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Estimates of the Variations in ECOST for Radial Distribution Systems using Analytical Techniques

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ABSTRACT: This paper analyzes different analytical techniques to evaluate the expected cost at the load points and the system. The analytical techniques vary in their complexity and the data utilized during the evaluation. The information obtained by using those techniques which is useful to utilities for the better investment in the system. The collection of the additional data may result in higher investment and operational costs for the utilities. The variation in the expected cost value using these different techniques may be used in determining the level of accuracy the utility may want and hence invest in the system. The variation in the results using these techniques may provide some indication of whether the application of more complex techniques and hence the additional investment costs can be justified**.**This paper estimates the variations in ECOST which is obtained from the results using the various analytical techniques. In this paper the techniques are divided into seven separate cases. The data requirement of the events and interruption costs increases with the increase in complexity of these techniques. This results in more accurate evaluation of ECOST. However, utilities may face huge investment and operation costs to collect the additional data. The variation in the results using these techniques may give indication of whether the application of complex techniques and hence additional investment costs can be justified.

KEYWORDS: Expected customer interruption cost (ECOST), customer damage function (CDF), composite CDF, sector CDF, system CCDF.

1 INTRODUCTION

An electric power system is required to supply electricity to customers with reasonable continuity and adequacy and as economically as possible. The system reliability can be increased with an increase in investment in the planning and operating Phases by improving the existing system and development of new infrastructure. However, over-investment can result in non-economic operation of the power system such as higher operating costs which must be reflected in the tariff structure. The finite economic constraint will be infringed even though the system itself may have less failures and hence better supply. The other end is under-investment in the system which will have the opposite effects. It is evident that the continuity and economic constraints can compete. Power system reliability analysis can help determine the balance between economy and continuity and provide the customers with an economical and reliable supply of electricity [1]. The investments related to the reliability of the electric system need to be evaluated in terms of their cost/benefit implications. This form of analysis is referred to as reliability cost/worth analysis and it helps to determine the balance between investment and reliability of the system.

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There have been many techniques and suitable criteria developed for better power system reliability evaluation over the last few decades. Canadian customer service continuity statistics compiled by utilities show that approximately 80% of the total customer interruptions are due to the result of failures in the distribution system [3]. A highly reliable generation and transmission system may still result in poor energy supply to the customers if the distribution system is unreliable. Therefore, distribution system reliability evaluation is important to ensure appropriate system reliability levels and to provide effective information for regulatory bodies to set proper benchmarks in the deregulated environment. Quantitative reliability assessment is an important aspect in distribution system planning and operation. Analysis of past performance and prediction of future performance are two crucial factors of distribution system reliability evaluation. Various analytical and simulation techniques have been developed for reliability assessment of distribution system [4]. A simple distribution system can be represented by a mathematical model and the expected values of the reliability indices can be calculated using analytical techniques.

2 RBTS Distribution System Analysis

The test system used in this research is taken from the Roy Billinton Test System (RBTS). The example system shown in Figure 1 is used to illustrate the proposed methodology. It is a part of the Roy Billinton Test System (RBTS) and represents a typical urban distribution system.

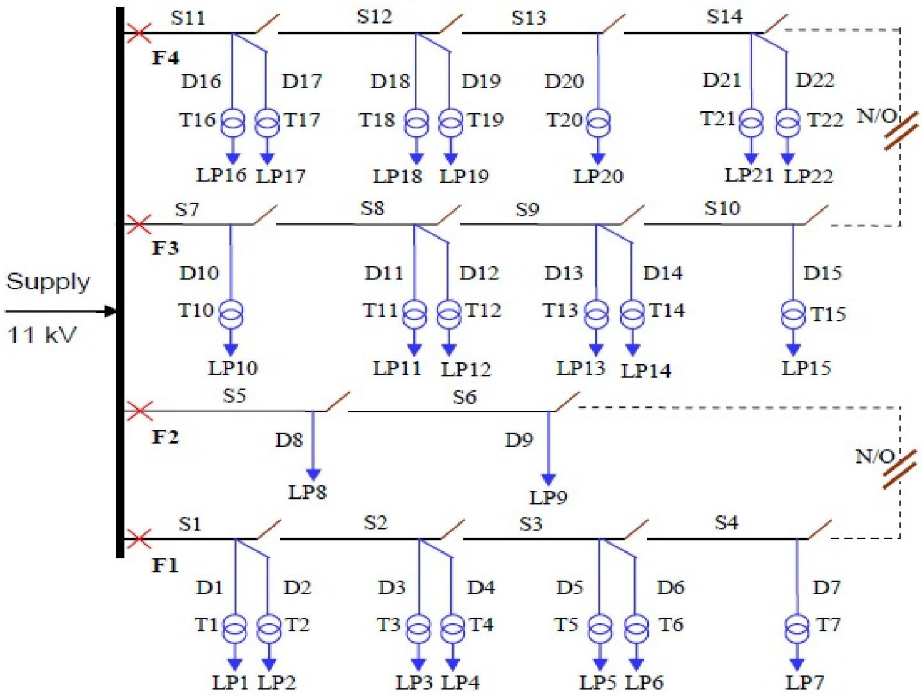

Fig. 1. Representative urban distribution system

3 Customer Damage Function

Customer interruption costs provide a good perspective on the reliability of the power system. Customer interruption costs can be represented by customer damage functions (CDF). The CDF can be determined for a group of customers belonging to particular standardized industrial classifications (SIC) [1]. In these cases, the customer damage functions are referred to as individual customer damage functions (ICDF). All the customer costs of a given sector combined result in the sector customer damage function (SCDF).The sector CDFs used in paper are shown as demand normalized values (Rs/kW) in Table1 [1].

Table 1. Sector interruption cost estimates (CDF) in (Rs/kW)

User sector	1min	20min	1hr	4hr	8hr
Residential	0.001	0.09	0.5	4.9	15.7
Commercial	0.381	2.97	8.6	31	83
Small user	4.778	9.88	21	69	119
Institutional	0.044	0.37	1.5	6.6	26

3.1 COMPOSITE CUSTOMER DAMAGE FUNCTION

A composite customer damage function (CCDF) is created by aggregating the sector CDF data. Table 2 shows the load composition based on annual peak demand for Bus 6 of the Roy Billinton Test System (RBTS) used in this paper. It is assumed that there is proportional distribution of load curtailment across all the sectors shown in Table 1.

Table 2. Load composition for the system based on annual peak demand

User Sector	Sector Peak(MW)	Sector peak (%)
Residential	7.25	36.25
Commercial	3.75	18.74
Small user	3.5	17.49
Institutional	5.50	27.50
Total	20.00	100

Table 3 shows the CCDF obtained for the system from the sector CDF using the load composition for the system from Table 2.

Table 3. System CCDF and sector CDF (Rs/kW)

User sector	1 min	20 min	60 min	240 min	480 min
Residential	0.001	0.09	0.48	4.91	15.6
commercial	0.381	2.96	8.55	31.3	83.0
small user	4.77	9.87	21.06	68.83	119.
institutional	0.04	0.36	1.49	6.55	26.0
CCDF	0.92	2.43	5.90	21.6	49.4

Fig.2. shows each sector CDF along with the system CCDF

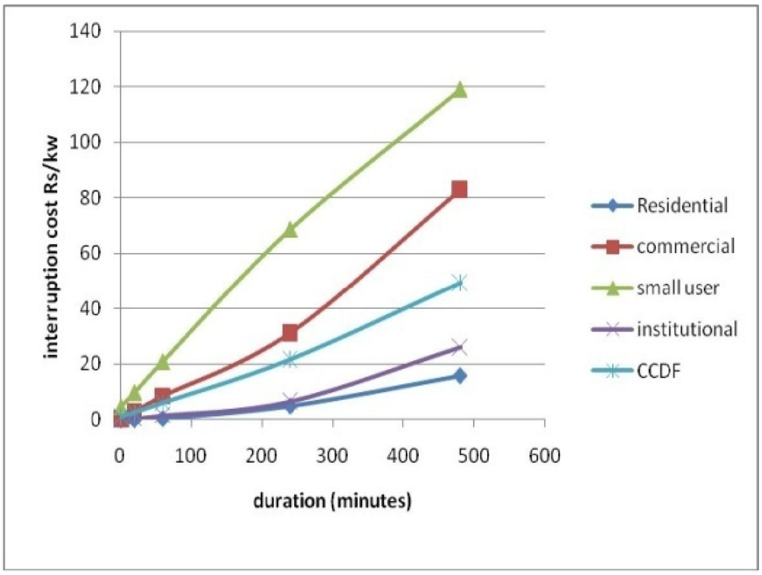

Fig. 2. Sector CDFs and System CCDF

Similarly, the Feeder CCDF can be obtained from sector CDF by using the load composition in each individual feeder. Feeder 1,3and 4 of Bus 6 contain residential, commercial and institutional sector customers. Feeder 2 contains small user sector customers. Table 4 shows the load composition by percentage at each of these feeders.

Table 4. Load composition by percentage for each feeder of Bus 6

User Sector	F1(%)	F2(%)	F3(%)	F4(%)
Residential	0.43	0	0.49	0.39
Commercial	0.25	0	0.14	0.27
Small user	0	1	0	0
Institutional	0.30	0	0.36	0.33

Table 5 shows the Feeder CCDF for each of the feeders of Bus 6 obtained using Tables 3 and Table 4.

Table 5. Feeder CCDF (Rs/kW)

CCDF	1 min	20 min	60 min	240 min	480 min
F1	0.12	0.99	3.07	12.9	37.8
F 2	4.77	9.87	21.0	68.8	119.1
F 3	0.07	0.66	2.16	9.86	30.3
F4	0.12	0.95	2.86	10.8	31.1

4 VARIATION IN ECOST USING ANALYTICAL TECHNIQUES

The distribution system is represented as a mathematical model for analytical techniques to be applied. Most analytical techniques are based on failure mode and effect analysis (FMEA). The analytical techniques utilize different data to calculate the ECOST at the load points and in the total system. These various techniques are analyzed on a case by case basis. The results are then compared to determine the variation in the expected customer cost values. Expected values are obtained using the analytical techniques. The respective sector CDF and CCDF used are shown in Table 3.The expected customer cost values are obtained at the system and individual load point levels.

4.1 ANALYTICAL TECHNIQUES

Technique 1

In which the expected system interruption cost ECOST can be determined by using the SAIFI for the system, the total peak load of the system and the cost associated with CAIDI using the system CCDF. Table 6 shows the ECOST for this technique.

Table 6. Total expected cost using technique 1

	SAIFI (int/cust)	$CCDF_{CAIDI}$ (Rs/kW)	ECOST (kRs/yr)
System	0.24	16.85	83.65

Applying a CAIDI of 3.084 hours, the equivalent customer interruption cost using the system CCDF is 16.85 Rs/kW. Thus, the ECOST for the system is 83.65 kRs/yr.

Technique 2

This technique is modification of the above mentioned technique 1. In which the ECOST can be determined by calculating the ECOST of each feeder (CAIDI).Finally the system ECOST can be obtained by summation of ECOST of each feeder. Table 7 shows the ECOST for this technique.

Table 7. Total expected cost using the technique 2

Feeder	SAIFI (int/cust)	$CCDF_{CAIDI}$ (Rs/kW)	ECOST (kRs/Yr)
1	0.24	9.17	13.49
2	0.13	66.08	32.32
3	0.24	7.068	8.91
4	0.24	9.48	12.94
Total			67.67

It can be seen that the ECOST for the system decreases to 67.67kRs/yr. Consideration of the ECOST at the feeder levels using the corresponding SAIFI and peak load gives a more accurate estimate of the ECOST at the system level.

Technique 3:

In which the ECOST at a particular load point was calculated using the system CCDF. The summation of ECOST of all the load points gives the system ECOST. Fig 3 shows the ECOST at each load point using system CCDF. The system ECOST is equal to 48.65 kRs/yr. It can be seen that the size of the peak load at the load point, position of the load point in the system and the operating scheme of the layout to that load point, i.e. the presence of disconnects, breakers, alternate supply significantly affects the load point expected costs.

The ECOST for the entire system is the summation of all the load point costs and is equal to 48.65 kRs/yr. This is a decrease of 28.10% from the ECOST calculated in Case 2 and a decrease of 41.844% from Case 1.

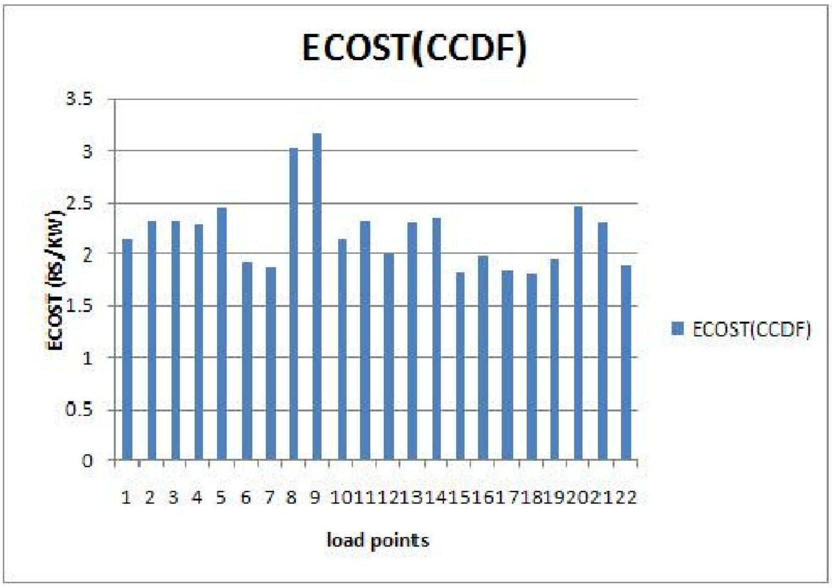

Fig. 3. Calculation of the load point ECOST using the system CCDF

Technique 4

In which the ECOST at a patirticular load point was calculated using the sector CDF. The summation of the ECOST of all the load points gives the system ECOST. Fig 4 shows the ECOST at each load point using sector CDF. The system ECOST is equal to 46.92 kRs/yr.

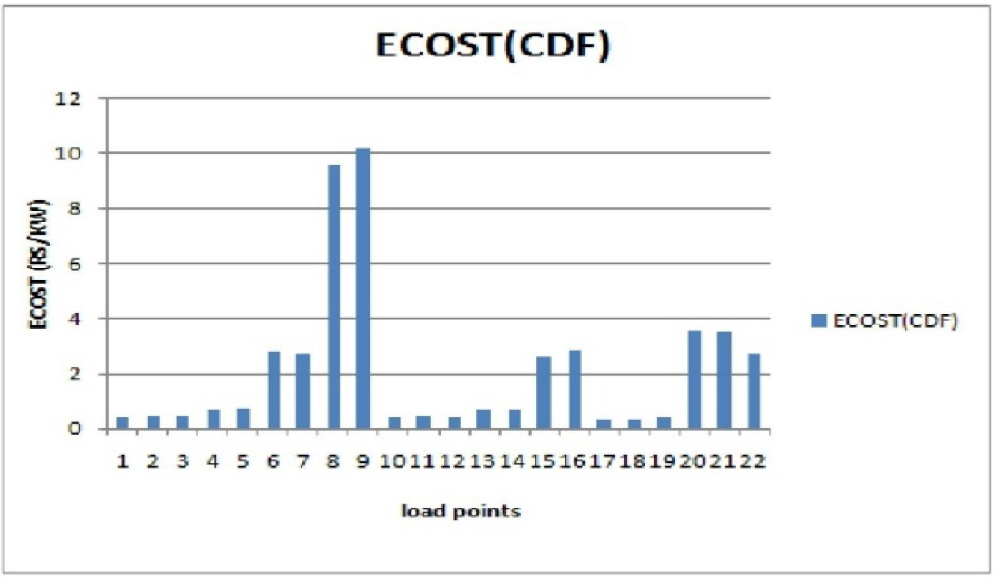

Fig. 4. Calculation of load point ECOST using sector CDF

The total expected cost is 46.92 kRs/yr which is a decrease of 3.5% from the ECOST value calculated in Case 3. The differences between these two values obtained using system CCDF and sector CDF is shown graphically by comparing the load point ECOST values in Fig 5.

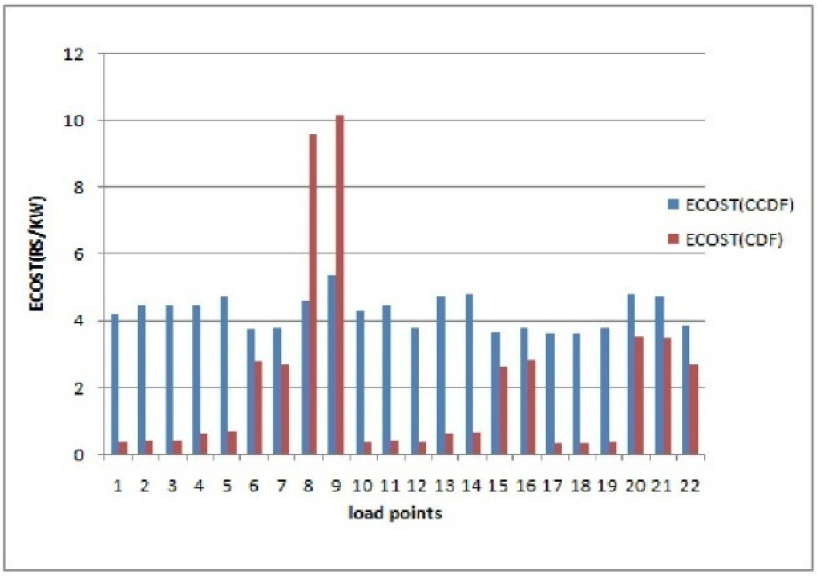

Fig. 5. Comparison of load point ECOST calculated using system CCDF and sector CDF

Fig. 5 shows that the type of customer at the load points and the proportion of the sectors in the system need to be considered when applying the system CCDF to calculate the expected cost. The customers at load points whose sector CDF are much higher than the rest of the sectors will have lower load point ECOST values while the rest might have a higher load point ECOST when the system CCDF is used. This is due to the assumption of proportional distribution of all load curtailments across all sectors while aggregating the sector CDFs to create the system CCDF.

Technique 5

In which the ECOST of a system can be calculated by using the concept of transferring of loads. The total ECOST in this case is equals to 59.02 KRs/yr. Table 8 shows the ECOST for this technique.

Table 8. ECOST technique 5

FEEDER	CDF (Rs/kW)	ECOST (KRs/yr)
1	3.18	31.81
2	3.09	8.79
3	4.53	2.72
4	3.06	15.69
system		59.029

Technique 6

In which the ECOST at a particular feeder was calculated using the feeder CCDF. The summation of the ECOST of all the feeders gives the system ECOST. The system ECOST is equals to 136.14 kRs/yr. Table 9 shows the total ECOST obtained from feeder CCDF.

Table 9. ECOST by technique 6

Feeder	CCDF (Rs/kW)	ECOST (kRs/yr)
1	9.21	7.26
2	66.08	39.71
3	6.98	32.53
4	9.51	56.63
Total		136.14

Technique 7

The entire system is considered as a single load and the system ECOST is calculated directly. The system ECOST obtained by this technique is equals to 1095.39 kRs/yr. Table 10 shows the ECOST by this technique.

Table 10. ECOST by technique7

	CDF (Rs/kW)	ECOST (kRs/yr)
System	16.903	1095.39

5 CONCLUSION

This paper introduces various analytical techniques to evaluate the expected cost at the load points and the system. These techniques require general data which usually are available from most utilities. These technique are, therefore, more realistic for most utilities to estimate the customer interruption costs. The results obtained using the various analytical techniques which shows variation in ECOST using different approaches. The ECOST at a patirticular load point was calculated using the sector CDF and summation of the ECOST of all the load points gives the system ECOST.Which gives more accurate value of ECOST compared to other techniques.

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