

# Reliability Analysis of Distribution Automation Using Interval and Affine Arithmetics

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**Abstract:** This paper looks into partial automation and proposes a feeder automation system based on substation automation platform that can be applied to electrical distribution systems for high economic-technical efficiency. Improved reliability is evaluated when feeder automation is applied to distribution. It also looks into a case study involving reliability evaluation of Urban, Rural and Industrial feeders. Interval and affine arithmetic takes into consideration the uncertainty of all the information, and is able to provide strict bounds for the solutions to the problem: all possible solutions are included within the bounds given by interval and affine arithmetic.

**Keywords:** distribution automation, partial automation, feeder automation, reliability improvement, interval arithmetic, affine arithmetic.

## 1. Introduction

These days, almost all utilities are facing a tremendous increase in demand as the technology is advancing rapidly making a pathway to more reliable, efficient system to depend upon. Customers look out for improved reliability and power quality supply which is both economical and efficient. Meanwhile some equipments used in distribution systems are outdated, non synchronized with low operational efficiency, low reliability leading to loss for utilities as well as their customers. Electrical distribution system is an important part of power system in delivering power to the customers worldwide. Hence it is needed to automate the distribution system and make it more reliable for successful functioning of the utility with customer satisfaction. Distribution automation allows utilities to implement flexible control of distribution systems, which can be used to enhance efficiency, reliability, and power quality.

Feeder automation has slowly emerged as a viable technology over the past few decades. Feeder automation allows efficient fault location and rapid system reconfiguration for customer service restoration. This translates into improved system reliability. Historically, feeder automation related reliability improvements have been difficult to quantify and application has been limited. The increasing importance placed on reliability by performance based rates and customer demands have changed the economic scenario of feeder automation resulting in greater use of the technology. Customers generally seek guaranteed reliable system to depend upon and expect the utilities to penalize for poor reliability performance based on performance based rates. In such cases, feeder automation can address these issues and may provide a cost competitive alternative when compared to traditional reliability improvement techniques.

## 2. Explanation to Terms Used

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**Distribution Automation** is basically about automating a distribution system and providing a reliable, efficient supply to meet the increasing demand. It refers to automation of repetitive tasks on the electric utility's distribution system. In DA system, normally closed sectionalizing switches (SS) and normally open route switches (RS) are used to automate the distribution feeder function. These switches restrict the extent of distribution caused by long power interruption when properly positioned.

**Partial Automation** is a viable switching/restoration strategy when a feeder contains automated devices. Most distribution systems either have no automated devices or are *partially automated* with a combination of manual and automated devices [1]. In this strategy, a first stage quickly restores a limited set of customers using automated switches. A later stage restores additional customers using manual switches. Hence this is also known as **Two Stage Restoration**.

**Interval Arithmetic:** In interval arithmetic (IA), also known as interval analysis, a real quantity  $x$  is represented by an interval  $x = [x_{\min}, x_{\max}]$  of floating-point numbers. Those intervals are added, subtracted, multiplied, etc., in such a way that each computed interval  $x$  is guaranteed to contain the corresponding ideal quantity  $x$  — the (unknown) real value of the corresponding variable in the exact (error-free, uncertainty free) computation which is being approximated [2][5][6].

**Affine Arithmetic:** Affine arithmetic (AA) is a model for self-validated computation which, like standard interval arithmetic (IA), produces guaranteed enclosures for computed quantities, taking into account any uncertainties in the input data as well as all internal truncation and round off errors. Unlike standard IA, the quantity representations used by AA are first-order approximations, whose error is generally quadratic in the width of input intervals. In many practical applications, the higher asymptotic accuracy of AA more than compensates for the increased cost of its operations [3].

## 2.1. Reliability indices

Reliability can be evaluated and analyzed using Reliability Indices. The reliability indices include load point indices and overall system indices. The used reliability indices in the paper are shown below.

- (i) Average Energy Not Supplied (AENS) (kWh/cus.yr) and
- (ii) % Energy not supplied (% E.N.S)

## 2.2. Case studies

### Case study 1: Urban Feeder

It is an urban feeder with 33/11 KV radial distribution system. It includes laterals, distribution transformers, load points and switch. The feeder consists of 28 laterals, 19 distribution transformers, and 8 switches with 2550 customers with an overall average load consumption of 313.1731MW. Network data, customer can be obtained from [7].

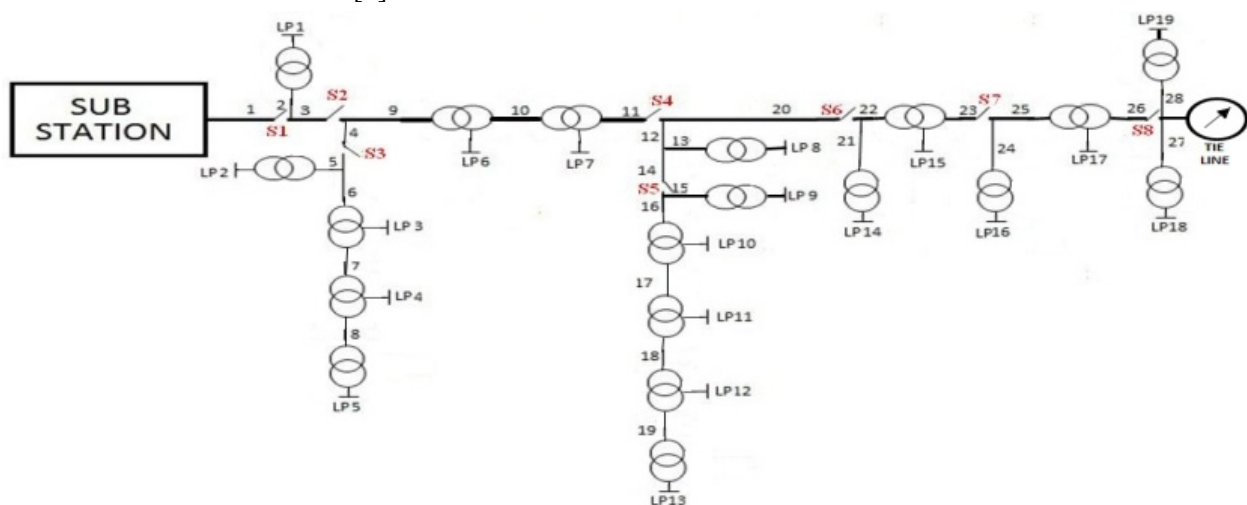


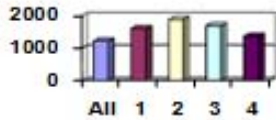
Fig 1: Distribution System Urban Feeder

Table 1: Comparing the results of all combinations of Urban Feeder

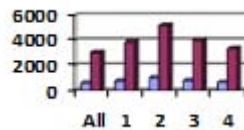
	All Switches as MMMMMAAA	1,3,5,6,8 as AAAMM	2,5,6,7,8 as AAAMM	1,2,3,4,7 as MMAAA	1,3,4,5,7 as MMAAA
Normal	1211.91722	1593.684	1878.3400	1691.52549	1361.911
Interval	[592.0921_3033.5505]	[757.113_3871.172]	[1021.82_5208.712]	[789.7723_4035.6311]	[653.249_3342.540]
Affine	[1301.154_1549.325]	[1661.89_1979.114]	[2240.94_2664.496]	[1731.805_2065.037]	[1434.55_1708.259]

Considering economic constraints, for minimizing the switches we considered 5 out of 8 switches.

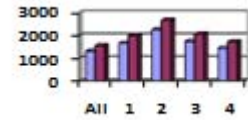
The AENS of the urban feeder for different combinations is pictorially represented from the following graph. In the graph, X- axis represents all the switching combinations and Y- axis represents Average Energy Not Supplied (AENS).



Graph 1: Comparison on all combinations of Urban Feeder using Normal method



Graph 2: Comparison on all combinations of Urban Feeder using interval Arithmetic



Graph 3: Comparison on all combinations of Urban Feeder using Affine Arithmetic

### Case Study 2: Rural Feeder

It is a rural feeder with 33/11 KV radial distribution system. It includes laterals, distribution transformers, load points and switch. The feeder consists of 27 laterals, 21 distribution transformers, and 6 switches with 422 customers with an overall average load consumption of 72.304 MW. Network data, customer can be obtained from [7].

Considering economic constraints, for minimizing the switches we considered 5 out of 6 switches.

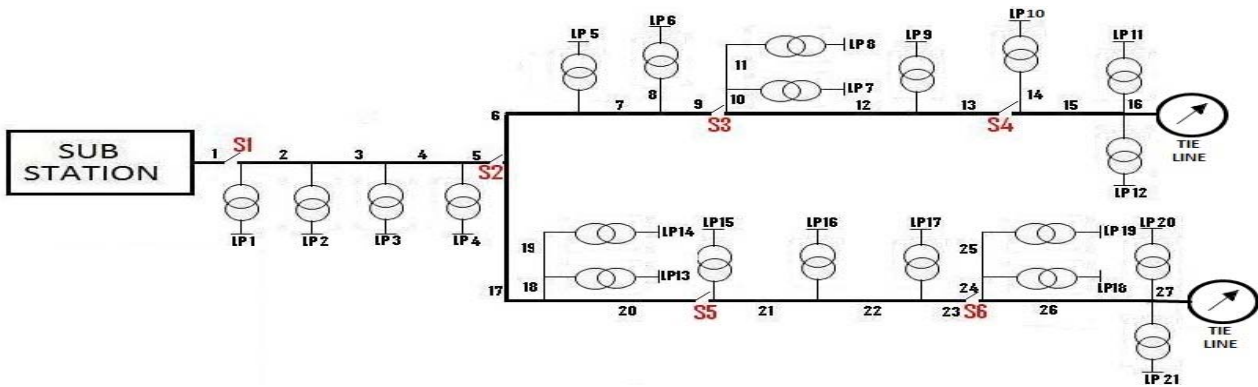
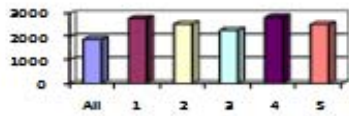


Fig 2: Distribution System Rural Feeder

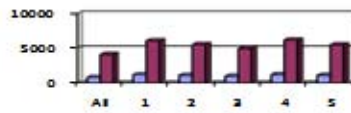
Table 2: Comparing the results of all combinations of Rural Feeder

	All Switches as AAMMMA	1,3,4,5,6 as AMMAA	1,2,4,5,6 as AAMMA	1,2,3,5,6 as AAMMA	1,2,3,4,6 as AAMMA	1,2,3,4,5 as AMMAA
Normal	1881.2104	2775.14	2540.10	2269.596	2836.46	2520.83
Interval	[796.971_4092.162]	[1176.1_6034.35]	[1076.6_5515.16]	[962.43_4932.34]	[1202.8_6164.13]	[1068.7_5479.57]
Affine	[1753.39_2086.613]	[2586.80_3077.92]	[2366.45_2814.86]	[2115.82_2516.96]	[2644.30_3145.6]	[2349.92_2795.69]

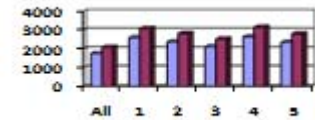
The AENS of the rural feeder for different combinations is pictorially represented from the following graph. In the graph, X- axis represents all the switching combinations and Y- axis represents Average Energy Not Supplied (AENS).



Graph 4: Comparison on all combinations of Rural Feeder using Normal method



Graph 5: Comparison on all combinations of Rural using Interval Arithmetic



Graph 6: Comparison on all combinations of Rural using Affine Arithmetic

### Case Study 3: Industrial Feeder

It is an industrial feeder with 33/11 KV radial distribution system. It includes laterals, distribution transformers, load points and switch. The feeder consists of 43 laterals, 32 distribution transformers, and 8 switches with 42 customers with an overall average load consumption of 460.207MW. Network data, customer can be obtained from [7].

Considering economic constraints, for minimizing the switches we considered 5 out of 8 switches.

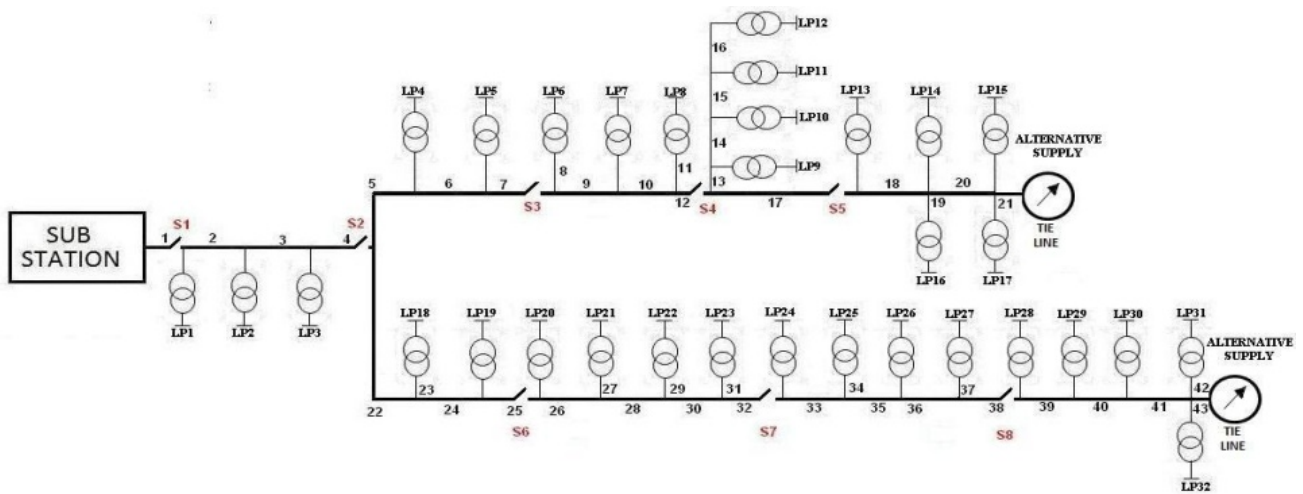
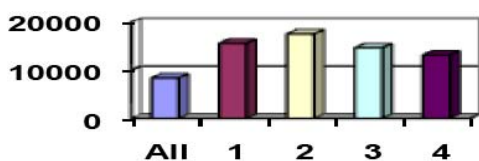


Fig 3: Distribution System Industrial Feeder

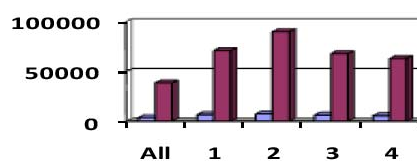
Table 3: Comparing the AENS results of all combinations of Industrial Feeder

	All Switches as AAMMMAMM	1,2,5,6,8 as AAMAM	1,2,3,5,8 as AAAMM	1,3,5,6,8 as AAMAM	1,2,4,6,7 as AAMMA
Normal	8416.159	15628.55	17591.56	14682.51	13173.38
Interval	[3602.986_38298.09]	[6570.907_70717.22]	[7381.768_89718.2]	[6169.239_67653.81536]	[5539.966_62804.87983]
Affine	[8047.852_9626.491]	[14587.125_17407.59]	[16419.02_19608.23]	[13704.04_16357.7]	[12295.58884_14671.66]

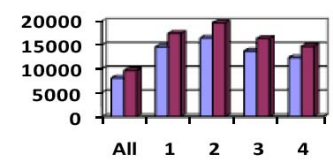
The AENS of the industrial feeder for different combinations is pictorially represented from the following graph. In the graph, X- axis represents all the switching combinations and Y- axis represents Average Energy Not Supplied (AENS).



Graph 7: Comparison on all combinations of Industrial Feeder using Normal method



Graph 8: Comparison on all combinations of Industrial Feeder using Interval Arithmetic



Graph 9: Comparison on all combinations of Industrial Feeder using Affine Arithmetic

## 2.3. Results

Table 4: Comparing AENS for all Feeders

	URBAN	RURAL	INDUSTRIAL
Normal	1361.911	2269.596	13173.38
Interval	[653.249_ 3342.54]	[962.43_ 4932.344]	[5539.96_ 62804.87]
Affine	[1434.51_ 1708.25]	[2115.82_ 2516.9]	[12295.5_ 14671.6]
% ENS before DA	37.756428	45.2349417	4.776839254
% ENS after DA	1.540181475	1.83978126	0.190833

## 2.4. Conclusions

This paper thus indicates the most feasible distribution feeder which can be practically proved to be reliable and economical using partial automation and optimal placement of switches. By implementing two stage restoration, it has shown that industrial feeder has less Percentage of energy not supplied is less for industrial therefore it is reliable than urban and rural feeders.

This paper also illustrates interval and affine arithmetic which are self validating tools to calculate reliability indices of optimal placement of switches. Interval and affine arithmetic deals with uncertain input data in power flow problems. Interval and affine methods has shown the boundaries for all the values such that all the possible solutions are included within the obtained bounding. When compared to interval, affine arithmetic has confined boundaries with more accurate ranges.

## 3. Acknowledgements

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