\ number\ of\ customers\ interruption} \quad (3)$$

$= \frac{\Sigma\ interruption\ duration\ x\ affected\ customers}{\Sigma\ customers}$ Table 3 provides 11 kV feeder outage data provided in the CCDD monthly reports. It should be noted that the interruptions shown in this table relate to feeder tripping and maintenance outages only. It does not include interruptions due to planned outages for load shedding.

In order to provide measures of system reliability from the consumer's point of view, SAIFI, CAIDI and SAIDI reliability indices are used as international standards.

$$SAIFI = \frac{204}{500} = 0.408 \quad (4)$$

$$SAIDI = \frac{152*60}{500} = 18.24 \text{ minutes} \quad (5)$$

$$CAIDI = \frac{152*60}{204} = 44.7 \text{ minutes} \quad (6)$$

It should be noted that these values refer only to MV distribution system reliability, and they do not account for interruptions due to load shedding, transmission and LV feeder interruptions. In any case, these reliability indices of the 11 kV network indicate low levels of supply reliability. This reliability levels compared with international norms indicates serious reliability issues that need to be addressed.

Based on the issues identified in the existing system analysis, proposed developments to improve reliability and quality of supply provided through the 11 kV system are provided in this section as follows.

5.1 Reducing Voltage Drops in 11 kV Feeders using Voltage Regulators

There are 23 Nos 11 kV feeders in Duhok Governorate with excessive voltage drops exceeding 20% and up to 36%. The voltage drop issues in some of these feeders can be corrected using new 11 kV feeders from proposed substations. However, there are some isolated 11 kV feeders for which no new feeders could be connected. Automatic Voltage Regulators were considered to resolve voltage drops in such feeders.

In order to continuously regulate voltage variations in real-time by increasing or decreasing the output voltage, automatic voltage regulators provide the optimum solution. Both three phase and single-phase line voltage regulators are popularly used in countries such as Australia, USA and in Asia as a cost-effective solution. Up to ±10% voltage regulation can be achieved using standard types available in the market.

5.2 Reducing Voltage Drops in 11 kV Feeders using line Capacitors

Voltage Regulators were considered as a preferred option over line capacitors to improve voltage drop in feeders due to the following reasons;

1. Limitation of maximum capacitance to be installed on distribution lines due to possible voltage rise above maximum during light load conditions.
2. Limited voltage regulation due to the above constraint.
3. Lifetime of capacitors is limited due to switching surges, harmonics etc. which are frequently under existing KRG conditions.

However, as discussed above, voltage regulators are not recommended for overloaded lines. Therefore, in such cases the use of pole mounted 11 kV capacitors has been recommended.

5.3 Improvement of Reliability in 11 kV feeders using Auto-Reclosers

The majority (over 70%) of the faults in distribution networks are temporary (transient) faults which are normally cleared by one of more auto-reclosing shots. However, this facility is not enabled in the 11 kV breakers at the substations in KRG (possibly to minimize number of substation breaker operations). Upon feeder tripping, manual reclosing process is initiated to clear such transient faults. (Switch 'ON' after 5 minutes).

The installation of Auto-Reclosers (AR) is recommended for long 11 kV feeders to improve reliability. ARs can be installed at the beginning of long branches and main feeder sections downstream of the feeder. This will provide the following benefits;

1. Immediate clearance of transient faults.
2. In case of permanent faults, only faulty section (and sections downstream of it) will be isolated.
3. Reduced downtime of feeder due to faster location of fault.
4. Additional protections provided though the AR downstream of the feeder.
5. Stress on substation breakers due to frequent tripping operations is reduced.

5.4 Fault Indicators (FI) to Minimize Feeder Tripping Downtime

Fault indicators (also referred to as fault passage indicators) detect feeder faults by sensing variable in electromagnetic fields in overhead distribution lines caused by transient fault currents. The fault passage indicators can detect both earth faults and phase to phase faults in medium voltage distribution feeders.

If a fault is detected in the line, the fault passage indicator Xenon / LED flasher starts flashing. This is clearly visible for considerable distance. The flashing continues after tripping until re-energization of the line or restoration of load current. Therefore, the maintenance crews can identify that the fault has occurred downstream of that location.

The following benefits can be achieved by using fault indicators in distribution feeders to improve reliability.

1. Rapid location of faulty section.
2. Rapid isolation of the faulty section and immediate restoration of supply to healthy sections of the feeder (upstream of fault).
3. Minimized feeder outage duration.
4. Avoidance of undesirable ‘on fault’ operation of substation circuit breakers and load break switches (improved lifetime).

Among the four measures described above, the second and fourth are applied in this case study. The use of switches and reclosers allows for easy network reconfiguration, minimizing the number of customers impacted by interruptions. Additionally, employing fault passage indicators (FPIs) helps quickly identify fault locations, thereby reducing the duration of interruptions.

Table 4. Feeder outages after improvements

Months 2024	Tripping (forced)		
	Number	Total Duration (hrs)	Number of affected customers
January	23	4	160
February	18	9	320
March	17	8	400
April	18	10	280
May	10	8	300
June	14	8	325
July	18	7	200
August	18	5	2500
September	16	5	285
October	17	8	400
November	15	7	320
December	20	8	355
Totals	204	87	

As shown in Figure 3, four load break switches are installed along the feeder, along with two proposed switches. These switches enable the system operator to isolate only the faulty section of the feeder, thereby reducing the number of customers affected by the interruption. Additionally, the inclusion of fault passage indicators helps crews locate faults more efficiently, resulting in shorter interruption durations. For the purpose of the case study, it is recommended to install a FPI beside each load break switch.

The table 4, is the modification of table three after including the effect of feeder reconfiguration and installing the fault passage indicators. It has been assumed that the same number of faults are occurring for each month, but the duration and the number of customers affected is different.

After adding the effect of the switches and FPIs to the system, the reliability indices are as:

$$SAIFI = \frac{204}{500} = 0.408 \quad (7)$$

$$SAIDI = \frac{87*60}{500} = 10.44 \text{ minutes} \quad (8)$$

$$CAIDI = \frac{87*60}{204} = 25.6 \text{ minutes} \quad (9)$$

6. CONCLUSION

Results of the existing system analysis presented indicate high tripping downtime of 11 kV feeders significantly affecting system reliability and inconveniencing consumers. This study illustrates that the reliability of the network can be significantly improved by installing additional switches and FPIs in overhead lines. It is therefore recommended to improve feeder tripping downtimes by installing fault indicators on selected feeders in all 11kV feeders. Accordingly, FPIs are recommended to be allocated to each section of the network.

It is recommended to install the FPIs and switches for all 11kV feeders in order to improve the system reliability. Future research should investigate the economic benefits of reliability improvements for both the system operator and the customers.

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