

# MODELING THE IMPACT OF AUTOMATION FAILURE ON DISTRIBUTION SYSTEM RELIABILITY

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**Abstract**— Distribution Automation (DA) optimizes a utility's operations and directly improves the reliability of power distribution system. Utilities using Distribution Automation can achieve significant reduction in outage time for customers with minimal circuit reconfiguration resulting improved reliability indices. The gauge of effectiveness of DA implementations depends on the failure rate of the implemented automation technology. In this paper the effect of failure of automation technologies on the reliability of a distribution system is evaluated. The reliability of the system is measured in terms of SAIDI, CAIDI, SAIFI and ENS. These reliability indices are calculated for the Roy Billinton Test System (RBTS) Bus2 using Failure Modes and Effects Analysis technique.

**Keywords**:- RBTS, Distribution automation, Automation Failure rate, FMEA Technique

## I. INTRODUCTION

Power utilities have made remarkable progress in improving the quality and quantity of power supplied to the customers. There is a social demand for better services provided to the customers. The demand of reduced outage rates (both quality and duration) has led the utilities to reconfigure their distribution networks from radially opened looped, such that once the faulted section is isolated power can be restored to the rest of the network from an alternative sources. This task is economically achieved by introducing distribution automation switches which are remotely controlled from a central control room. In this manner, quality and continuity of service to the customer are vastly improved as is user convenience. DA provides a fast method for improving the reliability making the whole operation functions more efficient. In the event of a fault in any feeder section downstream, the circuit breaker at the substation trips. As a result there is a blackout over a large section of the distribution network. With the automation of the distribution system, the faulty feeder segment could be precisely identified and it is possible to substantially reduce the blackout area, by re-routing the power to the healthy feeder segments through the operation of switches placed at strategic location in

various feeder segments. Utilities using DA can achieve:[1,2]

- Significant reduction outage time for customers, with minimal circuit reconfiguration resulting in improved reliability indices.
- Automatic/semi-automatic feeder tie switches.
- Reduction in travel time to remote locations, reducing fuel and labor costs.
- Reduction in feeder patrol time to isolate faults.
- Information reported back to the office immediately, providing a clearer picture of what is happening in the field.

**DA Architecture:**

The basic architecture for distribution automation comprises three main components [3]: the device to be operated (IED), a communication system and a DA gateway as shown in Fig.1.

This configuration can be applied to both substation and feeder automation. The gateway is the substation computer capturing and managing all data from protective devices and actuators in the switchgear bays. DA gateway manages the communication to multiple intelligent switches.

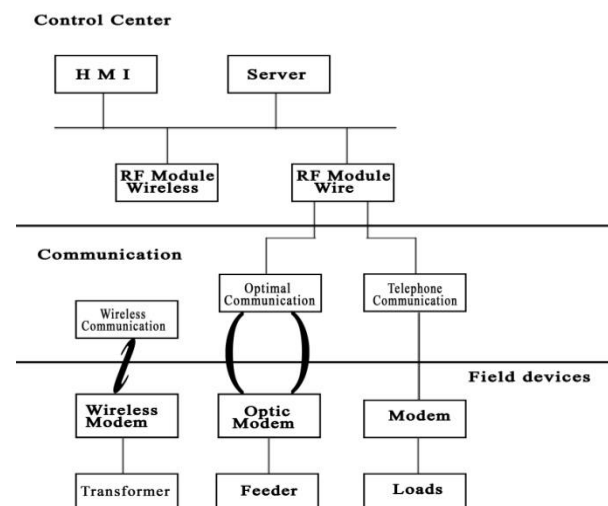


Fig.1 Generalised architecture

Automation requires IEDs to be installed in control cabinets, switches with actuator and specified IED ,communications ( low power radio, GSM etc.). Each device must comply with an inferred system specification such as communication protocol and satisfactory operation over a particular communication medium. The IEDs should work satisfactorily with the installed SCADA systems that will provide the control interface.

The advantages of automation are addressed if the installed automation system works satisfactorily i.e., without any failure rate. In this paper an attempt has been made to identify the effect of failure rate of the major components of automated devices on the reliability of the system and the following system indices are evaluated which are defined as below.

SAIFI (System Average Interruption Frequency Index)

$$SAIFI = \frac{\text{total number of customer interruptions}}{\text{total number of customers served}} = \frac{\sum \lambda_i N_i}{\sum N_i}$$

SAIFI is measured in customer interruptions/customer year

CAIFI (Customer Average Interruption Frequency Index)

$$CAIFI = \frac{\text{total number of customer interruptions}}{\text{total number of customers affected}}$$

CAIFI is measured in average interruptions per customer interrupted

SAIDI (System Average Interruption Duration Index)

$$SAIDI = \frac{\text{sum of customer interruption durations}}{\text{total number of customers served}} = \frac{\sum U_i N_i}{\sum N_i}$$

SAIDI is measured in hours/customer

CAIDI (Customer Average Interruption Duration Index)

$$CAIDI = \frac{\text{sum of customer interruption durations}}{\text{total number of customer interruptions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i}$$

CAIDI is measured in hours/customer interruption

ASAI (Average Service Availability Index)

$$ASAI = \frac{\text{customer hours of available service}}{\text{customer hours demanded}} = \frac{\sum N_i * 8760 - \sum U_i N_i}{\sum N_i * 8760}$$

ENS (Total Energy Not Supplied by the system)

$$ENS = \sum L_{ai} * U_i \text{ MWh/year}$$

AENS (Average Energy not supplied)

$$AENS = \frac{\text{total energy not supplied}}{\text{customer hours detotal number of customers served}} = \frac{\sum L_{ai} * U_i}{\sum N_i}$$

AENS is measured in kWh/customer year

Where  $\lambda_i$  is the failure rate,  $U_i$  is the annual outage time,  $L_{ai}$  is the average load connected to load point i and  $N_i$  is the number of customers of load point i.

The reliability analysis is carried out on a RBTS bus 2[4] considering the successful operation of the automation and failure of the implemented automation technology. The paper is organized as follows. The working of the automation system is discussed in Section II. Next in Section III the assumptions made in this analysis and RBTS bus 2 are given. The results of the case studies made on Bus 2 of RBTS are presented and discussed in sections IV and V. Finally a conclusion is provided in Section VI.

## II. AUTOMATION SCHEMES

Automation of an electric distribution system includes all the remote controlled devices at the substation and feeder levels, the local automation distributed at these devices and the communication infrastructure. A set of technologies that enable an Electric utility to remotely monitor , coordinate and operate distribution components in a real time mode from remote location. DA also supports the control room applications that facilitate the operations decision making process for the entire distribution network of remotely controlled and manually operated devices. There are three different ways of automation[3].

1. Local automation-switch operation by protection or local logic based decision making operation.
2. SCADA-manually initiated switch operation by remote control with remote monitoring of status, indications, alarms and measurements.
3. Centralized automation-automatics switch operation by remote control from central decision making for fault isolation, network reconfiguration and service restoration.

The proposed automation system consists of FPIs at strategic points on distribution system, generally at points where a switching decision can be made. Some type of FPIs are clip on the line and the other can be mounted on the pole. FPIs are configured to report

alarms to DA gateway as soon as they are detected using 'report by exception behaviour'. As soon as DA gateway receives the alarm it is available for the necessary action and there is always up to the minute information about the distribution network. All communication links to all FPI sites are monitored automatically by DA gateway.

#### System Working:

The working of automation system can be understood with the help of system shown in Fig.2.

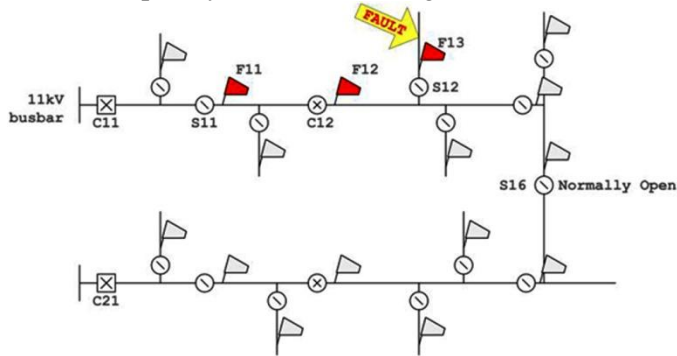


Fig.2 Basic operation of FPIs

A fault occurs on the system at the point indicated in the figure by the fault arrow. Circuit breaker C11 detects the fault and trips. All the customers between C11 and S16 are disconnected. Telecontrol alarms arrive at the DA gate way via the communication system that C11 has tripped. FPI units between C11 and the FAULT detect the passage of fault current communicate with the DA gateway using report by exception messages. FPI alarms arrive from locations F11, F12 and F13. Other FPIs do not detect the fault current and do not report alarms. DA gateway shows the location of the fault as beyond F13. Control engineers instruct the field staff to open switch S12 and remotely close C11 so that supply can be restored to the healthy part of the network.

#### Modeling of Automated systems for reliability evaluation

When the automation system elements fail there is a reduction in the system reliability. The successful operation of the automation system depends on the success of the automation system devices. The failure of any one of IED, Communication System and the DA gateway results in complete failure of the automation system. Thus these devices can be realized as the series connection of the IEDs/FPIs, Communication system and the DA gateway for reliability evaluation. The failure rate of Fault passage Indicators and DA gateway is assumed to be 0.015f/yr

- The failure rate of communication signal is assumed to be 0.0395f/yr[6]

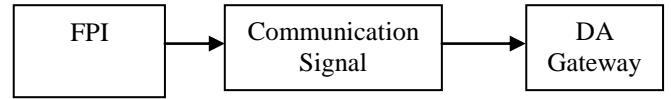


Fig 3.Realisation of automated devices for reliability evaluation

The fault probability of the automation system thus becomes

$$U_{\text{auto}} = 1 - ((1 - U_{\text{FPI}}) \times (1 - U_{\text{comm}}) \times (1 - U_{\text{DA Gateway}}))$$

Where  $U_{\text{aut}}$  = fault probability in automation system

$U_{\text{FPI}}$  = fault probability in FPI

$U_{\text{comm}}$  = fault probability in communication signal

$U_{\text{DA Gateway}}$  = fault probability in DA Gateway

The fault probability of the devices is calculated assuming that the devices failure rate follows the exponential distribution and the fault probability of the automated system is calculated as

$$U_{\text{auto}} = 1 - ((1 - 0.015) \times (1 - 0.039) \times (1 - 0.015)) \\ = 0.068 \text{ hr}$$

If the automation system works successfully then the time taken for the system to respond to the faults on the will be 0.25hours[7] and if any of these devices fail to notify the anomalies then the system will be in manual operating mode and the response time of faults will be 1.75hours [7]. Thus the switching time for the healthy section i.e., restoration of the supply depends on the successful operation of the automated device. The repair time includes the fault notification time[8] therefore the repair time also increases if the installed fault notification devices fail to notify the fault. The change in switching and repair time for the failure of the devices is calculated as described in [9].

$$S_{\text{line}} = (\text{Auto switching time}) \times P(\text{Automation Success}) + \\ (\text{Manual Switching time}) \times P(\text{Automation Fail})$$

$$S_{\text{line}} = (0.25 \times (1 - 0.068)) + (1.75 \times 0.068) \\ = 0.3521 \text{ hours}$$

$$r_{\text{time}} = (\text{repair time}) \times P(\text{Automation Success}) + \\ (\text{Repair time}) \times P(\text{Automation Fail})$$

$$r_{\text{line}} = (4.25 \times (1 - 0.0681)) + (5.75 \times 0.0681) \\ = 4.35 \text{ hours}$$

$$r_{\text{trans}} = 160.25 \times (1 - 0.0681) + (200.75 \times 0.0681)$$

$$= 163.01 \text{ hours}$$

Where  $s_{\text{line}}$  is the switching time of the lines

$r_{\text{line}}$  is the repair time of the lines

$r_{\text{trans}}$  is the repair time of the transformer

### III. APPLICATION OF FMEA TECHNIQUE

The analytical technique Failure Modes and Effects Analysis (FMEA) is used to evaluate the reliability indices. This is an inductive approach which systematically details, on a component-by-component basis, all possible failure modes and identifies their resulting effects on the system. Possible failure events of each component in the distribution system are identified and analyzed to determine the effects on the surrounding load points. For the evaluation of effects of automation on reliability of distribution system, a test system defined as Roy Billinton Test System is used which is shown in Fig. 4.

The system consists of four feeders and 22 load points which include all types of loads (commercial, residential etc.). The feeders are operated as radial feeders connected as a mesh through normally open sectionalizing points. The data required for the reliability evaluation is taken from [4].

#### A. Assumptions made in the analysis:

- Failures on 33 kV systems are not considered.
- Failures on the incoming 33 kV supply circuits are ignored.
- It is assumed that 11 kV source breaker operates successfully when required.
- Disconnects in the main feeder sections and fuses in the laterals and they operate with 100% efficiency whenever a fault occurs.
- The supply is restored to possible load points using appropriate disconnects and the alternative supply.
- Fault Passage Indicators are included for fault notification process.

Failure modes of each load point are identified and the failure rate of the each component is considered and is used to evaluate the load point indices and the system indices. The repair/switching time depends on the successful working of the automation system. The various times taken for fault diagnosis techniques are taken from [4].

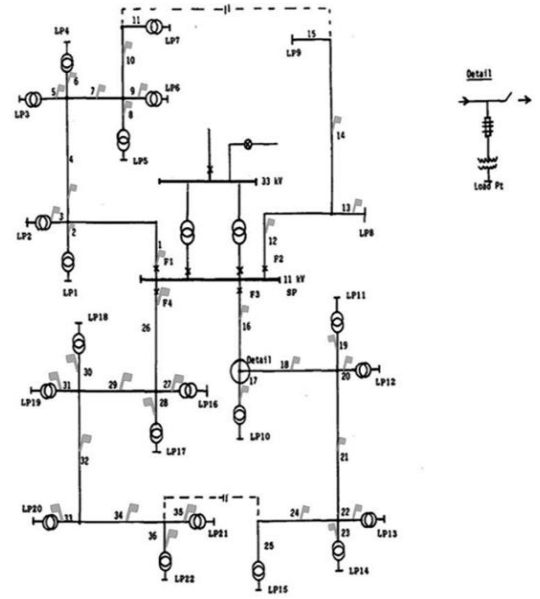


Fig. 4 Roy Billinton Test System Bus 2

### IV. RELIABILITY ANALYSIS

#### A. Automated Distribution System

The reliability indices are evaluated for the system shown in Fig.4 considering that the system is completely automated. This case study includes the majority of infrastructures required to develop a distribution automation system. It is possible to develop an advanced distribution automation system by integrating the implemented smart grid technologies with some new or modified technologies such as high speed communication systems and improved interfacing and decision supports. In this situation, the fault diagnosis activities can be accomplished more efficiently. When employing this distribution automation system, it is assumed that the fault diagnosis activities in the distribution test network are accomplished according to [7]. The total time required for the fault diagnosis activities in this case is 0.25 hrs. When the distribution system is integrated with high intensity automation level employing the advanced distribution automation system, the remote fault detection, isolation and service restoration activities can be accomplished in a very short period of time and therefore there is an improvement in the reliability of the system. The system oriented reliability indices are shown in Table 1.

For Line (Over Head) system:

$$\text{Length of section} = 0.75 + 0.75 + 0.75 + 0.6 + 0.6 = 3.45 \text{ km}$$

$$\text{The failure rate } \lambda = (\lambda_{\text{Line}} * \text{length}) + \lambda_{\text{T/f}} \\ = (0.065 * 3.45) + 0.015 = 0.24 \text{ f/yr.}$$

The annual unavailability

$$U_1 = (\lambda_{Line} * length * r_{S_{Line}}) + \lambda_{T/f} * r_{T/f}$$

$$u_1 = 2.4037 + (0.065 * 0.75 * 4.25) + (0.065 * 0.75 * 0.25) + (0.065 * 0.75 * 0.25) + (0.065 * 0.6 * 0.25) + (0.065 * 0.6 * 4.25) = 2.81 \text{ hr}$$

The outage time of the load point  $r_1 = U_1 / \lambda_1 = 18.12 \text{ hr}$ .

The load point indices for all the load points are calculated and are used to determine the reliability indices.

Table 1: Reliability Indices for complete Automation

Feeder	SAIFI	SAIDI	CAIDI	ENS	AENS
F1	0.25	2.84	11.43	10.37	15.91
F2	0.14	0.42	3	0.9	0.45
F3	0.25	2.85	11.34	8.82	13.95
F4	0.24	2.83	11.44	9.62	15.47
System	0.25	2.84	11.41	29.71	15.57

#### B. Impact of Automation Failure

Automation system processes the signals and initiates control actions. When the automation system fails the service restoration process becomes a completely manual one. The load points interrupted will remain disconnected until the originally faulted component is isolated manually. The implication in this concept is one of conditional probability associated with outage time for active failure events which can be eliminated by switching actions. The outage time  $r$  is equal to the automatic switching time if the automation system works successfully, or equal to the manual switching time if the automation system fails. If the automation system works successfully then the time taken for the system to respond will be 0.25 hours and if any of these devices

fail then it is 1.75 hours. The switching time for the healthy sections depends on the successful operation of the automated device and it is calculated as

$$S_{time} = (\text{Auto switching time}) \times P(\text{Automation Success}) + (\text{Manual Switching time}) \times P(\text{Automation Fail})$$

$$S_{time} = (0.25 \times (1 - 0.0681)) + (1.75 \times 0.0681) = 0.3521 \text{ hours}$$

$$r_{time} = (\text{repair time}) \times P(\text{Automation Success}) + (\text{repair time}) \times P(\text{Automation Fail})$$

$$r_{time} = (4.25 \times (1 - 0.0681)) + (5.75 \times 0.0681) = 4.35 \text{ hours}$$

$$\text{Transformer repair time} = (160.25 \times (1 - 0.0681)) + (200.75 \times 0.0681) = 163.01 \text{ hours}$$

The load point indices are calculated taking the above calculated values of repair and switching times. These load point indices are used to evaluate the system indices. The results are tabulated in table 2.

Table 2: Reliability Indices for Automation failure

Feeder	SAIFI	SAIDI	CAIDI	ENS	AENS
F1	0.25	2.91	11.70	10.59	16.2
F2	0.14	0.43	3.07	921	491
F3	0.25	2.91	11.63	9.01	14.62
F4	0.24	2.89	11.70	9.84	15.82
System	0.25	2.90	11.67	30.36	15.92

## V. RESULTS AND CONCLUSIONS

From the above analysis it can be observed that the successful working of the automation devices will affect the reliability of the system. The variation of the above indices is shown in the Fig.5, Fig.6, Fig.7, Fig.8 and Fig.9.

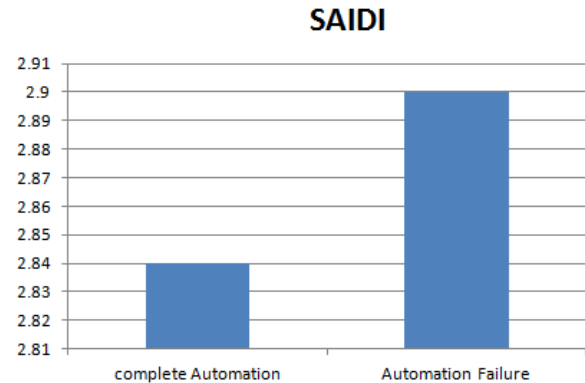


Fig. 5. Variation of System Average Interruption Duration Index

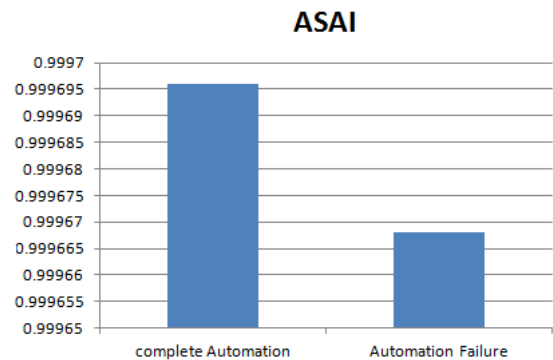


Fig. 6. Variation of Average Service Availability Index

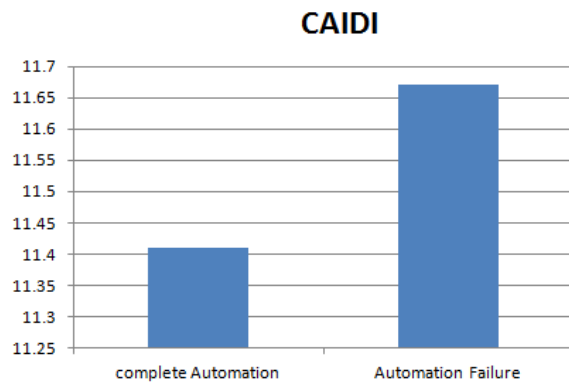


Fig. 7. Variation of Customer Average Interruption Duration Index

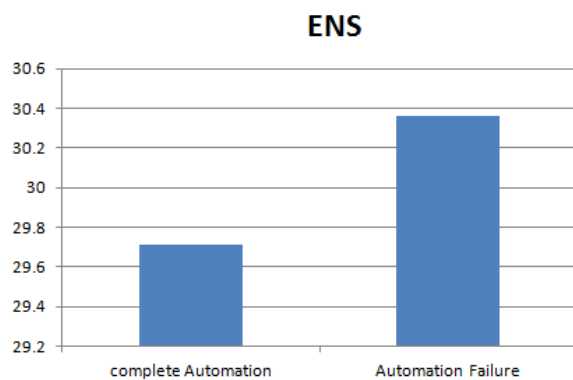


Fig. 8. Variation of Energy Not Supplied

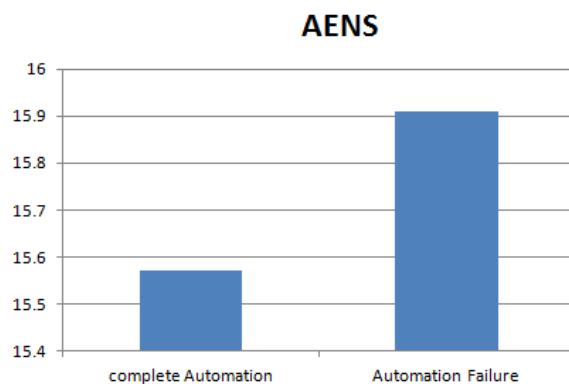


Fig. 9. Variation of Average Energy Not Supplied

Graphic representation of System Average Interruption Duration Index, Customer Average Interruption Duration Index indicates that the interruption duration is increasing whenever the components in the automation system are failed. The failure of the automation system

components also results in the increase in the Energy Not Supplied index.

The distribution system reliability can be improved by reducing the outage time of the faults which includes the time taken to locate and diagnose the fault. This can be achieved by implementing the automation in the system. If the devices of the automation system are failed to serve their function then location and diagnose of the fault has to be done manually. This will increase the total outage time. In this work the probability of failure of the devices is taken into account for calculation of the outage time and the failure of the automation devices is modelled for the reliability analysis. It is observed that the successful working of the automation devices also has considerable effect on the system reliability and the deterioration of the system reliability has been quantified for the failure of the devices used in automation.

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