CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of electrical engineering

Department of electrical power engineering

Distribution system reliability improvement using Smart Grid technologies

Bachelor thesis

Study program : (BP99) Electrical Engineering and Computer Science
Supervisor : Ing. Martin Čerňan

Yunis Yunisli

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BACHELOR‘S THESIS ASSIGNMENT

I. Personal and study details

Student's name: **Yunisli Yunis** Personal ID number: **471662**

Faculty / Institute: **Faculty of Electrical Engineering**

Department / Institute: **Department of Electrical Power Engineering**

Study program: **Electrical Engineering and Computer Science**

II. Bachelor’s thesis details

Bachelor’s thesis title in English:

Distribution system reliability improvement using Smart Grid technologies

Bachelor’s thesis title in Czech:

Zlepšování spolehlivosti distribuční soustavy s využitím Smart Grids technologií

Guidelines:

1. Prepare the overview of topic focused on distribution system reliability (basic reliability theory, reliability indicators in distribution system, factors affecting the distribution system reliability).
2. Perform a comparative analysis of distribution system reliability indicators in various countries.
3. Make an overview of technologies that can improve the reliability of the distribution system.
4. Create examples of the use of the described technologies for demonstration of their benefits.

Bibliography / sources:

1. Brown R.E.. (2017). Electric power distribution reliability, second edition. 10.1201/9780849375682.
2. SHORT T.A. Electric Power Distribution Handbook. Second edition. CRC Press, 2014. ISBN 978-1-4665-9866-9.

Name and workplace of bachelor’s thesis supervisor:

Ing. Martin Čerňan, Department of Electrical Power Engineering, FEE

Name and workplace of second bachelor’s thesis supervisor or consultant:

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Ing. Martin Čerňan Supervisor’s signature	Head of department’s signature	prof. Mgr. Petr Páta, Ph.D. Dean’s signature

III. Assignment receipt

The student acknowledges that the bachelor’s thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the bachelor’s thesis, the author must state the names of consultants and include a list of references.

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Declaration

I hereby declare that this thesis is the result of my own work and that I have clearly stated all information sources used in the thesis according to “Methodological Instructions of Ethical Principle in the Preparation of University Thesis”.

In Prague, 04.01.2021 ………………………..

Yunis Yunisli

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Abstract

This bachelor thesis is aimed to inspect the possible ways of improvement of distribution reliability system using various technologies. It will mainly be based on the numbers obtained from two reliability indicators, which are SAIDI and SAIFI. In further chapters, it will be discussed the data of the listed indicators for various countries in both numerical and graphical form, moreover the possible ways of reduction of these values will be the next part of this work. For fulfilling the main goal of this work, firstly the presentation of various automation instruments will be shown. However, in order to see the possible positive or negative impact of automation components to our distribution reliability system, some of the presented tools will be applied to various medium voltage feeders in different scenarios.

Key words

SAIFI, SAIDI, distribution system, reliability, automation, recloser, sectionizer, remotly controled sectionizer, medium voltage feeder.

Abstrakt

Tato bakalářská práce si klade za cíl prověřit možné způsoby zlepšení spolehlivosti distribuční soustavy pomocí různých technologií. Bude vycházet hlavně ze dvou indikátorů spolehlivosti, kterými jsou SAIDI a SAIFI. V dalších kapitolách budou pojednány údaje uvedených indikátorů pro různé země v numerické i grafické podobě a v další částí této práce budou prezentovány možnosti snížení těchto hodnot. Ke splnění hlavního cíle této práce budou nejprve představeny různé nástroje automatizace. Abychom však viděli možný pozitivní nebo negativní dopad automatizačních komponent na spolehlivost distribuční soustavy, budou některé z prezentovaných nástrojů použity pro různé vývody vysokého napětí v různých scénářích.

Klíčová slova

SAIFI, SAIDI, distribuční soustava, spolehlivost, automatizace, recloser, úsečníkový odpojovač, dálkově ovládaný úsečníkový odpojovač, vývod vysokého napětí.

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List of Abbreviations

SAIFI System Average Interruption Frequency Index

SAIDI System Average Interruption Duration Index

CAIDI Customer Average Interruption Duration Index

ASAI The Average Service Availability Index

ASIFI Average System Interruption Frequency Index (ASIFI)

ASIDI Average System Interruption Duration Index (ASIDI)

λP Permanent Short Circuit Failure Rate

λT Temporary Short Circuit Failure Rate

λOC Open Circuit Failure Rate

MTTR Mean Time to Repair

MTTS Mean Time to Switch

POF Probability of Operational Failure

λM Scheduled Maintenance Frequency

MTTM Mean Time To Maintain

POF Probability of Operational Failure

MTTS Mean Time to Switch

RMU Ring Main Unit

RTU Remote Terminal unit

FPI Fault Passage Indicator

CR Czech Republic

GB Great Britain

EU European Union

NOP Normal Open point

LBS Load Break Switch

PLC Programmable logic circuits

DCS Distributed control systems

ACR Automatic circuit reclosers

SF6 Sulfur hexafluoride

SS Stainless Steel

1 Introduction

Electric power distribution is the final link for the delivery of electrical power. Its main goal is conveying electricity from the transmission lines to individual consumers. Electric power distribution became essential only within the 1880s when electricity started being generated at power stations. Before that electricity was usually generated where it had been used. Gradually with improvement of the distribution system, it occurred a high demand for maintenance of the system's stability and reliability. Hence, it brought us up to a term the reliability of distribution system. By reliability of a power distribution system is meant, the ability of the system to deliver uninterrupted service to the client. Distribution system reliability indices are often presented in some ways to reflect the reliability of individual customers, feeders and system-oriented indices associated with substation. The distribution system is a crucial part of the entire electrical supply system. It has been reported that more than eighty percent of all customer interruptions occur due to failures within the distribution system.

This thesis work will mainly focus on improvement of distribution system reliability using various technologies. The work will start with discussion of the basic reliability theory and various failure rates. It will be presented several types of failure rates, the reason of its expression and a bit broader discussion can be explained as in case of facing outage of the system, it will ease the ability of quick respond to the failure and its repair time. Thus, it will help to maintain the distribution system more reliable and efficient. Furthermore, it will be briefly discussed the reliability indicators and their importance in our calculations. Although there are pretty enough reliability indicators in terms of its variety, like CAIDI, ASAI, ASIFI e.t.c. However, the further calculations and assumptions will predominantly relied on SAIFI and SAIDI parameters. These parameters will help with visual evidence of the significance of automation components in the power distribution reliability. The upcoming chapter will investigate the overview of the reliability in various distribution system. By „various distribution system "here will mostly mean the various indicator values for different countries around the globe. The ongoing chapter will be separated into four parts. In the first part there will be graphical and numerical representation of the above-mentioned parameters for the case of the Czech Republic. In this assignment it was brought up a wider data for the central European country, with mentioning its distribution companies' data over a specific range of years. The second part will involve the comparison of EU member countries during some specific range of years. This part will mostly include in itself countries with huge power systems potential and few countries with relatively smaller electrical power system potential. SAIDI and SAIFI parameters will be for both planned and unplanned occasions and will be compared in graphs. The third part will involve investigation of the same indicators for the countries outside the Schengen zone. In this case again will be applied the same strategy and will be chosen the countries with huge power system potential from various continents. The graph will cover all the above-mentioned countries either. It will remarkably emphasize each countries‘ success in terms of continuous delivery of the power to its citizens over some period of time. The last part of this chapter was previously planned on investigations of these parameters for the case of Azerbaijan. However, as not all countries are following this specific policy for their distribution system, there was a demand to switch the rote to neighborhood countries in the Caucasian and Anatolia region. Moving on the next chapter, for improving and automation of the distribution network some technologies will be described as: reclosers, sectionalizers, ring-main unit and other tools. In the following chapter will be inspected and explained the importance of integration of these tools into the distribution system. For some components there will be expressed more than one example model. Furthermore, these technologies will be applied to example feeders in the case study section. Some of this automation components will be applied to the medium voltage feeder models and compared the feeders with and without automation tools. Afterwards, the results will be implemented into table form to highlight the impact of these tools. Finally, the sensitivity analysis will be done on each of these cases for all the three scenarios. To fulfill that task, the travel and localization time will be doubled for each case respectively. The main goal in increasing the travel time in first analysis and afterwards the localization time in the second, can be explained it here it was considered variability in localization time and travel time, depending on specific conditions in feeder area.

2 Distribution system reliability

2.1 Basic reliability theory

The reliability theory is a term, which is accosted with random occurrence of undesirable events or failures during the lifetime of a physical or biological system. The importance of reliability in a system is as much inherent as is the system's capacity or power rating. Yet before the past decade, the necessity of reliability concept wasn't as remarkable as it is now, however due to the impact of automation, development of complex missile and space programs, it got greater significance.[1]

Moving further and speaking up about the purpose of Reliability theory. It investigates the effect of mean time to repair upon overall system failure rates, nevertheless for critical systems such calculations doesn't match requirements, as an important performance criterion relates to operational failures, which are fundamentally different to unsafe failures: essentially they are the result of the system-level response to avoid unsafe failures. The reliability theory and relevant methodologies have been developed by splitting into several phases. Mainly three main technical fields are mentioned during the growth process:[2]

- Reliability engineering, which includes system reliability analysis, design review, and related task.
- Operation analysis, which includes failure investigation and corrective action.
- Reliability mathematics, which includes statistics and related mathematical knowledge.

However, the main goal here is aiming at a better way to balance the cost of failure reduction against the value of the enhancement. Accurately providing the failure rate of a system is necessary. Statistically the majority of the faults in a power distribution system are the result of short circuits or insulation breakdown between two or several points. Moreover, faults can be specified into groups mainly they are: temporary or permanent. A temporary fault is the ability of a protective system to be re-energized (fault clearing) after a reclosing operation. Some popular examples of these faults are: insulation breakdown by the interaction between components and external agents (lightning strikes, wind, transient tree contacts, etc.). Speaking up the permanent faults, they need to be repaired or the damaged component must be changed. Speaking up about examples of permanent faults, it includes insulators damage by flashover, underground cable breakdown and surge arrester damage. Coming up to failure reduction, it will be brought up some popular terms as "Failure" and "Failure Rate" and other related terms.[3]

Failure rate is the frequency with which an engineered system or component fails, expressed in failures per unit of time. It is usually denoted by the Greek letter λ (lambda). The failure rate of a system usually depends on time, with the rate varying over the life cycle of the system.[4]Simple reliability models are based on component failure rates and its repair times, however more complicated models can include other reliability parameters. Down below will be provided most common component reliability parameters:

Permanent Short Circuit Failure Rate (λP) — λP defines the number of times, a component might experience a permanent short circuit, per year. This type of failure causes fault current to flow, requires the operation of the protection system and needs a crew to be dispatched for the fault to be repaired.

Temporary Short Circuit Failure Rate (λT) — λT describes the number of times per year that a component can expect to experience a temporary short circuit. As is in Permanent Short Circuit failure, this failure causes fault current to flow either, however will clear itself if the circuit is de-energized (allowing the arc to de-ionize) and then reenergized.

Open Circuit Failure Rate (λOC) — λOC represents the number of times per year that a component will cause an interruption of the flow without causing fault current to flow. As an example of a component causing an open circuit is when a circuit breaker false trips.

Mean Time To Repair (MTTR) — MTTR expresses the expected time, which is needed for a failure to be repaired (measured from the time that the failure occurs). A single MTTR is typically used for each component, but separate values can be used for different failure modes.

Mean Time To Switch (MTTS) — MTTS represents the expected time required for a sectionalizing switch to operate after a fault emerges on the system. For manual switches, this is the time that is takes for a crew to be dispatched and drive to the switch location, while for an automated switch, the MTTS will be much shorter.

Probability of Operational Failure (POF) — POF is the conditional probability, which represents the possibility of a device to not operate if it is supposed to operate. For instance, if an automated switch fails to function properly 5 times out of every 100 attempted operations, it has a POF of 5%. This reliability parameter is usually associated with switching devices and protection devices.

Scheduled Maintenance Frequency (λM) — λM represents the frequency of scheduled maintenance for a piece of equipment.

Mean Time To Maintain (MTTM) — MTTM describes the average amount of time that it takes to perform scheduled maintenance on a piece of equipment.

All of the up-mentioned reliability parameters have their major impact, however component failure rates have historically got the most attention. Mostly because failure rates have unique characteristics and are important for all types of reliability analyses.

The **Bathub Curve** will be a next term, which is found crucial to speak up**.** It is a graph that is mostly used to describe the dependence of component's failure rate over the time. The bathtub curve starts with a high failure rate (infant mortality), after goes down to a constant failure rate (useful life), and then goes up again (wear out). The bathtub hazard function is an equivalent name for defining this curve. The use of the term "hazard rate" is common in the field of reliability assessment and is equivalent to the failure rate of the component

Hazard Rate (Failure Rate) — The hazard rate of a component at time t is the probability of a component failing at time t if the component is still functioning at time t.

More detailed curve used to represent a component's hazard function is the **Sawtooth bathtub** curve. Instead of using a constant failure rate in the useful life period, this curve uses an increasing failure rate.

Down below, it will be presented examples of Standard and Sawtooth Bathup curves and Hazard function :

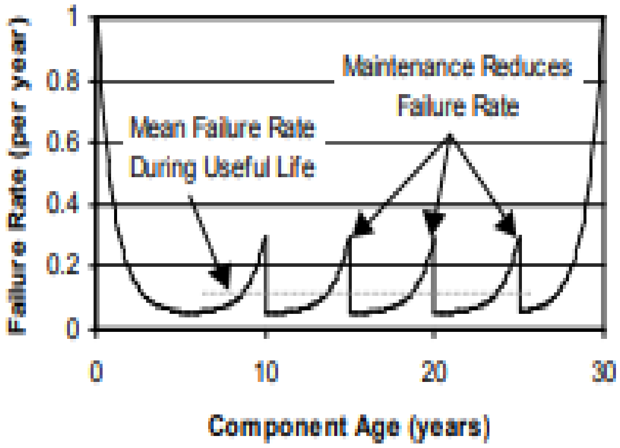

Figure 2.1 *Sawtooth bathtub curve [5]*

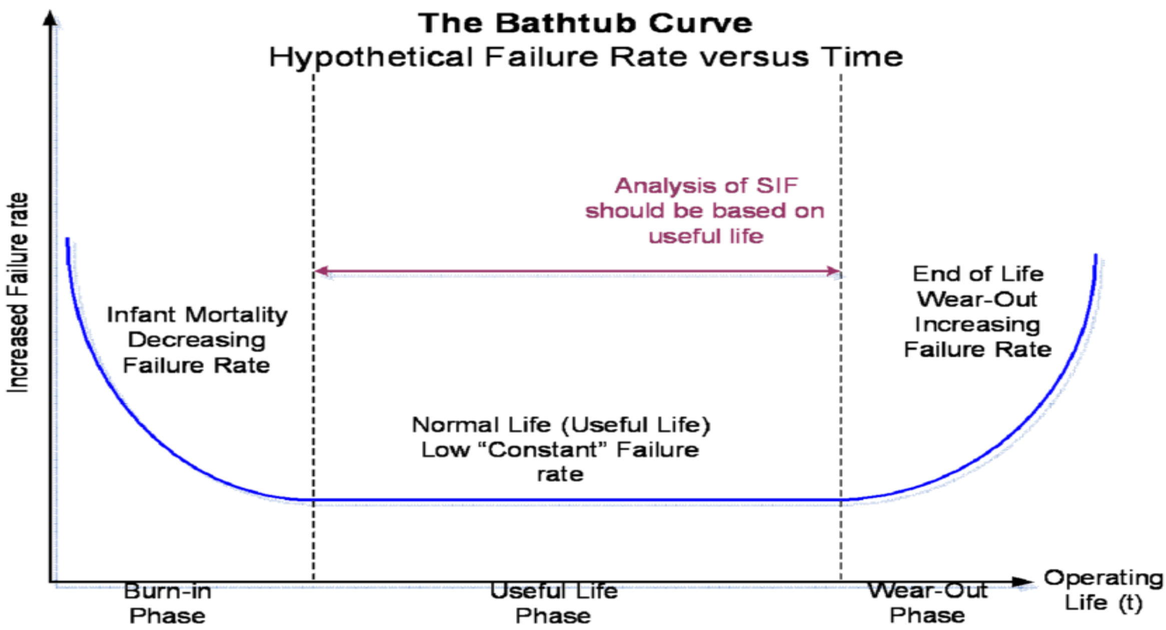

Figure 2.2 *Standard bathtub curve.[6]*

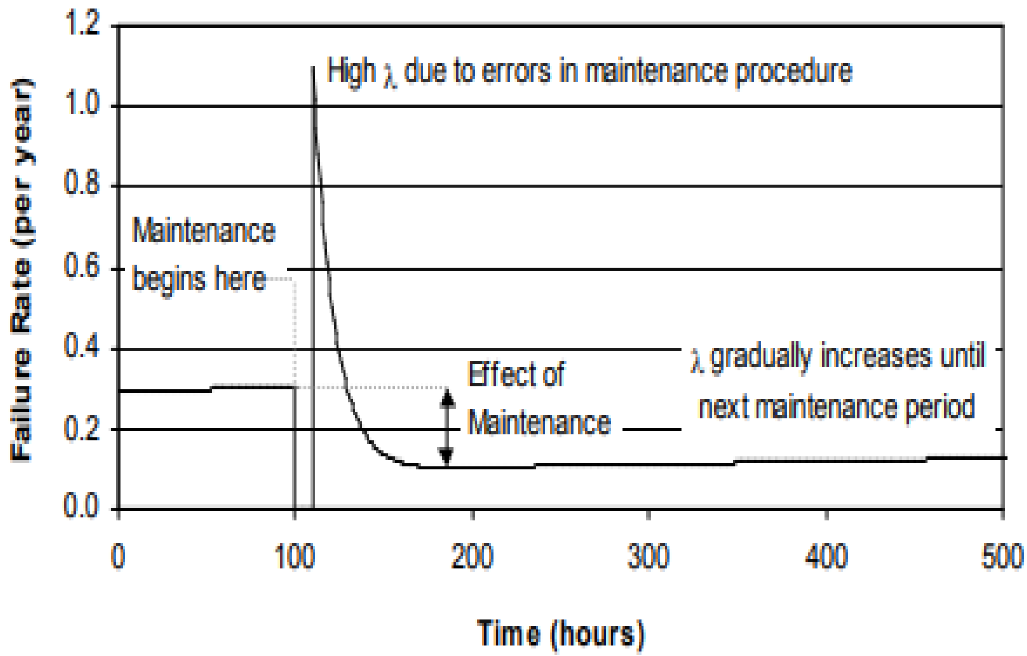

Figure 2.3 *Hazard function. [5]*

To sum up all three graphs represented, the Standard bathtub curve (Fig2.1) is characteristic of the failure rates of many electrical components that are susceptible to face a shipping damage or installation errors. It is usually an approximation of the Sawtooth bathtub curve (Fig 2.2), which models the increasing failure rate of a component between maintenance and shows a reliability improvement after maintenance has been performed.

Moving on to hazard function (Fig2.3), it illustrates and explicit behavior of equipment reliability during maintenance period. When maintenance is performed at hour 100 the failure rate (λ) is relatively high, λ is reduced to zero during maintenance, and then peaks to a very high level due to the possible occurrence of mistakes happening during maintenance. λ quickly decreases to a level lower than pre-maintenance, and then gradually rises until it is time for the next maintenance activity.

2.2 Reliability indicators in distribution system

Reliability indices are statistical collection of reliability data for set of customers, loads and components. Majority of the indices are average values of a reliability characteristic for an entire system, operating region, substation service territory, or feeder. The reliability index definitions provided, where applicable, follow the recently adopted IEEE standard 1366-2003.19 [7]. This standard has not been universally adopted by US utilities but is growing in popularity and provides a document to which individual utility practices can be compared. Numerous reliability evaluation of a distribution system can be divided into two basic segments; evaluation of past performance, alongside prediction of the future performance. Below will be presented bunch of basic indices that have been used for computation of the past performance, which are:

- System Average Interruption Frequency Index (SAIFI)
- System Average Interruption Duration Index (SAIDI)
- Customer Average Interruption Duration Index (CAIDI)
- The Average Service Availability Index {Unavailability} (ASAI)

The following part of research will dive in more deeply and give more detailed information about listed performances.

System Average Interruption Frequency Index (**SAIFI)-** it is a measure for calculating the amount of sustained interruptions, which an average customer will face over a year (2.1). One of the obvious ways for SAIFI improvement is reduction of sustained interruptions, but this method can be doable once the number of customers is fixed.

$$SAIFI = \frac{Total\ number\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customers\ Served} \tag{2.1}$$

Moving on, the next parameter which is on the list is **System Average Interruption Duration Index** (**SAIDI)** is a measure, which defines how many interruption hours an average customer will experience over the course of a year (2.2). For a fixed number of customers, it can be improved by reducing the number or duration of these interruptions.

$$SAIDI = \frac{\sum Customer\ Interruption\ Durations}{Total\ Number\ of\ Customers\ Served} \tag{2.2}$$

Customer Average Interruption Duration Index (CAIDI) is the average time needed to restore service to the average customer per sustained interruption (2.3). In more simpler words, it's duration of an average interruption and used as a measure of utility response time to system contingencies. Customer Average Interruption Index can be improved by reducing the length of interruptions or increasing the number of short interruptions.

$$CAIDI = \frac{\sum Customer\ Interruption\ Durations}{Total\ Number\ of\ Customer\ Interruptions} \tag{2.3}$$

Average Service Availability Index (**ASAI)** is customer-based availability of the system, which serves for the same purpose and information as SAIDI (2.4). Higher ASAI value, the higher reflection levels of system reliability.

$$ASAI = \frac{\sum Customer\ Hours\ Service\ Availabilty}{Customer\ Hours\ Service\ Demand} \tag{2.4}$$

To sum up, all the above-mentioned Reliability indices are **Customer-based** Indicators. Customer-based indices are popular with maintaining and equalizing authorities, regardless of a small residential customer or large industrial customer. They have limitations but are generally considered good aggregate measures of reliability and are often used as reliability benchmarks and improvement targets. Regarding, the indices specifically, SAIDI and SAIFI in general are good reliability indicators but can potentially be bias spending towards areas of the system that may already have proper reliability. CAIDI is confusing since increasing CAIDI could be either good or bad.

Load-Based Reliability Indices - is distribution reliability index weight customers based on connected kVA instead of weighting each customer equally. Below will be presented two Load Reliability Indices**- Average System Interruption Frequency Index (ASIFI) (2.5) and Average System Interruption Duration Index (ASIDI) (2.6).**

$$ASIFI = \frac{Connected\ kVA\ Interrupted}{Total\ Connected\ kVA\ Served} \tag{2.5}$$

$$ASIDI = \frac{Connected\ kVA\ Hours\ Interrupted}{Total\ Connected\ kVA\ Served} \tag{2.6}$$

The reason for load-based indices predating customer-based indices is empiric. Previously, utilities knew the size of distribution transformers however there was not any exact data regarding the number of customers connected to each transformer. When a protection device operated, interrupted transformer kVA was easily determined while interrupted customers required estimation. Today, customer information systems (CIS) associate customers with transformers and allow customer-based indices to be easily computed. From a utility perspective, ASIFI and ASIDI probably represent better measures of reliability than SAIFI and SAIDI. Larger kVA corresponds to higher revenue and should be considered when making investment decisions.

Overall, SAIFI and SAIDI indicator are based on failure registry of distribution system. Moreover it could be observed that there are planned (maintenance, reconstruction, upgragding devices, e.t.c) and unplanned outages (random failures – short circuit, device broken by weather issues, e.t.c). As a rule, it is considered that outages which are longer than 3 minutes are included in the SAIFI and SAIDI reportings.

3 Overview of reliability in various distribution systems

In this section, it will be seen a comparison of the distribution system reliability indicators(SAIFI & SAIDI) for various countries. In the first part of section, it will separately be discussed distribution system reliability of the Czech Republic, afterwards as an example it will be taken some countries, which are EU members and their SAIFI and SAIDI indicators will be compared. Then, the scope will go a bit wider and the countries outside the EU zone will be compared with the ones which are in it. In the last part of this section, as there was lack of data of these parameters for the case of Azerbaijan, the main focus will be done on the countries, which are in neighborhood.

3.1 Distribution systems in Czech Republic

As is mentioned above, the starting point for us will be Czech Republic. Below will be presented distribution reliability indicators(SAIFI & SAIDI) obtained from various distribution companies over last 10 years.

Distribution continuity ratios	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
SAIFI(interruption/year)	2.54	2.37	2.36	2.40	2.66	2.38	2.64	2.21	2.76	2.24
ČEZ Distribuce	3.05	2.86	2.88	3.10	3.11	2.77	3.29	2.87	3.41	2.74
E.ON Distribuce	2.13	2.09	2.00	1.67	2.40	2.27	2.27	1.60	2.34	2.01
PREdistribuce	0.92	0.56	0.65	0.54	1.04	0.74	0.36	0.33	0.57	0.40

Table 3.1 *SAIFI index (Interruptions/year) for the CR(2009-2018).* [8]

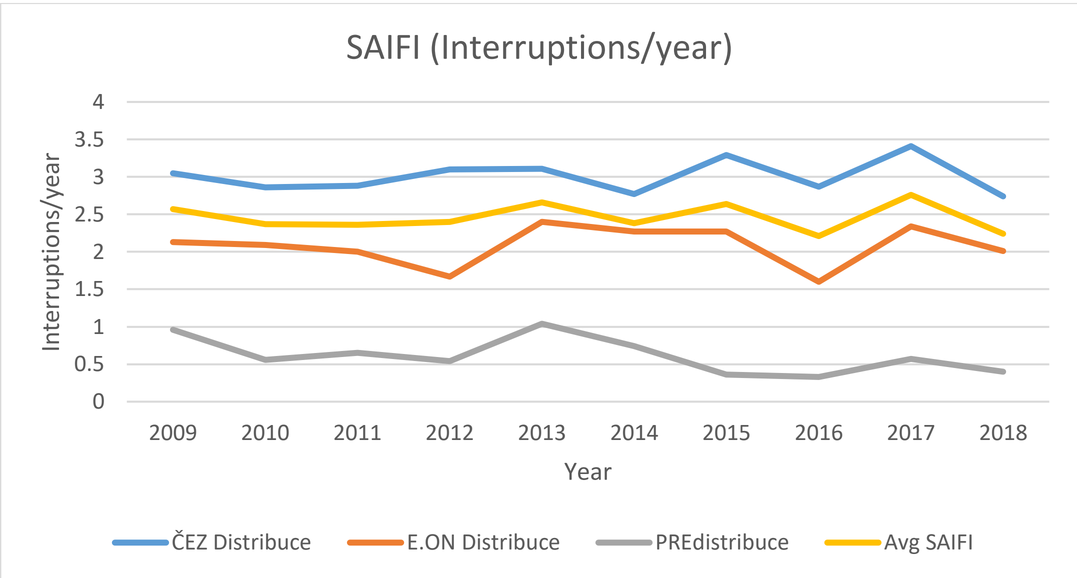

Figure 3.1 *Graphical representation of SAIFI index for the Czech Republic over 10 years.* [8]

Distribution continuity ratios	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
SAIDI(minutes/year)	351.57	296.57	268.82	272.65	354.76	283.22	316.06	258.29	431.45	256.05
ČEZ Distribuce	420.81	321.56	296.70	313.04	402.00	281.42	361.72	309.64	501.47	379.09
E.ON Distribuce	338.67	359.08	314.40	293.05	386.66	409.30	352.90	252.14	466.68	249.79
PREdistribuce	44.98	42.47	46.79	42.12	70.38	43.37	30.93	32.52	40.34	34.06

Table 3.2 *SAIDI index(minutes/year) for the CR(2009-2018).* [8]

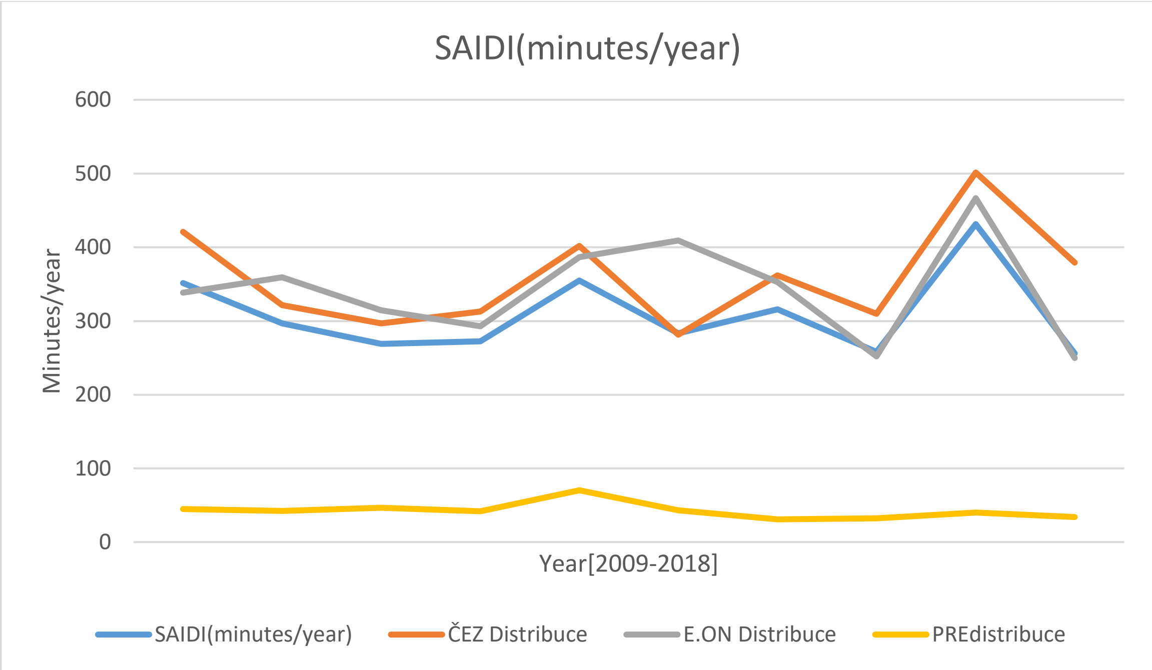

Figure 3.2 *Graphical representation of SAIDI index for the Czech Republic over 10 years.*[8]

For the case of the Czech Republic, it could be seen that PREdistribuce brings up very promising number compared to its local opponents**.** E.ON Distribuce does slightly better job, rather than ČEZ Distribuce in both parameters. However, compared to previous year the improvements in this sphere by local companies are evident.

3.2 Distribution systems in other EU countries

The next part of our report will mainly include in itself EU member countries and its former member Great Britain over 10 years (2007-2016). Compared to the case with the Czech Republic, it won't be mentioned all distribution companies of each country, instead it will again be focused on both planned and unplanned SAIDI and SAIFI indices.

Countries	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
France	72.40	93.50	197.00	119.10	72.80	78.50	99.50	67.30	73.80	70.50
Germany	49.52	30.13	28.82	29.87	27.37	29.20	39.98	21.06	22.19	23.56
Great Britain	108.44	87.64	82.17	88.14	76.70	74.75	66.70	98.23	55.74	50.43
Italy	104.05	138.99	122.25	144.55	169.81	198.70	160.88	153.40	195.65	143.74
Portugal	143.31	164.74	282.03	277.61	133.48	95.83	260.26	97.34	77.47	77.65
Poland	531.00	589.69	518.66	518.88	478.81	410.51	420.94	324.81	363.32	272.00
Latvia	506.00	497.00	678.00	1292	944.00	636.00	621.00	466.00	350.00	286.00
Lithuania	326.36	231.50	256.63	421.64	460.50	467.33	366.69	361.49	300.71	345.96
Malta	490.40	262.18	763.74	693.00	260.00	366.60	421.08	777.60	227.59	163.82
Slovenia	NA	253.35	264.65	186.12	202.39	286.04	224.41	1027.19	199.95	191.82

Table 3.3 *SAIDI index(minutes/year) for the EU member countries (2007-2016).*[9]

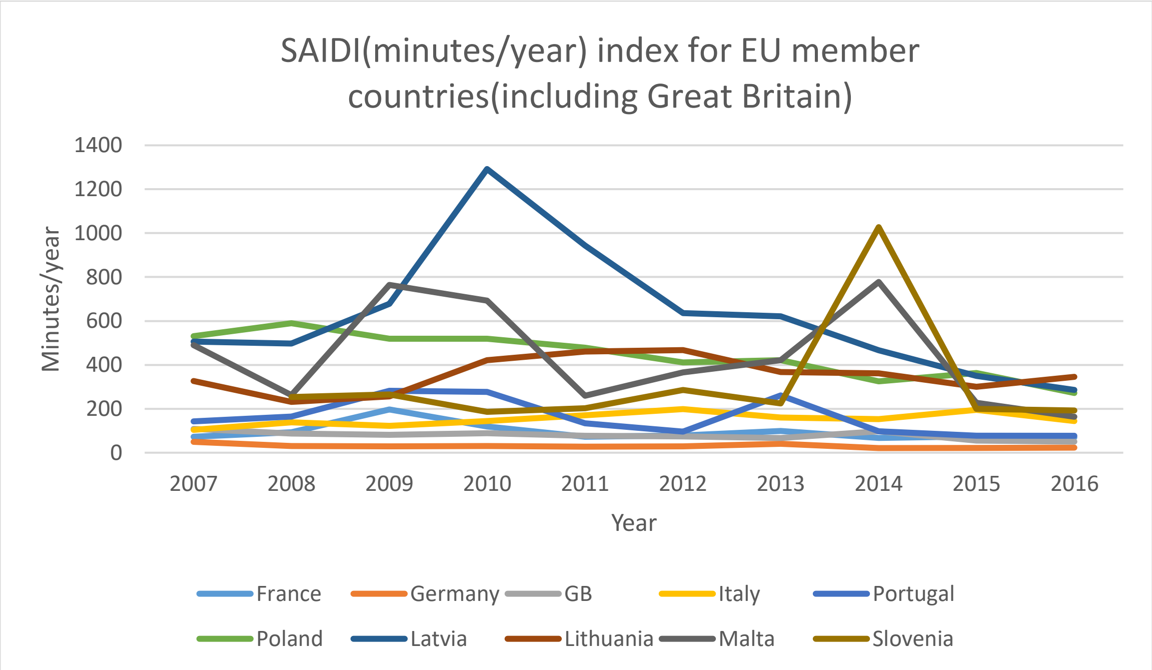

Figure 3.3 *Graphical representation of SAIDI index for the EU member countries (2007-2016).*

Countries	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
France	0.19	0.32	0.34	0.28	0.19	0.19	0.23	0.20	0.22	0.22
Germany	0.55	0.44	0.40	0.40	0.44	0.41	0.58	0.45	0.91	0.59
Great Britain	0.90	0.79	0.75	0.74	0.72	0.68	0.63	0.74	0.58	0.54
Italy	2.46	2.73	2.66	2.65	2.46	2.74	2.57	2.35	2.81	2.17
Portugal	2.66	2.82	3.64	4.33	2.42	1.89	3.10	1.90	1.55	1.65
Poland	3.50	4.88	4.60	4.45	5.04	4.14	3.94	3.52	4.11	3.46
Latvia	3.01	2.95	1.80	5.00	5.59	4.78	4.48	3.77	3.18	3.13
Lithuania	2.44	1.89	1.89	2.45	2.67	2.36	1.97	1.85	1.72	1.83
Malta	NA	NA	NA	NA	NA	NA	0.40	0.38	0.43	0.28
Slovenia	NA	3.81	3.46	2.67	2.79	3.87	3.09	5.17	2.66	2.49

Table 3.4 *SAIFI index(interruptions/year) for the EU member countries (2007-2016).*[9]

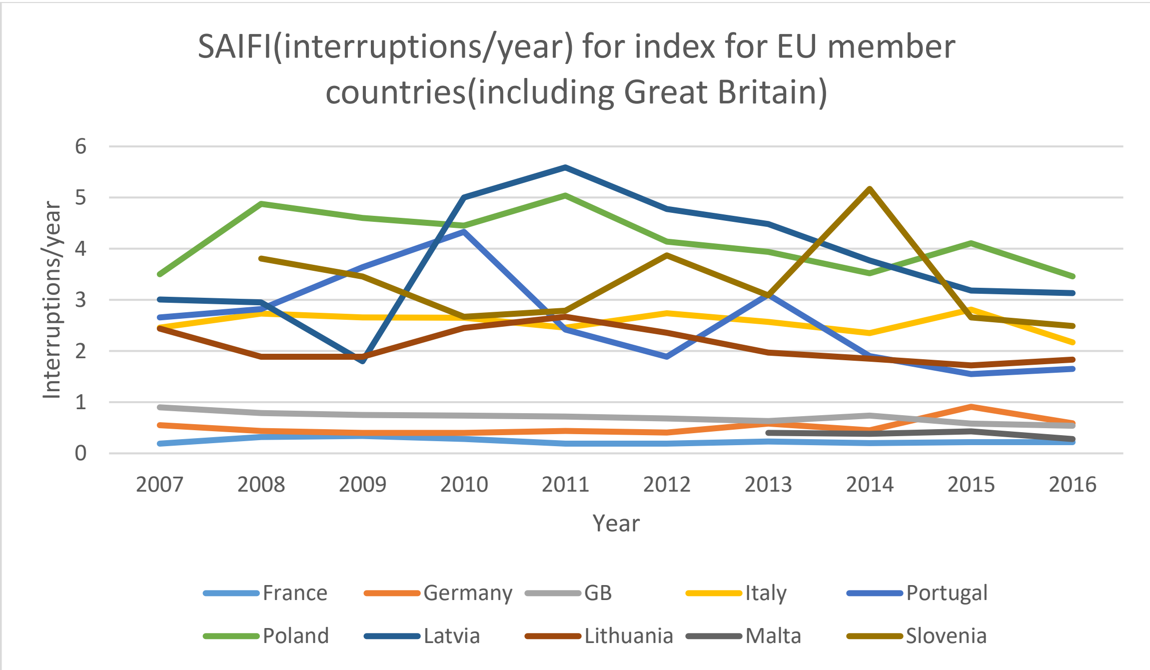

Figure 3.4 *Graphical representation of SAIFI index for the EU member countries (2007-2016).*

Going through the results obtained in EU countries, it can be seen that distribution system is pretty reliable compared to other countries. Great Britain, Germany, France, Italy tries to catch up. The rest of countries(like Poland, Latvia, Slovenia) are far behind, however compared to some other countries outside the EU, they are still doing a very good job.

3.3 Distribution systems of non EU members countries

In the next part of this section, it will be emphasized the countries, which do keep the SAIFI and SAIDI index policy in the power distribution reliability system and it could be seen the comparison of their results with some EU member countries. Taking into account 3nt that USA is pretty huge, consequently its power distribution system reports will be different for each state, so it will be mentioned specifically three of them(New York, California, Pennsylvania) from 2011 till 2015.

Countries	**2011**	**2012**	**2013**	**2014**	**2015**
USA(New York)	71	61	64	66	73
USA(California)	105	101	92	90	92
USA(Pennsylvania)	170	163	145	130	136
Indonesia	282	231	345.6	348.6	318.6
Japan	79	37	16	20	21
Singapore(SAIDI)	0.23	0.44	0.47	0.59	0.57

Table 3.5 *SAIDI index(minutes /year) for the countries outside EU membership (2011-2015).*[10][11][12]

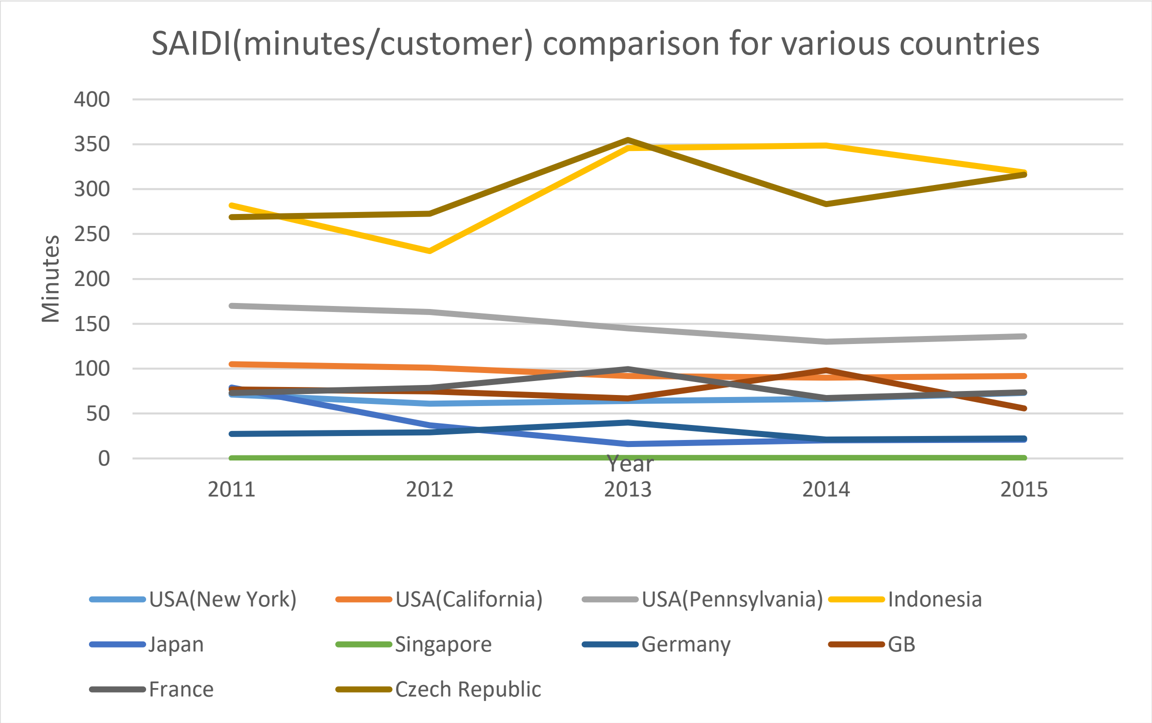

Figure 3.5 *Graphical representation of SAIDI indices(minutes/year) for the countries inside/outside of EU membership (2011-2015).*

Countries	2011	2012	2013	2014	2015
USA(New York)	0.62	0.53	0.57	0.57	0.62
USA(California)	0.89	0.88	0.87	0.85	0.82
USA(Pennsylvania)	1.22	1.09	1.08	1.05	1.08
Indonesia	4.9	4.22	7.26	5.58	5.97
Japan	0.22	0.18	0.16	0.16	0.13
Singapore(SAIFI)	0.042	0.008	0.009	0.015	0.013

Table 3.6 *SAIFI index(interruptions/year) for the countries outside EU membership (2011-2015).* [10][11][12]

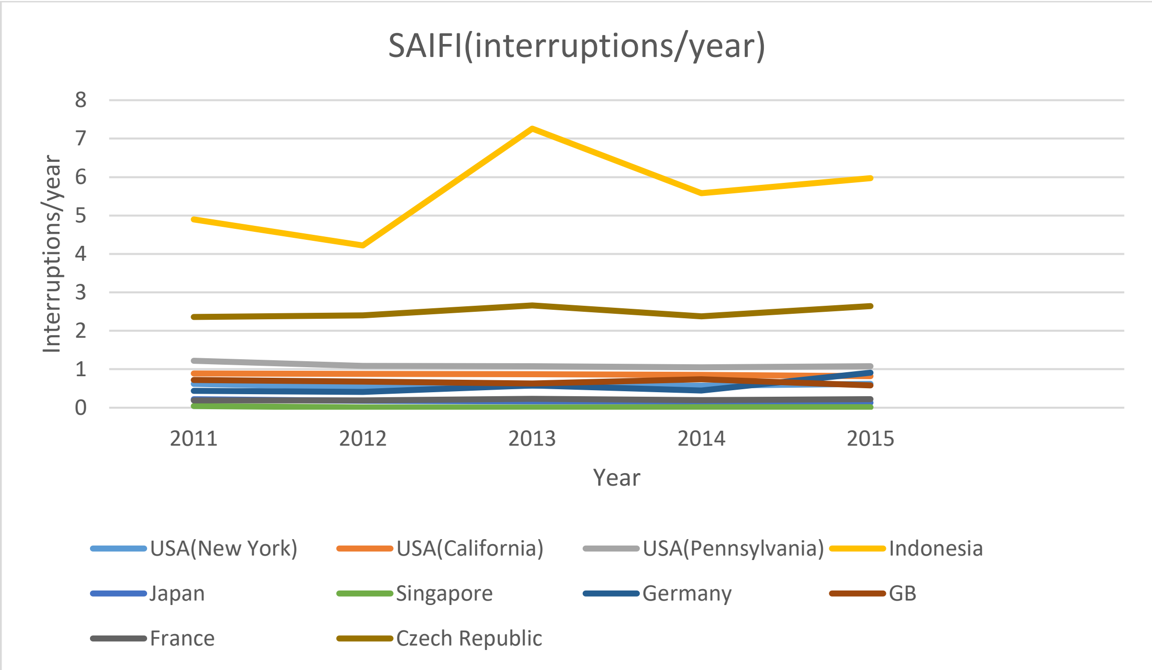

Figure 3.6 *Graphical representation of SAIFI indices(interruptions/year) for the countries inside/outside of EU membership (2011-2015).*

From the graphs in Figures 3.10 and 3.12 it can be seen that almost most of the countries have the same numbers in terms of reliability of distribution system. Singapore has surprisingly small values for both SAIDI & SAIFI indices, that's because it has high level of smart grid technologies implementation and cable networks. However, Czech Republic and Indonesia are slightly behind of other countries, which are in our graph. In the case of Indonesia, it could be explained due to predicted weather forecast for that region.

3.4 Distribution systems in Anatolian and Caucasian regions.

In the last part of this chapter, as is already mentioned, due to lack of data for the case of Azerbaijan. It will be studied the SAIFI and SAIDI indicator for countries in Caucasian and Anatolia region, which are Turkey and Georgia. This subchapter will be started with the country in Anatolian region, and it will be presented the data obtained from various local distribution companies for the year-2015.

Distribution Company	**SAIDI(minute/customer)**	**SAIFI (interruptions/year)**
Dicle	2,336.58	41.33
Vangölu	7,794.01	78.94
Aras	1,811.74	26.07
Çoruh	1,684.48	10.44
Fırat	6,196.37	22.44
Çamlıbe	295.54	4.43
Toroslar	1,583.26	13.36
Meram	2,875.45	17.67
Başkent	832.01	8.01
Akdeniz	1,027.68	12.99
Gediz	1,897.05	16.20
Uludağ	2,371.21	11.44
Trakya	676.95	7.42
Ayedaş	509.28	5.13
Sedaş	1,233.28	25.29
Osmangazi	1,312.76	18.20
Boğaziçi	1,497.46	13.02
Kayseri	849.39	8.78
Aydem	958.21	10.26
Akedaş	500.93	10.64
Yeşilırmak	2,898.25	18.63

Table 3.7 *SAIFI(Interruptions/year) and SAIDI index (minutes/year) for Turkey in 2015.* [13]

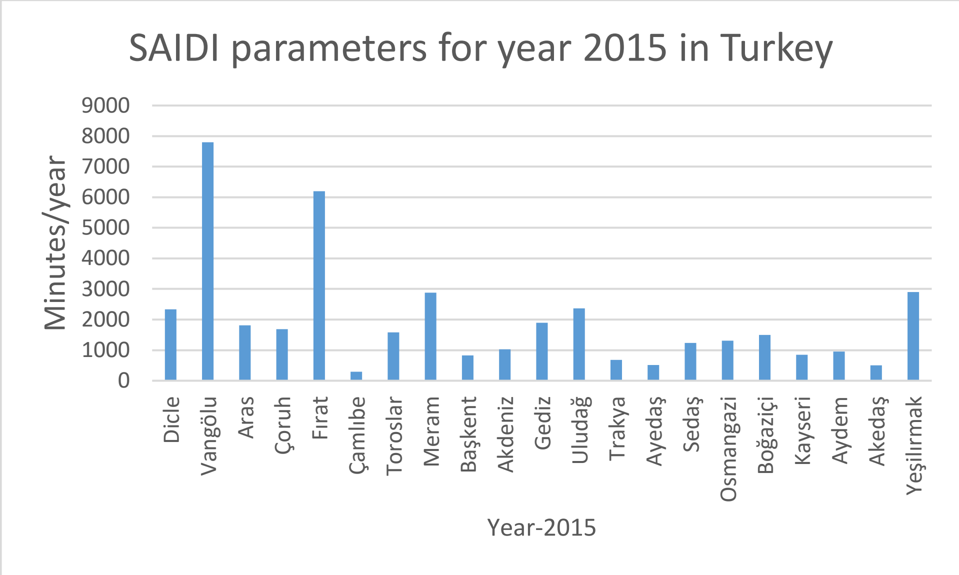

Figure 3.7 *Graphical representation of SAIDI indices(minutes /year) for Turkey in 2015.*

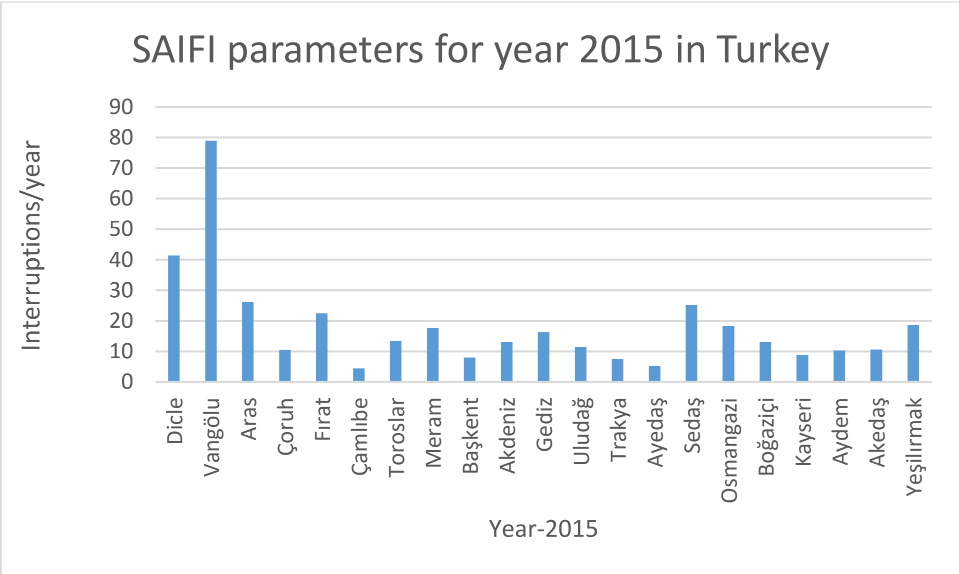

Figure 3.8 *Graphical representation of SAIFI indices(interruptions /year) for Turkey in 2015.*

From these graphs the following conclusion can be done: the distribution reliability system seems quite unstable in Turkey for year 2015. Especially, for the companies like: Vangölu, Fırat they are leaving the other companies far behind doing an anti-record.

The second part will be about the country in the region of the Caucasus, which is Georgia.

Company/year		**2014**		**2015**		**2016**	
		SAIDI	**SAIFI**	**SAIDI**	**SAIFI**	**SAIDI**	**SAIFI**
Telasi		487.5	6.85	323.83	5.897	314.2	5.44
Energo-Pro Georgia	**City**	422	3.5	331	2.72	305	3.4
	Borough	937	8.1	750	7.05	669	7.55
	Village	3061	26.2	2476	22.96	2203	24.9
Kaketi-Energy Distribution	**City**	394	3.8	220.6	3.2	236.4	2.18
	Village	1705	11.7	1271.9	9.63	1618.6	8

Table 3.8 *SAIDI(minutes/year) & SAIFI indices(interruptions /year) for Georgia (2014-2016).*[14]

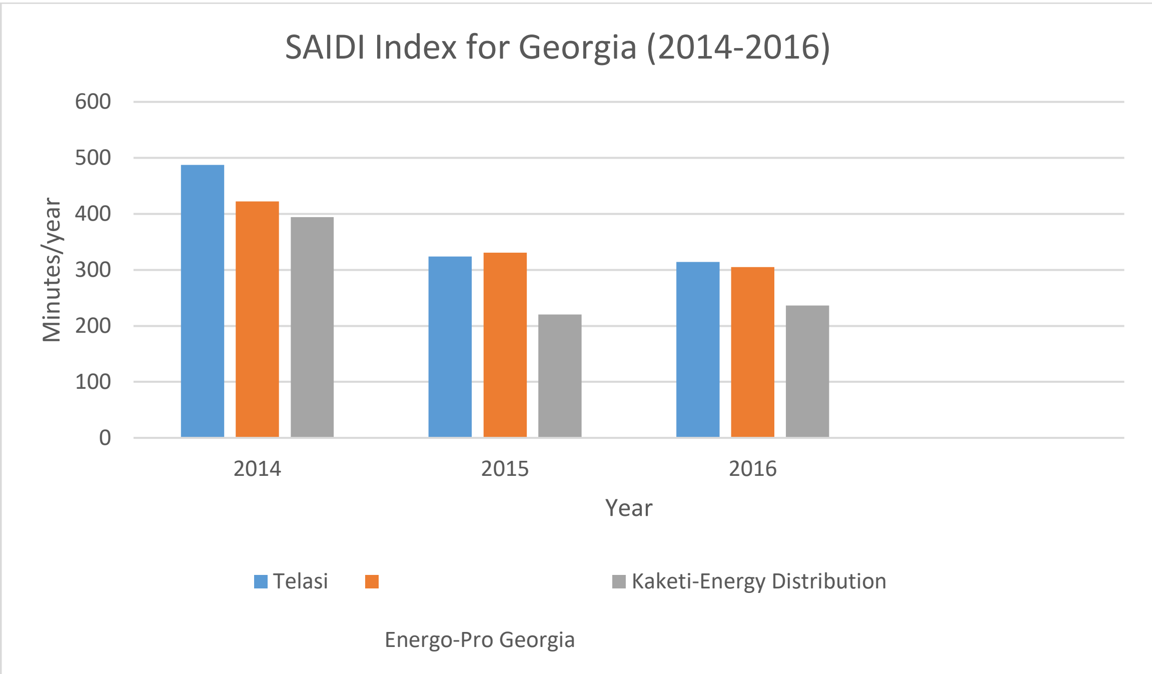

Figure 3.9 *Graphical representation of SAIDI indices(Minutes /year) for Georgia(2014-2016).*

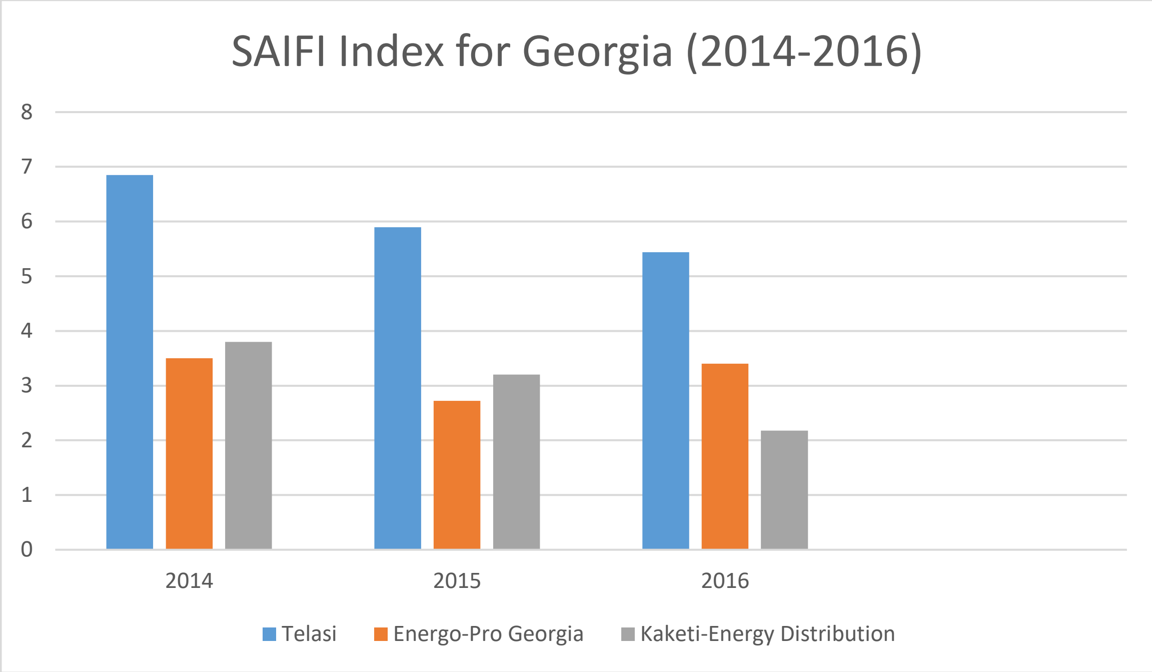

Figure 3.10 *Graphical representation of SAIFI indices(Interruptions /year) for Georgia(2014-2016)*

In this case it was ignored in the cases for borough and villages and mainly focused on city based indices. From the graph it is pretty noticeable the following fact that distribution reliability system seems promising in Georgia, it could be observed that the SAIFI & SAIDI parameters are mainly decreasing from 2014 to 2016 years. However, based on the results expressed for the villages, there is still the potential of improvement of the indicators in some specific areas.

4 Technologies for improving distribution system reliability

The distribution system has a crucial role in the total electric system, as it is served to connect the final link between the bulk system and the client. Mostly, these links are radial in nature, therefore susceptible to outage due to a single occasion. In common, many distribution systems have normally open points in a meshed configuration, so that the system is utilized as a radial feed. However, during fault conditions normally open switches could be used so that the load can be restored to unaffected areas. The goal is to isolate the faulted part and connect the healthy part of the system as soon as possible to increase overall system reliability. Although reliability assessment models can give us much understanding into the state of a distribution system, their primary necessity is quantifying the impact of design improvement options. Essentially, the temptation of quickly identifying effective design improvement options often results in an abbreviated system analysis effort, which is not suggested. A thorough system analysis of the existing system will generally be more preferable, as it will allow for higher quality design improvement options to be identified in a shorter period of time. Another important step to conclude before exploring reliability improvement options is defining criteria and constraints. Both criteria and constraints may contain one or more of the following: reliability indices, individual customer reliability, risk profiles, and cost. Other factors, such as redundancy, equipment loading, and voltage can usually be neglected since they are not usually binding. In this section we will mostly focus on reliability improvement strategies and list the most common strategies and technologies for reliability improvement.

4.1 Protection devices

One of the most straightforward and effective methods for improving distribution system reliability is adding **Protection Devices.** Increasing the number of protection devices reduces the number of customers that face interruptions after a fault occurs in other words, it increases the selectivity of the protection system. Protection device includes fuse, circuit breaker, polyswitch, RCCB, metal oxide varistor, gas discharge tube, etc. In this particular case we will place a fuse, on all radial branches. According to the recent reliability studies, we can deduce that laterals should be fused. The only persuasive reasons for not applying a fusing method on a lateral are nuisance fuse blowing (which can generally be avoided by specifying larger fuses) and the inability to coordinate. Three-phase laterals may require gadgets with 3ϕ lockout capability in the event that they serve huge engines, which may be harmed by unbalanced voltages, or transformers with essential delta-connected windings, which may make safety issues due to the plausibility of back feeding. Lateral fusing gets more efficient as total lateral exposure increments and as average lateral length diminishes. Assuming idealize fuse operation, a defect on an infused lateral will brake in the whole feeder whereas a fault on a fused lateral will as it were barged in clients on that lateral. Figure 4.1 presents the sensitivity of SAIFI to lateral exposure for different lateral lengths (indicated as a ratio of average lateral length to main trunk length, L/M)

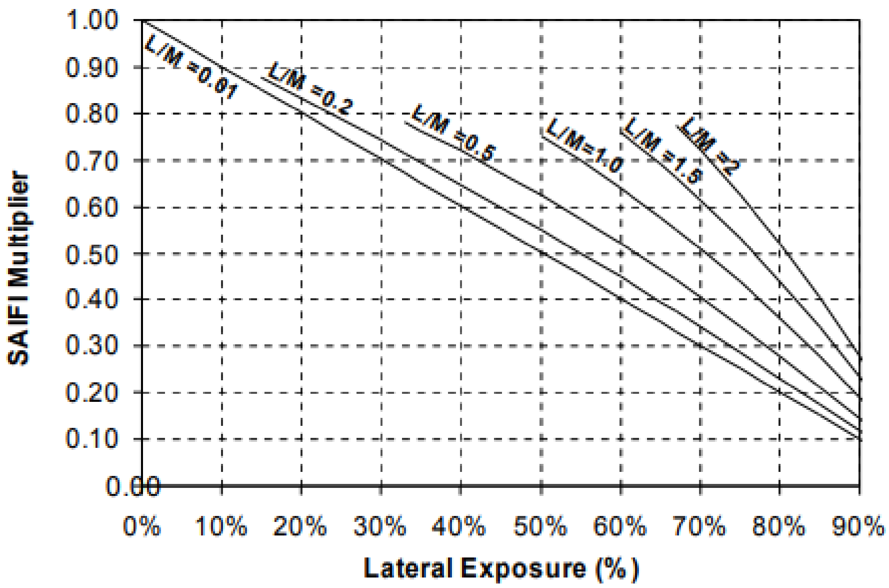

Figure 4.1 *Graphical representation Lateral Exposure in percentage [5]*

From this chart it can be concluded, that lateral fusing can significantly decrease feeder SAIFI. Effectiveness depends upon the amount of lateral exposure (as a percentage of total exposure) and average lateral length (shown as a proportion of average lateral length to primary trunk length, L/M). For feeders with shorter laterals, fusing X % of total exposure will diminish SAIFI by about X%.

4.2 Reclosers

Moving forward, another method of improving distribution reliability is **Reclosing Devices.** In electric power distribution, automatic circuit reclosers (ACRs) are a class of switchgear which is designed for use on overhead electricity distribution networks to detect and interrupt momentary faults. Also known as reclosers or autoreclosers, ACRs are essentially high voltage rated circuit breakers with integrated current and voltage sensors and a protection relay, optimized for use as an overhead network distribution protection asset.[15] Reclosers are used throughout the power distribution system, from the substation to private utility shafts. They run from small reclosers for utilization on single-phase power lines, to larger three-phase reclosers used in substations and on high-voltage power lines up to 38,000 volts.Reclosing devices are the most commonly utilized to permit temporary errors on overhead systems to self-clear. Since 70% to 80% of overhead issues are brief in nature, any feeders with fundamentally overhead introduction ought to be protected by a reclosing relay on its primary circuit breaker. Setting a line recloser on a feeder will progress the unwavering quality of all upstream clients by protecting them from downstream flaws. Below will be presented types of reclosers:

Figure 4.2 *Single phase recloser* [16]

Single-phase reclosers are used to ensure single-phase lines such as branches or taps of a three-phase feeder. They can moreover be utilized on three-phase circuits where the load is predominantly single-phase. When a lasting phase-to-ground fault occurs, one phase can be locked-out whereas benefit is kept up to the remaining two-thirds of the framework. Compared the lighter weight of single-phase recloser to bigger three-phase reclosers, single-phase reclosers are typically mounted straightforwardly to the pole or substation steel structure independently by the built-in mounting hanger bracket which disposes of the demand for an extra mounting frame. Single-phase reclosers can be controlled with a hydraulic control (integrated within the recloser tank), or an electronic control (housed in a separate enclosure) based upon the recloser design.[16]

Figure 4.3 *Three-phase recloser*[16]

Three-phase reclosers are applied on three-phase circuits to improve system reliability and to avoid single phasing of three-phase loads to where lockout of all three phases is demanded. The recloser selection is determined upon electrical appraisals required, hindering and insulation medium, and the choice of hydraulic or electronic control. The mode of operation is as follows: Three-phase trip and three-phase lockout: Bigger reclosers use this mode. For any fault (single-phase-to-ground, phase-to-phase or three-phase), all contacts open at the same time for each trip operation. The three phases, mechanically connected together for tripping and reclosing, are operated by a common instrument. A few mounting alternatives are accessible for three-phase reclosers including pole mounting frame and substation frame.

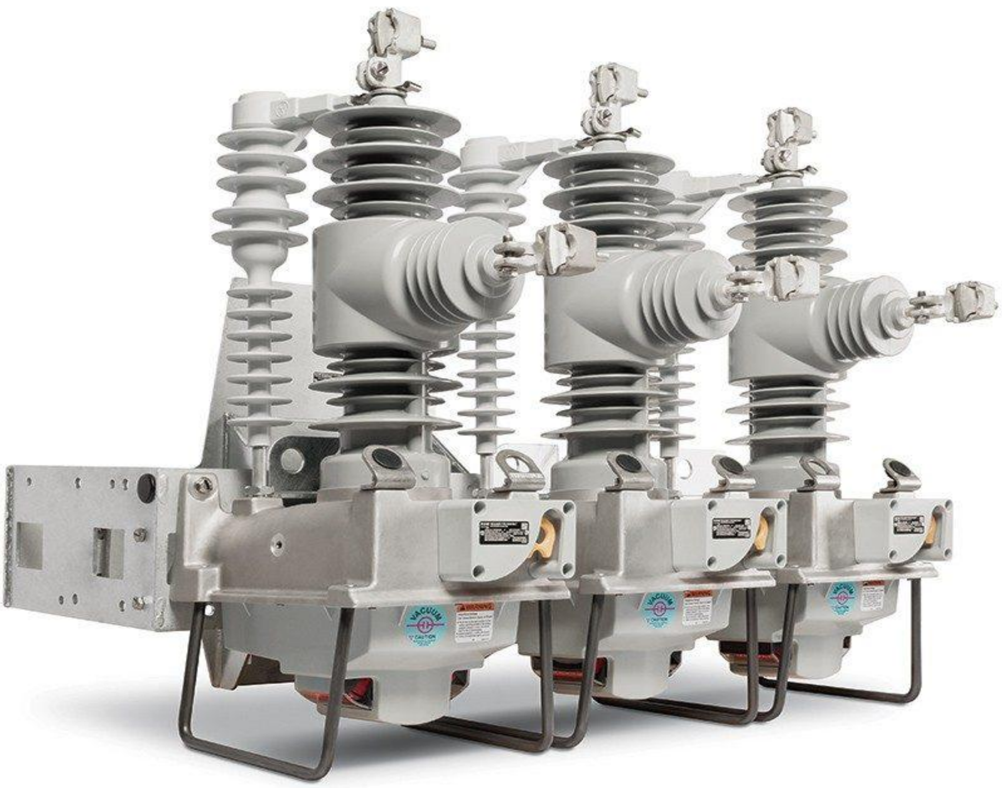

Figure 4.4 *Triple-single recloser*[16]

These reclosers are electronically controlled and have three modes of operation:

- Three-phase trip and three-phase lockout: All three phases trip on an overcurrent, reclose and sequence together.
- Single-phase trip and three-phase lockout: Each phase operates independently for overcurrent tripping and reclosing. If any phase sequences to lockout condition (due to permanent fault), or if "lockout" is locally or remotely asserted, the other two phases trip open and lock out. Extended single-phase energization of three-phase loads is prevented.
- Single-phase trip and single-phase lockout: Each individual phase trips and sequences to lockout independent of each other.

Triple-single reclosers can be mounted to a pole with use of pole mount frame or in the substation with substation frame (or directly to steel substation structure).

4.3 Sectionizers

Sectionalizing Switches is in the list of technologies to improve distribution reliability. A sectionalizer is a protective device, utilized in conjunction with a recloser, or breaker and reclosing relay, which isolates faulted parts of lines. The aim of sectionalizer is not concluded in interruption of fault current. Instead, sectionalizer counts the number of operations which is done by the interrupting device upstream and opens whereas the interrupting device is open.Sectionalizing switches have the potential to progress reliability by permitting faults to be isolated and customer service to be reestablished before the fault is repaired. The effectiveness of this process depends upon how much of the feeder must be switched out to isolate the fault and the capability of the system to reroute power to interrupted clients through normally opentie points. Generally more anual normally closed and open switches will result in decreased duration-oriented indices like SAIDI and will not affect frequency-oriented indices like SAIFI. However, since each switch has a failure probability, involving more and more switches on a feeder will eventually cause a degradation of system reliability. Additionally, could be mentioned the types of sectionlizers. Which are manual and remote controlled sectionizers. Manual sectionizer- there is no remote-control function, it can be manipulated just in field manualy by maintenance workers with qualification. Remote control sectionizer- has remote control function (controlled from dispatching centre). Different sorts of sectionalizing equipment and various sectionalizing schemes exist on distribution systems. Speaking more of them, below will be illustrated some examples of sectionalizers:

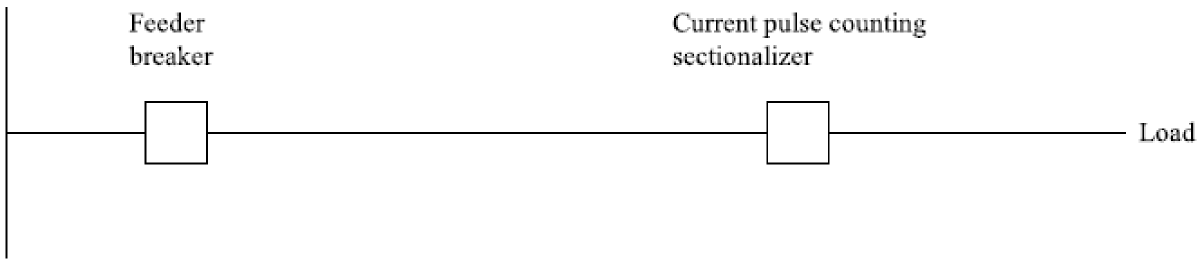

Figure 4.5 *Sectionalizer Scheme*

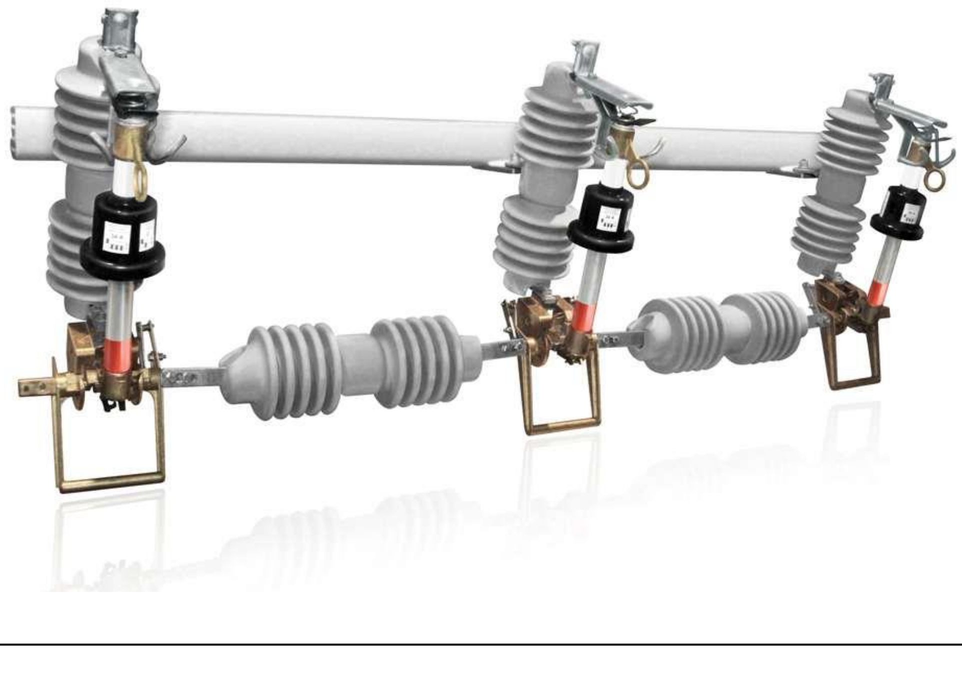

Figure 4.6 *Three phase Sectionalizer [17]*

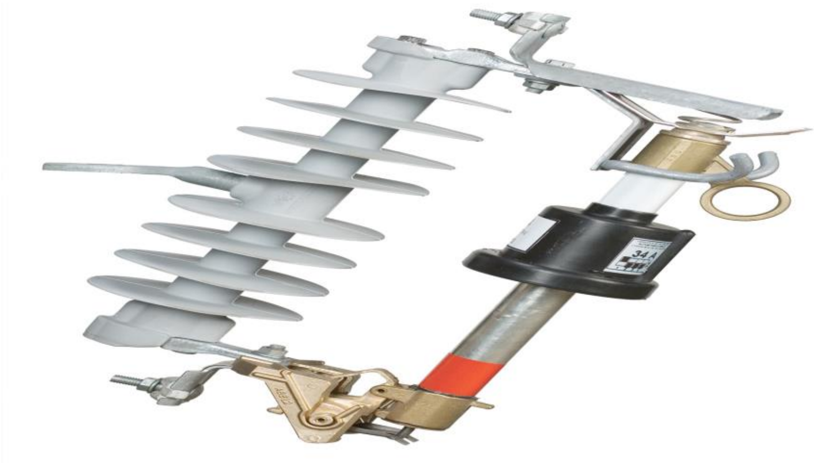

Figure 4.7 *One phase Sectionalizer* ***[17]***

4.4 Automation

Automation refers to remote monitoring and control of a device. For reliability improvement, automation typically alludes to remotely operated substation and feeder switches. Since the most outstanding advantage of automated switches is their capability to be opened and/or closed much more rapidly than manual switches, their reliability impact can be easily modified by adjusting their mean time to switch (MTTS). Users should also be careful to make sure that the influence of quick switching time is appropriately reflected in momentary interruption measures such as MAIFIE and sustained interruption measures such as SAIFI. Users ought to indeed be aware that the dependability of automated switches may be below than that of manual switches, accounted for by a rise in the probability of operational failure (POF).

Next it will be seen the investigation and brief discussion of equipments for the cases of automation:

Ring Main Unit (RMU)- is a compact switchgear broadly used in Urban Power Distribution Network. RMU contains a combination of one or more Load Break Switch (LBS) cum Earth Switch as incomer and outgoing feeder and Vacuum Circuit Breaker with associated Disconnector and Earth Switch for load feeders. Depending on the prerequisite, this unit is accessible in several voltage ratings and serves for both indoor and outdoor installation.

All the switching devices and the busbars are enclosed in a sealed for life SS enclosure filled with SF6 to create the design compact whereas guaranteeing a level of security and also a maintenance-free system. One of the major factors of RMU is that it incorporates SF6 gas insulation, compact and modular construction, integral protection system, completely extendable options, and low maintenance.Below will be presented an example image of a typical RMU switchgear. [18]

Figure 4.8 *Ring Main Unit* ***[19]***

Speaking of its pluses and minuses, this device brings out an innovative solution that makes it easier to manage simultaneously the numerous tasks of electrical distribution. It’s is safe, relatively easy in terms of installation and maintenance free switchgear, by this helping the utilities to have more advanced reliability and reduce the operational costs. In the realities of modern power distribution system, RMU is widely used across India and around the world to effectively meet the growing demands of safe energy.

Another equipment, which needs a close investigation is:

Remote terminal unit (RTU) is device utilized for a multipurpose, mainly used for remote observations and control of various devices and systems for automation. In most cases, it is utilized in an industrial environment and has a lot in common with programmable logic circuits (PLCs). An RTU might be considered a self-contained computer as it has all the essential parts that, together, characterize a computer: a processor, memory and storage. This can guide us in usage as an intelligent controller or master controller for other devices that, together, automate a process such as a portion of an assembly line. Another term which is used to describe RTU is remote telecontrol units or remote telemetry unit. Alongside being more advanced versions of PLCs, they can only follow specific programming called ladder logic. An RTU is modern and intelligent enough to control multiple processes without requiring client intervention or input from a more intelligent controller or master controller. Because of this capability, the aim of the RTU is to interface with distributed control systems (DCS) and supervisory control and data acquisition (SCADA) systems by sending telemetry information to these systems. But in most cases, indeed intelligent RTUs are connected to a more modern control framework such as an actual computer, which makes their reprogramming and control of the complete system easier for a user. Below will be presented an example picture for RTU[20].

Figure 4.9 *Remote Terminal Unit* ***[21]***

The last device, which is worth to speak up is:
Fault Passage Indicator(FPI)- The uppermost goal of fault passage indicating system is to detect faults occurring in the medium voltage system, more precisely in the downstream section from the point of its installation. This might be obtained by constant monitoring of voltage presence and current flow in medium voltage line. The equipment detects and signals any growth in current alongside voltage absence. When there is an error occurrence, the flashing lights in FPI; consequently this information is sent with help of radio signals to the communication portal installed nearby for onward transmission to SCADA system. Using this system, the utility procures data with respect to the section of the line having fault. This distinguishing proof helps eliminate the watching of whole line for finding the fault, eventually diminishing restoration time. Down below there will be shown a sample image for FPI[22].

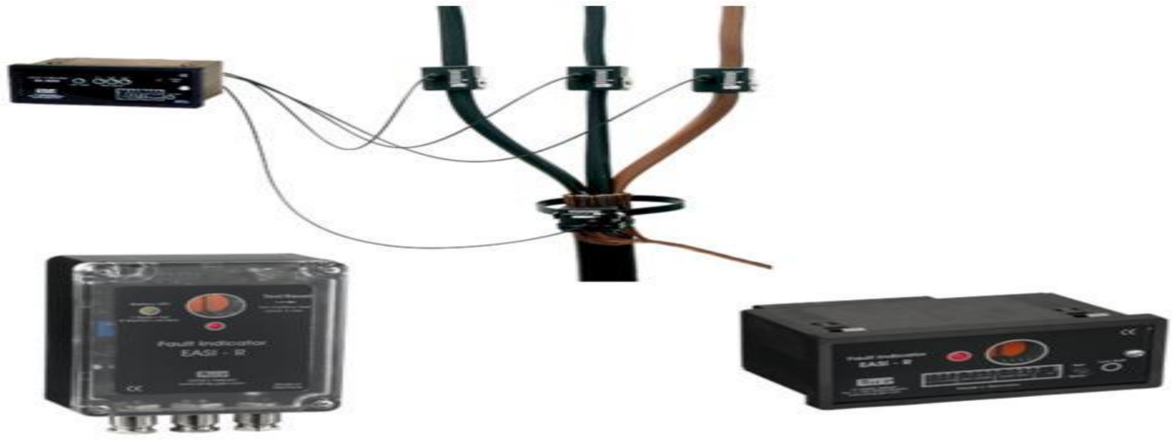

Figure 4.10 *Fault Passage Indicator* ***[23]***

To sum up, the systematic use of broad automation isn't suggested as an introductory technique makes strides of reliability. Automating tie switches and several extra switches can certainly improve reliability, but is generally costly, compared to other reliability advancement choices. Being focused on feeder automation can be costeffective, moreover broad automation is generally demanded for dramatic reliability advancements. A straightforward but effective approach is to test the effectiveness of switch automation in the order of expected switching frequency. Apparently, a switch anticipated to function a larger number of times per year includes a more prominent chance of profiting from automation than a switch anticipated to function a little number of times per year. In any occasion, reliability models can easily measure the reliability gains for different automation scenarios to assist guarantee that the best number and location of automated switches are identified.

5 Case study

5.1 Studied problem focus

In this chapter a case study will be done for the feeders with various automation components. It will be investigated 9 cases, and, in each case, it will be able to observe the calculation of the SAIFI and SAIDI indicators. Fault passage indicators and reclosers are targeted as our main automation components in these case study model. At first, there will be a necessity to afresh the formulas for the above-mentioned indicators, afterwards in order to bring out the predicted results, we will make some assumptions.

$$SAIFI = \frac{\sum \lambda i * Ni}{Nt} \tag{5.1}$$

where, λ_I-feeder failure rate $N_{i,}$-number of customers in each segment N_t -total number of customers.

$$SAIDI = \frac{\sum Ti * Ni}{Nt} \tag{5.2}$$

where, T_I-time of disconnection duration, $N_{i,}$-number of customers in each segment N_t -total number of customers.

From these formulas we might assume following parameters:

	Input parameter	Unit	Value
I N P U T S	Feeder failure rate λ	failure/year	3
	Number of segments N	-	12
	Segment failure rate λs	failure/year/segment	0.25
	Travel time T_t	min	40
	Localization time T_l	min	30
	Repair time T_r	min	15
	Total number of customers N_t	-	1
	Number of cutomers per segment N_s	-	0.083333

Table 5.1 *Input parameters for the cases 0-9*

From here it could be done basic calculations for some parameters, which will be the same for each of the cases.

$\lambda_{segment} = \frac{\lambda}{N} = \frac{3}{12} = 0.25$ failure/year, this applies for each case *(5.3)*

$T_i = (T_t + T_l) * N_t + T_r * N_t$ – total time in each segment, this will vary by the type and number of automation components in each feeder. *(5.4)*

$T_l = \frac{To}{2} + \frac{To}{2} * (\frac{1}{Nac+1})$, localization time will depend on number of automation components in each case. *(5.5)*

5.2 Studied scenarios

Now there will be deeper inspection of each case. However, before stepping into the process and calculations, there will be a demand to show the assumptions. Down below will be represented list of assumptions:

- Each segment has the same failure rate
- Each segment has the same number of customers
- Travel time is the same for each segment of feeder
- Localization time is the same for each segment of feeder
- Repair time is the same for each segment feeder
- In case of used model, the using od recloser or remotely controlled sectionizer is equal
- Two types of segment were used – segments of main feeder (1-6) and segments of branches (7-12).
- Switching element (recloser, manually controlled sectionizer, remotely controlled sectionizer) of each segment is in the beginning of segment and FPI are considered also in these positions.
- Normal open point is located in the end of segment 6.
- Circuit breaker is located in substation and allow the automatic reclosing function.

Case0:

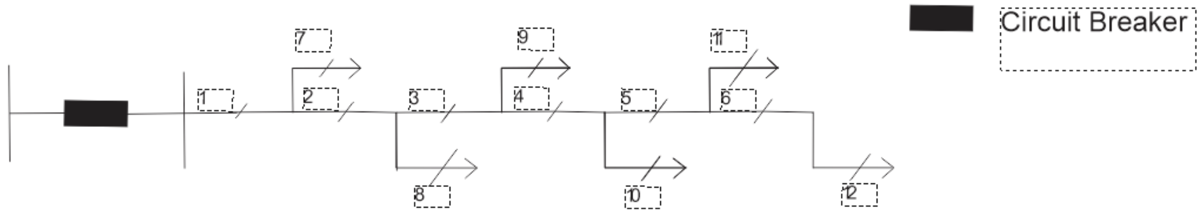

Figure 5.1 *Feeder scheme for case 0*

In this feeder there is no automation components. Hence all the input components will remain stable.

Case1:

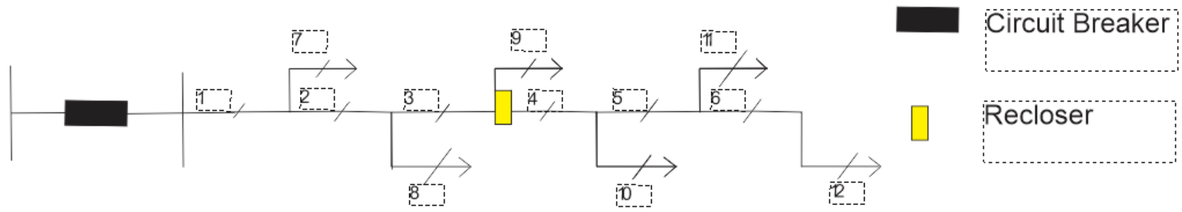

Figure 5.2 *Feeder scheme for case 1*

In this feeder there is one automation components, which is recloser. In this case, localization time will change and calculated according to the formula (5.5) and will be equal to 22.5 minutes. As we know that, travel time and repair time strictly depend on N_i , so N_i for the segment 4,5,6(main feeder) and 10,11,12(branch) will be equal to 0.5, while for the rest of cases will be equal to 1. This can be explained due to influence of Automation component.

Case2:

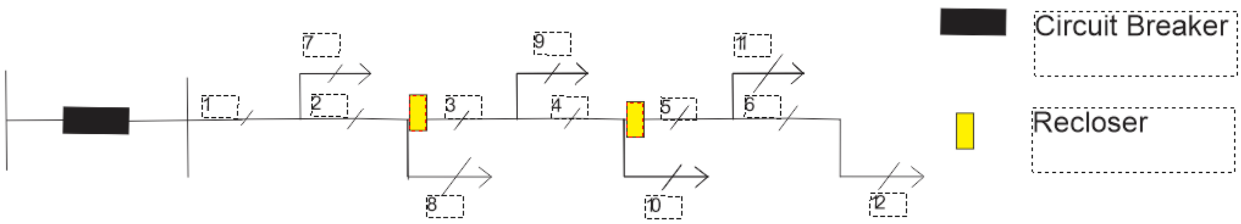

Figure 5.3 *Feeder scheme for case 2*

In this feeder there are two automation components, which is recloser. In this case, localization time will will be equal to 20 minutes. While N_i for the segment 3,4(main feeder) and 9,10(branch) and will be equal to 0.66, for the segment 5,6(main feeder) and 11,12(branch) will be equal to 0.33 and for the rest of cases will be equal to 1. These values could be explained by the fact of two recloser in the system, which makes our feeder more stable.

Case3:

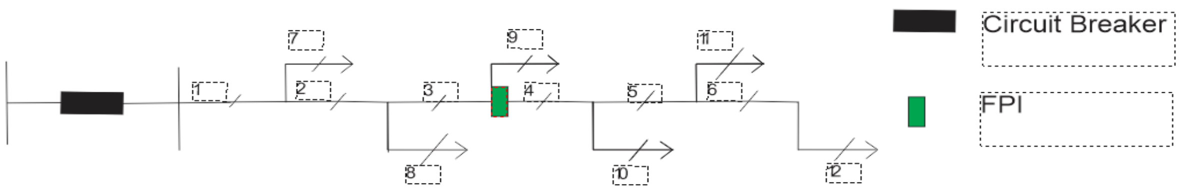

Figure 5.4 *Feeder scheme for case 3*

In this feeder we have a FPI. This automation component will affect just the localization time will be equal to 22.5 minutes, as in case 1. While the rest of the components will remain the same as it is in case-0.

Case4:

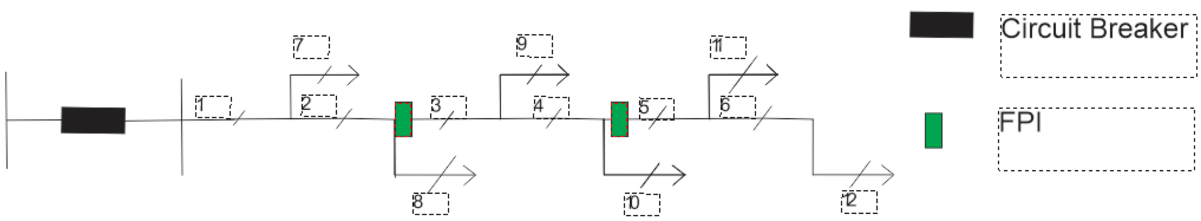

Figure 5.5 *Feeder scheme for case 4*

In this feeder there are two FPI-s. The localization time will be equal to 20 minutes and rest of the components will remain unchanged.

Case5:

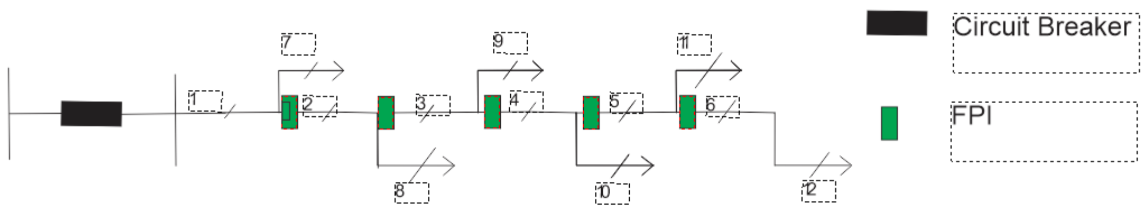

Figure 5.6 *Feeder scheme for case 5*

In this feeder there are five FPI-s. The localization time will be equal to 17.5 minutes and rest of the components stay unchanged.

Case6:

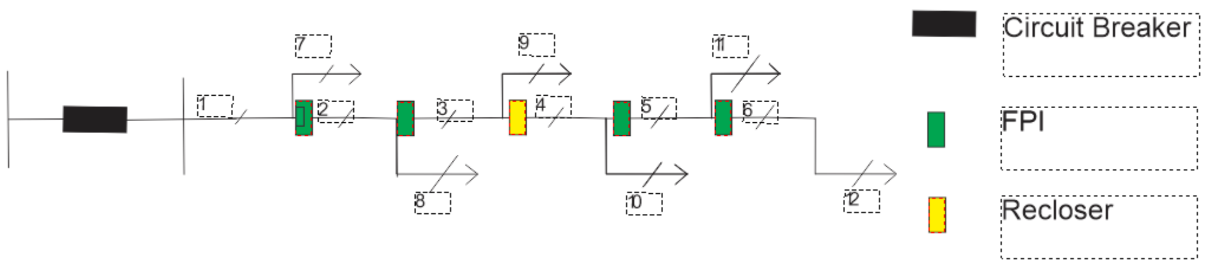

Figure 5.7 *Feeder scheme for case 6*

In this feeder there are five automation components, four of which are FPI-s and one recloser. The localization time will be equal to 17.5 minutes and rest of the components will be the same as in the case-1.

Case7:

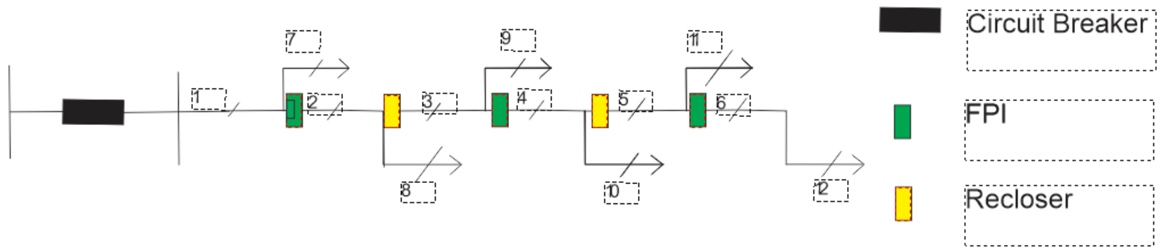

Figure 5.8 *Feeder scheme for case 7*

In this feeder there are again have five automation components, three of which are FPI-s and two reclosers. The localization time will be equal to 17.5 minutes and rest of the components will be the same as in the case-2.

Case8:

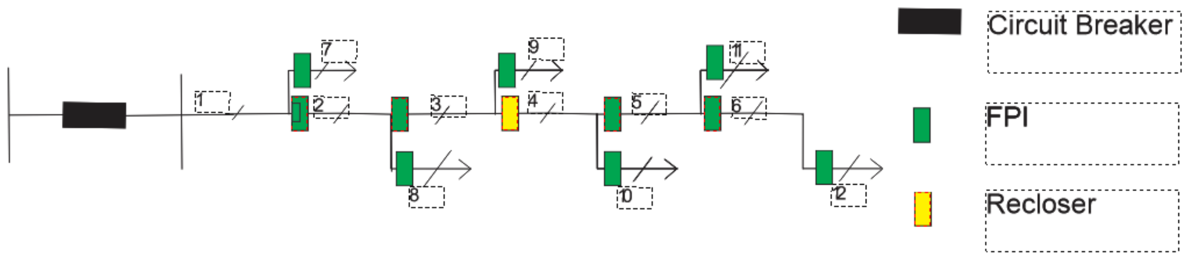

Figure 5.9 *Feeder scheme for case 8*

In this feeder there are 11 automation components, one recloser and the rest are FPI. The localization time will be vary due to number of automation components and will be equal to 16.25 minutes and rest of the components will be the same as in the case-1.

Case9:

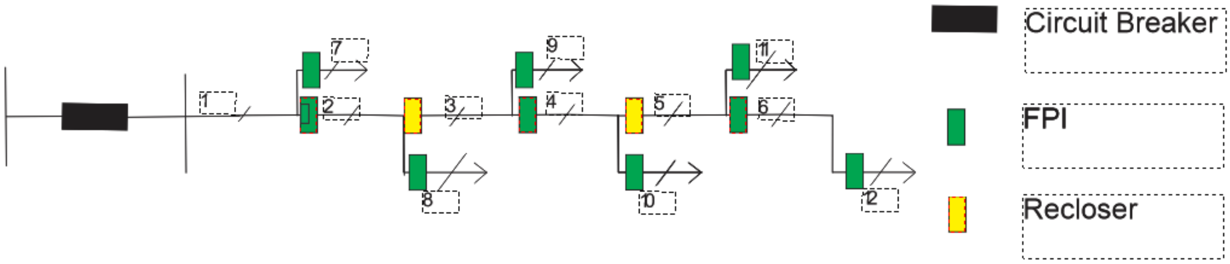

Figure 5.10 *Feeder scheme for case 9*

In this feeder there are same number of automation components as in case 8, however two of which are reclosers in this case. The localization time will be same as in case above, while the rest of the components will be the same as in the case 2.

After inspection of these cases in case without Normal Open point. Two more scenarios will be observed, with NOP (manual sectionizer) and with NOP (recloser or remote controlled sectionizer). The obtained SAIFI and SAIDI parameters will be presented in the table below and to see a difference between each case, we will represent following graphs.

5.3 Results

In this section it can be found the obtained results for SAIFI and SAIDI indicators for all three scenarios. Figure 5.1 and 5.2 shows the SAIFI values in both numerical and graphical form, while SAIDI parameters could be found in the Figure 5.3 and 5.4. In all four figures SAIDI and SAIFI results are presented for all the cases, including the scenarios with/ without NOP.

Case	Description	Without NOP	With NOP (manual sectionizer)	With NOP (recloser or remote controlled sectionizer)
		SAIFI	SAIFI	SAIFI
Case 0	No automation	3	3	3
Case 1	1 recloser	2.25	2.25	1.5
Case 2	2 recloser	1.99	1.99	0.99
Case 3	1 FPI	3	3	3
Case 4	2 FPI	3	3	3
Case 5	5 FPI	3	3	3
Case 6	1 recloser, 4 FPI	2.25	2.25	1.5
Case 7	2 recloser, 3 FPI	1.99	1.99	0.99
Case 8	1 recloser, 10 FPI	2.25	2.25	1.5
Case 9	2 recloser, 9 FPI	1.99	1.99	0.99

Table 5.2 *SAIFI values for each cases with/without NOP*

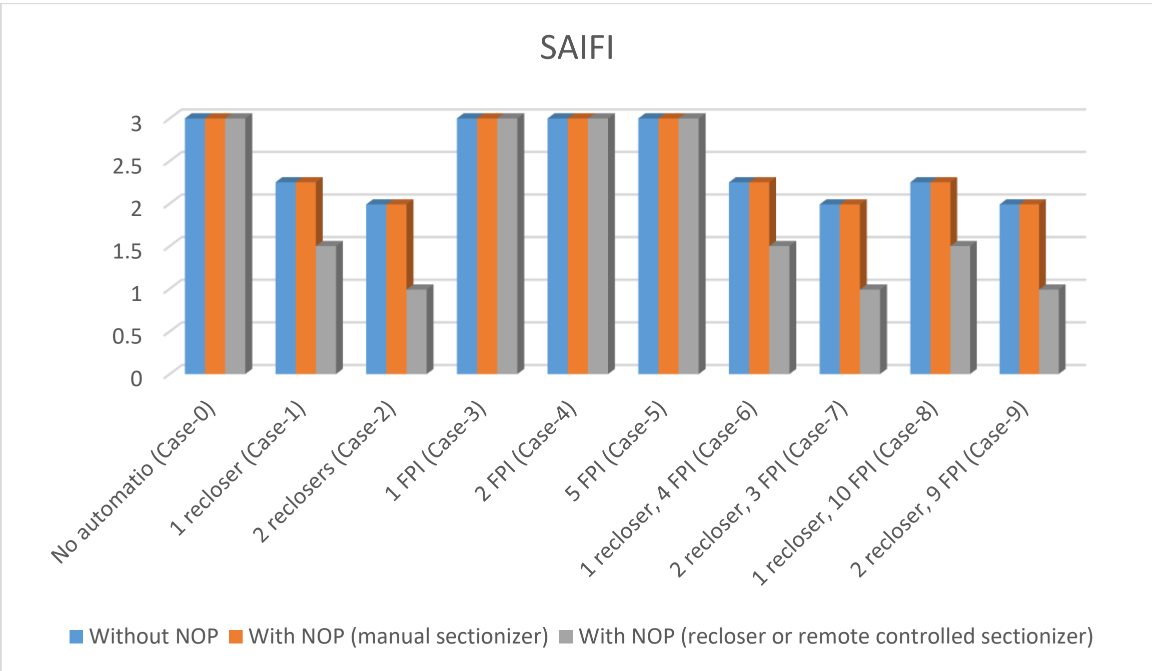

Figure 5.11 *Development of SAIFI for various numbers and types of deployed automation elements*

Case	Description	Without NOP	With NOP (manual sectionizer)	With NOP (recloser or remote controlled sectionizer)
		SAIDI [min.]	SAIDI [min.]	SAIDI [min.]
Case 0	No automation	165	155.625	155.625
Case 1	1 recloser	110.625	110.625	69.375
Case 2	2 recloser	94.6	85.225	65.225
Case 3	1 FPI	142.5	133.125	133.125
Case 4	2 FPI	135	125.625	125.625
Case 5	5 FPI	127.5	118.125	118.125
Case 6	1 recloser, 4 FPI	99.375	90	61.875
Case 7	2 recloser, 3 FPI	89.625	80.25	42.75
Case 8	1 recloser, 10 FPI	96.5625	87.1875	60
Case 9	2 recloser, 9 FPI	87.1375	77.7625	41.5125

***Table 5.3** SAIDI values for each cases with/without NOP*

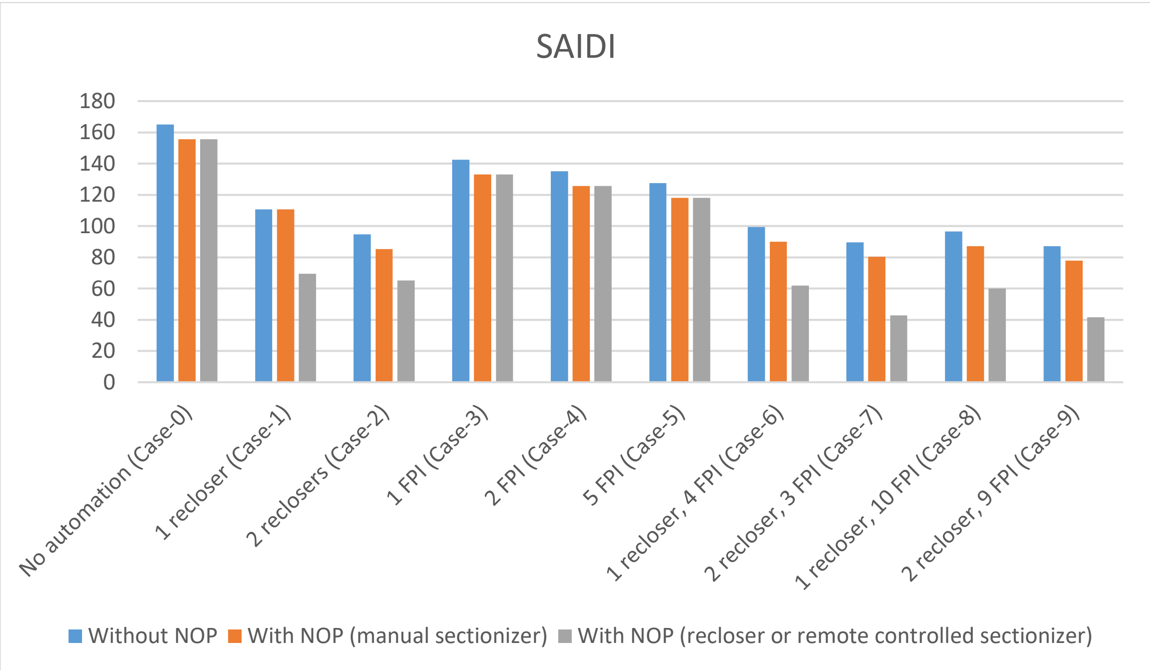

***Figure 5.12** Development of SAIDI for various numbers and types of deployed automation elements.*

5.4 Sensitivity analysis

In the last part of our case study task, the sensitivity analysis will be done for each case of feeders, with and without adding normal open point. In order to fulfil the goal, in the first analysis, it will be changed the input travel time from 20 minutes to 40 minutes, keeping the rest of parameters unchanged and recalculate SAIFI and SAIDI indicators. For the second analysis the change will be done only on input localization time increasing it from 30 to 60 minutes, without changing any other parameters and the calculation will be repeated. Down below, it can be seen the obtained results and the graphs for each case.

Case	Description	Without NOP	Without NOP Sensitivity Analysis 1	Without NOP Sensitivity Analysis 2
		SAIDI	SAIDI	SAIDI
Case 0	No automation	165	225	255
Case 1	1 recloser	110.625	155.625	161.25
Case 2	2 recloser	94.6	134.4	134.4
Case 3	1 FPI	142.5	202.5	210
Case 4	2 FPI	135	195	195
Case 5	5 FPI	127.5	187.5	180
Case 6	1 recloser, 4 FPI	99.375	144.375	138.75
Case 7	2 recloser, 3 FPI	89.625	129.425	124.45
Case 8	1 recloser, 10 FPI	96.5625	141.5625	133.125
Case 9	2 recloser, 9 FPI	87.1375	126.9375	119.475

Table 5.4 *Numerical representation of sensitivity analysis of SAIDI indicators for feeder without NOP*

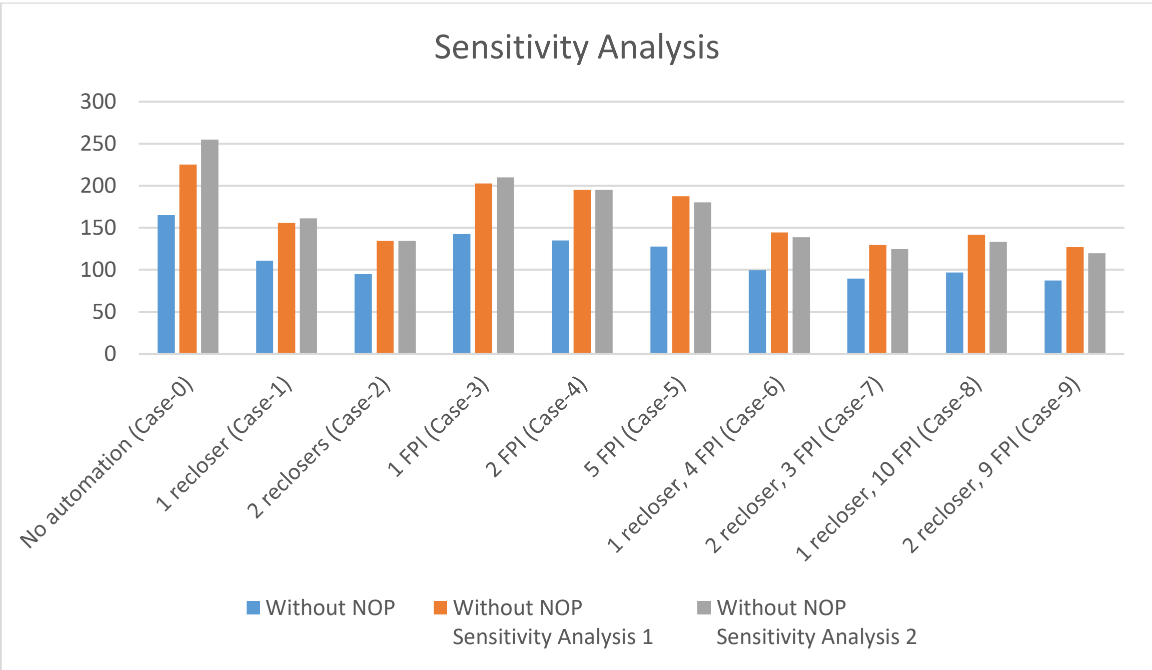

Figure 5.13 *Graphical representation of sensitivity analysis of SAIDI indicators for feeder without NOP.*

Case	Description	With NOP (manual sectionizer)	With NOP (manual sectionizer) Sensitivity Analysis 1	With NOP (manual sectionizer) Sensitivity Analysis 2
		SAIDI	SAIDI	SAIDI
Case 0	No automation	155.625	215.625	245.625
Case 1	1 recloser	110.625	155.625	161.25
Case 2	2 recloser	85.225	125.025	125.025
Case 3	1 FPI	133.125	193.125	200.625
Case 4	2 FPI	125.625	185.625	185.625
Case 5	5 FPI	118.125	178.125	170.625
Case 6	1 recloser, 4 FPI	90	135	129.375
Case 7	2 recloser, 3 FPI	80.25	120.05	115.075
Case 8	1 recloser, 10 FPI	87.1875	132.1875	123.75
Case 9	2 recloser, 9 FPI	77.7625	117.5625	110.1

***Table 5.5** Numerical representation of sensitivity analysis of SAIFI indicators for feeder with NOP(manual sectionizer)*

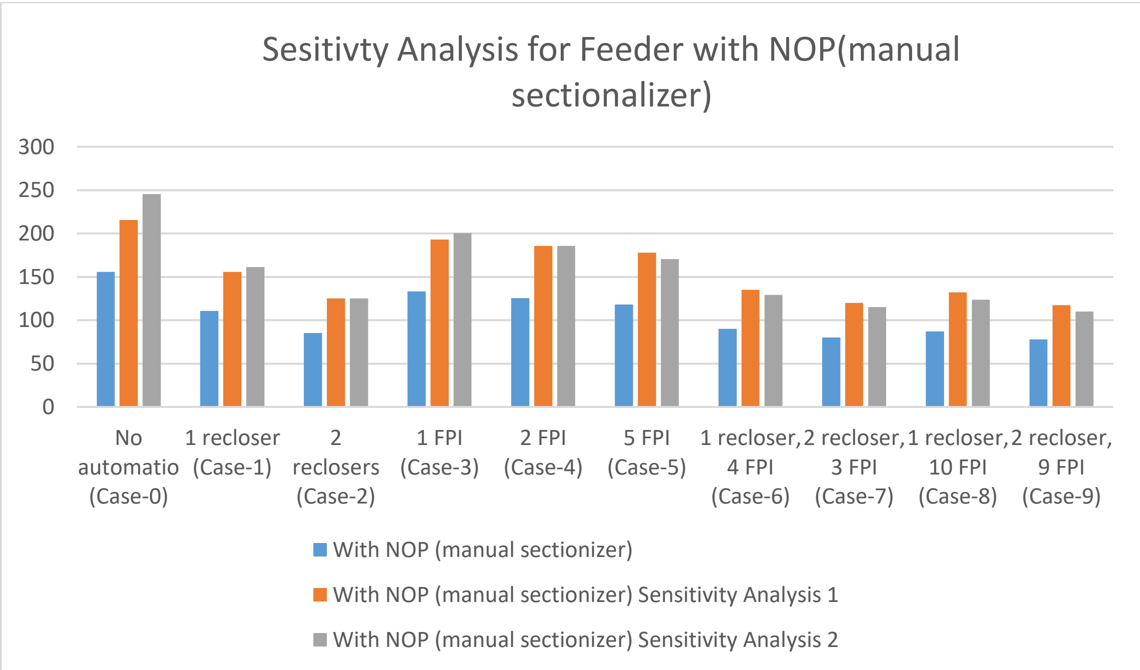

***Figure 5.14** Graphical representation of sensitivity analysis of SAIDI indicators for feeder with NOP(manual sectionalizer)*

Case	Description	With NOP (recloser or remote controlled sectionizer)	With NOP (recloser or remote controlled sectionizer) Sensitivity Analysis 1	With NOP (recloser or remote controlled sectionizer) Sensitivity Analysis 2
		SAIDI	SAIDI	SAIDI
Case 0	No automation	155.625	215.625	245.625
Case 1	1 recloser	69.375	99.375	103.125
Case 2	2 recloser	65.225	85.025	105.025
Case 3	1 FPI	133.125	193.125	200.625
Case 4	2 FPI	125.625	185.625	185.625
Case 5	5 FPI	118.125	178.125	170.625
Case 6	1 recloser, 4 FPI	61.875	91.875	88.125
Case 7	2 recloser, 3 FPI	42.75	62.55	60.075
Case 8	1 recloser, 10 FPI	60	90	84.375
Case 9	2 recloser, 9 FPI	41.5125	61.3125	57.6

Table 5.6 *Numerical representation of sensitivity analysis of SAIFI indicators for feeder with NOP(recloser or remote controlled sectionizer)*

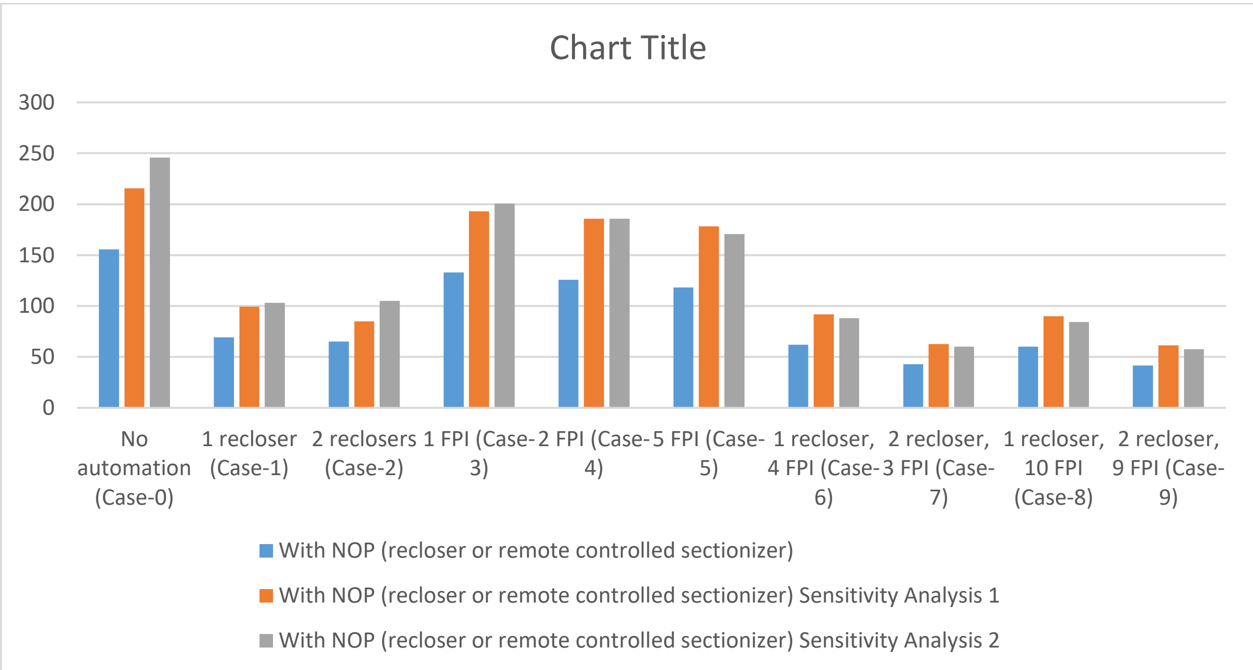

Figure 5.15 *Graphical representation of sensitivity analysis of SAIDI indicators for feeder with NOP (recloser or remote controlled sectionizer)*

5.5 Results discussion

To sum up, it was preferred to apply FPI-s and reclosers to the feeders. As is presented in the subchapters above, for most of the cases like in 3,4,5 where it was just FPI-s, in the presence of this automation component the only change has occurred in the localization time, while the rest of input parameters remained the same. However, in case of only recloser component (1,2), we experienced a change in all input parameters like travel/repair time and number of interrupted customers. In the rest of the cases with mixed components(recloser+FPI), the change was again faced in all aspects, as in this case recloser is the major aspect of changing the number of interrupted customers in each segment, while the only difference between the case of just recloser and this one, will be reduction of localization time. To sum up the scenarios without Normal Open point, it could observed the following, unless there isn't any component, like in case-0, the reduction will always be seen in localization time, this can be explained as one of positive impacts of automation components to our distribution system's reliability, also we can more obviously notice that from the formula (5.5). In this next part of this chapter it was added the NOP (with manual/ remote controlled sectionizers) to the feeders. In case of SAIFI values, it was obtained exactly same results for NOP with manual sectionizer and without NOP, while for remote controlled sectionizer NOP the slight decrease was for SAIFI values, however that applied only for the case feeder with reclosers. Coming to SAIDI values, compared to the scenario without NOP, to the NOP with the manual/remote controlled sectionizer reduced our interruption minutes for all the cases. Finally, we did a sensitivity analysis for each case. In the first analysis we doubled the travel time, remaining all other input parameters. Coming up to the second analysis, it was applied the same process with localization time. The reason of this analysis could be explained as for different regions with more complicated landscapes, like in the mountains, these parameters can be longer than it is predicted for cities or urban areas. That could be more clearly seen by the combined tables for both SAIDI and SAIFI indicators for all cases, which will be presented below for.

SAIFI							
Case	Description	Without NOP					
		Base case (tt=20 min., tl=30 min., tr=15 min)		Travel time change (tt=40 min., tl=30 min., tr=15 min)		Localiz. time change (tt=20 min., tl=60 min.,	
		SAIFI [-]	Change [%]	SAIFI [-]	Change [%]	SAIFI [-]	Change [%]
Case 0	No automation	3.0	0%	3.0	0%	3.0	0%
Case 1	1 recloser	2.3	-25%	2.3	-25%	2.3	-25%
Case 2	2 recloser	2.0	-34%	2.0	-34%	2.0	-34%
Case 3	1 FPI	3.0	0%	3.0	0%	3.0	0%
Case 4	2 FPI	3.0	0%	3.0	0%	3.0	0%
Case 5	5 FPI	3.0	0%	3.0	0%	3.0	0%
Case 6	1 recloser, 4 FPI	2.3	-25%	2.3	-25%	2.3	-25%
Case 7	2 recloser, 3 FPI	2.0	-34%	2.0	-34%	2.0	-34%
Case 8	1 recloser, 10 FPI	2.3	-25%	2.3	-25%	2.3	-25%
Case 9	2 recloser, 9 FPI	2.0	-34%	2.0	-34%	2.0	-34%

Table 5.7 *SAIFI change in percentage after each sensitivity analysis for the case without NOP*

SAIFI							
Case	Description	With NOP manual sectionizer					
		Base case (tt=20 min., tl=30 min., tr=15 min)		Travel time change (tt=40 min., tl=30 min., tr=15 min)		Localiz. time change (tt=20 min., tl=60 min., tr=15 min)	
		SAIFI [-]	Change [%]	SAIFI [-]	Change [%]	SAIFI [-]	Change [%]
Case 0	No automation	3.00	0%	3.00	0%	3.00	0%
Case 1	1 recloser	2.25	-25%	2.25	-25%	2.25	-25%
Case 2	2 recloser	1.99	-34%	1.99	-34%	1.99	-34%
Case 3	1 FPI	3.00	0%	3.00	0%	3.00	0%
Case 4	2 FPI	3.00	0%	3.00	0%	3.00	0%
Case 5	5 FPI	3.00	0%	3.00	0%	3.00	0%
Case 6	1 recloser, 4 FPI	2.25	-25%	2.25	-25%	2.25	-25%
Case 7	2 recloser, 3 FPI	1.99	-34%	1.99	-34%	1.99	-34%
Case 8	1 recloser, 10 FPI	2.25	-25%	2.25	-25%	2.25	-25%
Case 9	2 recloser, 9 FPI	1.99	-34%	1.99	-34%	1.99	-34%

***Table 5.8** SAIFI change in percentage after each sensitivity analysis for the case with NOP manual sectionizer*

SAIFI							
Case	Description	With NOP recloser					
		Base case (tt=20 min., tl=30 min., tr=15 min)		Travel time change (tt=40 min., tl=30 min., tr=15 min)		Localiz. time change (tt=20 min., tl=60 min., tr=15 min)	
		SAIFI [-]	Change [%]	SAIFI [-]	Change [%]	SAIFI [-]	Change [%]
Case 0	No automation	3.00	0%	3.00	0%	3.00	0%
Case 1	1 recloser	1.50	-50%	1.50	-50%	1.50	-50%
Case 2	2 recloser	0.99	-67%	0.99	-67%	0.99	-67%
Case 3	1 FPI	3.00	0%	3.00	0%	3.00	0%
Case 4	2 FPI	3.00	0%	3.00	0%	3.00	0%
Case 5	5 FPI	3.00	0%	3.00	0%	3.00	0%
Case 6	1 recloser, 4 FPI	1.50	-50%	1.50	-50%	1.50	-50%
Case 7	2 recloser, 3 FPI	0.99	-67%	0.99	-67%	0.99	-67%
Case 8	1 recloser, 10 FPI	1.50	-50%	1.50	-50%	1.50	-50%
Case 9	2 recloser, 9 FPI	0.99	-67%	0.99	-67%	0.99	-67%

***Table 5.9** SAIFI change in percentage after each sensitivity analysis for the case with NOP recloser*

SAIDI							
Case	Description	Without NOP					
		Base case (tt=20 min., tl=30 min., tr=15 min)		Travel time change (tt=40 min., tl=30 min., tr=15 min)		Localiz. time change (tt=20 min., tl=60 min., tr=15 min)	
		SAIDI [min]	Change [%]	SAIDI [min]	Change [%]	SAIDI [min]	Change [%]
Case 0	No automation	165.0	0%	225.0	0%	255.0	0%
Case 1	1 recloser	110.6	-33%	155.6	-31%	161.3	-37%
Case 2	2 recloser	94.6	-43%	134.4	-40%	134.4	-47%
Case 3	1 FPI	142.5	-14%	202.5	-10%	210.0	-18%
Case 4	2 FPI	135.0	-18%	195.0	-13%	195.0	-24%
Case 5	5 FPI	127.5	-23%	187.5	-17%	180.0	-29%
Case 6	1 recloser, 4 FPI	99.4	-40%	144.4	-36%	138.8	-46%
Case 7	2 recloser, 3 FPI	89.6	-46%	129.4	-42%	124.5	-51%
Case 8	1 recloser, 10 FPI	96.6	-41%	141.6	-37%	133.1	-48%
Case 9	2 recloser, 9 FPI	87.1	-47%	126.9	-44%	119.5	-53%

Table 5.10 *SAIDI change in percentage after each sensitivity analysis for the case without NOP*

SAIDI							
Case	Description	With NOP manual sectionizer					
		Base case (tt=20 min., tl=30 min., tr=15 min)		Travel time change (tt=40 min., tl=30 min., tr=15 min)		Localiz. time change (tt=20 min., tl=60 min., tr=15 min)	
		SAIDI [min]	Change [%]	SAIDI [min]	Change [%]	SAIDI [min]	Change [%]
Case 0	No automation	155.6	0%	215.6	0%	245.6	0%
Case 1	1 recloser	110.6	-29%	155.6	-28%	161.3	-34%
Case 2	2 recloser	85.2	-45%	125.0	-42%	125.0	-49%
Case 3	1 FPI	133.1	-14%	193.1	-10%	200.6	-18%
Case 4	2 FPI	125.6	-19%	185.6	-14%	185.6	-24%
Case 5	5 FPI	118.1	-24%	178.1	-17%	170.6	-31%
Case 6	1 recloser, 4 FPI	90.0	-42%	135.0	-37%	129.4	-47%
Case 7	2 recloser, 3 FPI	80.3	-48%	120.1	-44%	115.1	-53%
Case 8	1 recloser, 10 FPI	87.2	-44%	132.2	-39%	123.8	-50%
Case 9	2 recloser, 9 FPI	77.8	-50%	117.6	-45%	110.1	-55%

Table 5.11 *SAIDI change in percentage after each sensitivity analysis for the case with NOP manual sectionizer*

SAIDI							
Case	Description	With NOP recloser					
		Base case (tt=20 min., tl=30 min., tr=15 min)		Travel time change (tt=40 min., tl=30 min., tr=15 min)		Localiz. time change (tt=20 min., tl=60 min., tr=15 min)	
		SAIDI [min]	Change [%]	SAIDI [min]	Change [%]	SAIDI [min]	Change [%]
Case 0	No automation	155.6	0%	215.6	0%	245.6	0%
Case 1	1 recloser	69.4	-55%	99.4	-54%	103.1	-58%
Case 2	2 recloser	65.2	-58%	85.0	-61%	105.0	-57%
Case 3	1 FPI	133.1	-14%	193.1	-10%	200.6	-18%
Case 4	2 FPI	125.6	-19%	185.6	-14%	185.6	-24%
Case 5	5 FPI	118.1	-24%	178.1	-17%	170.6	-31%
Case 6	1 recloser, 4 FPI	61.9	-60%	91.9	-57%	88.1	-64%
Case 7	2 recloser, 3 FPI	42.8	-73%	62.6	-71%	60.1	-76%
Case 8	1 recloser, 10 FPI	60.0	-61%	90.0	-58%	84.4	-66%
Case 9	2 recloser, 9 FPI	41.5	-73%	61.3	-72%	57.6	-77%

Table 5.12 *SAIDI change in percentage after each sensitivity analysis for the case with NOP recloser*

Conclusions

In conclusion, to briefly sum up, the goal of this bachelor thesis work. As is presented in the introduction part, it could be seen the observation of the distribution reliability and delving deeper into the process. In each chapter, it was presented a brief summarization and conclusions. However, to conclude in general, in the first chapter we got more acquainted with the various indicators, especially with SAIDI and SAIFI and tried to give a basic explanation of these terms and usage in our calculations. After getting the idea of these parameters, following step was to give a comparison of these indicators for various countries and see the gaps in each country's distribution system. Not surprisingly, the majority of the presented countries did a very good job, excluding some years, when it happened a natural disaster. However, still there was plenty of work, which could make the distribution system more reliable and a step closer to perfection. So, there was attempts to inspect the various ways for improvement of the distribution reliability. As with the modern world, being more automated in all the fields, it was important to apply the same process to the distribution system. Consequently, we tried to present and speak up about various automation components and their possible assistance with the reliability of our process. Finally, from the previous chapter it was taken two of these automation components, which were Fault Passage indicators and recloser and we tried to apply them to various feeders, with different scenarios. The comparison of the SAIFI and SAIDI indicators for each case and calculation of their total for each part of the feeder was part of the goal of this case study, additionally it was added the two more cases with NOP(with manual/remote controlled sectionalizer) and in the last part it was done a sensitivity analysis. Overall, the purpose to reduce the values for these indicators while adding automation components was pretty successful in terms of the gained numbers, however in terms of financial prospect adding too many automation components won't be very economical. As it was applied only two automation tools, therefore to compare these components, recloser did a better job, compared to FPI. This could me more visibly seen by the obtained SAIDI and SAIFI results. In case of fault passage indicators, it was just reducing the localization time, the case feeders with reclosers did much greater impact on reduction of both components. This could be explained while recloser's purpose is to detect and interrupt momentary faults, FPI just provides visual or remote indication of a fault. Overall, an important note is that, our study case and examples aren't enough accurate for making any deductions or assumptions. As they are pretty simplified, in real project each feeder should be analyzed in more deep detail, furthermore while placing the automation components we should more relied on experiences.

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Appendix – selected calculations

In this section will be inserted some example tables, which were used for our calculations. It will be presented the case without NOP, with Normal open point with manual sectionizer and remote sectionizer respectively for case 0,1 and 7.

CASE 0	Number of automation components	0	SAIFI		SAIDI									
					Travel time			Localization time			Repair time			Total
	Segment ID	Segment type	Ni	λi*Ni	Ni	tt	λi*Ni*tt	Ni	tl	λi*Ni*tl	Ni	tr	λi*Ni*tr	λNt total
	1	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	1	15	**3.75**	**16.25**
	2	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.8333	15	**3.125**	**15.625**
	3	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.6667	15	**2.5**	**15**
	4	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.5	15	**1.875**	**14.375**
	5	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.3333	15	**1.25**	**13.75**
	6	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	7	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	8	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	9	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	10	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	11	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	12	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
			SAIFI	**3**									SAIDI	**165**

Table 7.1 *SAIFI and SAIDI calculations for the case 0 without NOP*

CASE 0	Number of automation components	0	SAIFI		SAIDI									
					Travel time			Localization time			Repair time			Total
	Segment ID	Segment type	Ni	λi*Ni	Ni	tt	λi*Ni*tt	Ni	tl	λi*Ni*tl	Ni	tr	λi*Ni*tr	λNt total
	1	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	2	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	3	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	4	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	5	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	6	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	7	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	8	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	9	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	10	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	11	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	12	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
			SAIFI	**3**									SAIDI	**155.625**

Table 7.2 *SAIFI and SAIDI calculations for the case 0 with NOP manual sectionizer.*

CASE 0	Number of automation components	0	SAIFI		SAIDI									
					Travel time			Localization time			Repair time			Total
	Segment ID	**Segment type**	**Ni**	**λi*Ni**	**Ni**	**tt**	**λi*Ni*tt**	**Ni**	**tl**	**λi*Ni*tl**	**Ni**	**tr**	**λi*Ni*tr**	**λNt total**
	1	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	2	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	3	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	4	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	5	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	6	Main feeder	1	0.25	1	20	**5**	1	30	**7.5**	0.1667	15	**0.625**	**13.125**
	7	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	8	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	9	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	10	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	11	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
	12	Branch	1	0.25	1	20	**5**	1	30	**7.5**	0.0833	15	**0.3125**	**12.8125**
			SAIFI	**3**									SAIDI	**155.625**

Table 7.3 *SAIFI and SAIDI calculations for the case 7 with NOP recloser.*

CASE 1	Number of automation components	1	SAIFI		SAIDI									
					Travel time			Localization time			Repair time			Total
	Segment ID	**Segment type**	**Ni**	**λi*Ni**	**Ni**	**tt**	**λi*Ni*tt**	**Ni**	**tl**	**λi*Ni*tl**	**Ni**	**tr**	**λi*Ni*tr**	**λNt total**
	1	Main feeder	1	0.25	1	20	**5**	1	22.5	**5.625**	1	15	**3.75**	**14.375**
	2	Main feeder	1	0.25	1	20	**5**	1	22.5	**5.625**	0.8333	15	**3.125**	**13.75**
	3	Main feeder	1	0.25	1	20	**5**	1	22.5	**5.625**	0.6667	15	**2.5**	**13.125**
	4	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.5	15	**1.875**	**7.1875**
	5	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.3333	15	**1.25**	**6.5625**
	6	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.1667	15	**0.625**	**5.9375**
	7	Branch	1	0.25	1	20	**5**	1	22.5	**5.625**	0.0833	15	**0.3125**	**10.9375**
	8	Branch	1	0.25	1	20	**5**	1	22.5	**5.625**	0.0833	15	**0.3125**	**10.9375**
	9	Branch	1	0.25	1	20	**5**	1	22.5	**5.625**	0.0833	15	**0.3125**	**10.9375**
	10	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
	11	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
	12	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
			SAIFI	**2.25**									SAIDI	**110.625**

Table 7.4 *SAIFI and SAIDI calculations for the case 1 without NOP.*

	Number of automation components	1	SAIFI		SAIDI									
					Travel time			Localization time			Repair time			Total
	Segment ID	Segment type	Ni	λi*Ni	Ni	tt	λi*Ni*tt	Ni	tl	λi*Ni*tl	Ni	tr	λi*Ni*tr	λNt total
CASE 1	1	Main feeder	1	0.25	1	20	**5**	1	22.5	**5.625**	1	15	**3.75**	**14.375**
	2	Main feeder	1	0.25	1	20	**5**	1	22.5	**5.625**	0.8333	15	**3.125**	**13.75**
	3	Main feeder	1	0.25	1	20	**5**	1	22.5	**5.625**	0.6667	15	**2.5**	**13.125**
	4	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.5	15	**1.875**	**7.1875**
	5	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.3333	15	**1.25**	**6.5625**
	6	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.1667	15	**0.625**	**5.9375**
	7	Branch	1	0.25	1	20	**5**	1	22.5	**5.625**	0.0833	15	**0.3125**	**10.9375**
	8	Branch	1	0.25	1	20	**5**	1	22.5	**5.625**	0.0833	15	**0.3125**	**10.9375**
	9	Branch	1	0.25	1	20	**5**	1	22.5	**5.625**	0.0833	15	**0.3125**	**10.9375**
	10	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
	11	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
	12	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
			SAIFI	**2.25**									SAIDI	**110.625**

Table 7.5 *SAIFI and SAIDI calculations for the case 1 with NOP manual sectionizer.*

	Number of automation components	1	SAIFI		SAIDI									
					Travel time			Localization time			Repair time			Total
	Segment ID	Segment type	Ni	λi*Ni	Ni	tt	λi*Ni*tt	Ni	tl	λi*Ni*tl	Ni	tr	λi*Ni*tr	λNt total
CASE 1	1	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.1667	15	**0.625**	**5.9375**
	2	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.1667	15	**0.625**	**5.9375**
	3	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.1667	15	**0.625**	**5.9375**
	4	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.1667	15	**0.625**	**5.9375**
	5	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.1667	15	**0.625**	**5.9375**
	6	Main feeder	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.1667	15	**0.625**	**5.9375**
	7	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
	8	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
	9	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
	10	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
	11	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
	12	Branch	0.5	0.125	0.5	20	**2.5**	0.5	22.5	**2.8125**	0.0833	15	**0.3125**	**5.625**
			SAIFI	**1.5**									SAIDI	**69.375**

Table 7.6 *SAIFI and SAIDI calculations for the case 1 with NOP recloser.*

CASE 7	Number of automation components	5	SAIFI		SAIDI									
					Travel time			Localization time			Repair time			Total
	Segment ID	Segment type	Ni	λi*Ni	Ni	tt	λi*Ni*tt	Ni	tl	λi*Ni*tl	Ni	tr	λi*Ni*tr	λNt total
	1	Main feeder	1	0.25	1	20	**5**	1	17.5	**4.375**	1	15	**3.75**	**13.125**
	2	Main feeder	1	0.25	1	20	**5**	1	17.5	**4.375**	0.8333	15	**3.125**	**12.5**
	3	Main feeder	0.66	0.165	0.66	20	**3.3**	0.66	17.5	**2.8875**	0.6667	15	**2.5**	**8.6875**
	4	Main feeder	0.66	0.165	0.66	20	**3.3**	0.66	17.5	**2.8875**	0.5	15	**1.875**	**8.0625**
	5	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.3333	15	**1.25**	**4.34375**
	6	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.1667	15	**0.625**	**3.71875**
	7	Branch	1	0.25	1	20	**5**	1	17.5	**4.375**	0.0833	15	**0.3125**	**9.6875**
	8	Branch	1	0.25	1	20	**5**	1	17.5	**4.375**	0.0833	15	**0.3125**	**9.6875**
	9	Branch	0.66	0.165	0.66	20	**3.3**	0.66	17.5	**2.8875**	0.0833	15	**0.3125**	**6.5**
	10	Branch	0.66	0.165	0.66	20	**3.3**	0.66	17.5	**2.8875**	0.0833	15	**0.3125**	**6.5**
	11	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
	12	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
			SAIFI	**1.99**									SAIDI	**89.625**

Table 7.7 *SAIFI and SAIDI calculations for the case 7 without NOP*

CASE 7	Number of automation components	5	SAIFI		SAIDI									
					Travel time			Localization time			Repair time			Total
	Segment ID	Segment type	Ni	λi*Ni	Ni	tt	λi*Ni*tt	Ni	tl	λi*Ni*tl	Ni	tr	λi*Ni*tr	λNt total
	1	Main feeder	1	0.25	1	20	**5**	1	17.5	**4.375**	0.1667	15	**0.625**	**10**
	2	Main feeder	1	0.25	1	20	**5**	1	17.5	**4.375**	0.1667	15	**0.625**	**10**
	3	Main feeder	0.66	0.165	0.66	20	**3.3**	0.66	17.5	**2.8875**	0.1667	15	**0.625**	**6.8125**
	4	Main feeder	0.66	0.165	0.66	20	**3.3**	0.66	17.5	**2.8875**	0.1667	15	**0.625**	**6.8125**
	5	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.1667	15	**0.625**	**3.71875**
	6	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.1667	15	**0.625**	**3.71875**
	7	Branch	1	0.25	1	20	**5**	1	17.5	**4.375**	0.0833	15	**0.3125**	**9.6875**
	8	Branch	1	0.25	1	20	**5**	1	17.5	**4.375**	0.0833	15	**0.3125**	**9.6875**
	9	Branch	0.66	0.165	0.66	20	**3.3**	0.66	17.5	**2.8875**	0.0833	15	**0.3125**	**6.5**
	10	Branch	0.66	0.165	0.66	20	**3.3**	0.66	17.5	**2.8875**	0.0833	15	**0.3125**	**6.5**
	11	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
	12	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
			SAIFI	**1.99**									SAIDI	**80.25**

Table 7.8 *SAIFI and SAIDI calculations for the case 7 with NOP manual sectionizer.*

CASE 7	Number of automation components	5	SAIFI		SAIDI									
					Travel time			Localization time			Repair time			Total
	Segment ID	Segment type	Ni	λi*Ni	Ni	tt	λi*Ni*tt	Ni	tl	λi*Ni*tl	Ni	tr	λi*Ni*tr	λNt total
	1	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.1667	15	**0.625**	**3.71875**
	2	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.1667	15	**0.625**	**3.71875**
	3	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.1667	15	**0.625**	**3.71875**
	4	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.1667	15	**0.625**	**3.71875**
	5	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.1667	15	**0.625**	**3.71875**
	6	Main feeder	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.1667	15	**0.625**	**3.71875**
	7	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
	8	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
	9	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
	10	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
	11	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
	12	Branch	0.33	0.0825	0.33	20	**1.65**	0.33	17.5	**1.44375**	0.0833	15	**0.3125**	**3.40625**
			SAIFI	**0.99**									SAIDI	**42.75**

Table 7.9 *SAIFI and SAIDI calculations for the case 7 with NOP recloser.*