Economic Analysis of Electricity Interruption with Distribution System Reliability Enhancement

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ABSTRACT
A power system is to supply reasonable level of reliable, qualitative electricity supply to its customers in an acceptable price. Reasonable level is one balancing the need for power supply and the cost involved. An effective way to solving this issue is by the use of quantitative assessment of the reliability indices based on the probability of availability and unavailability of supply. The unavailability of supply (an interruption in the supply of electricity) brings in economic impacts for both the customers and the utilities. Customer interruption mean the loss of service due to a forced outage for more than five minutes, for one or more customers, which is the result of one or more failures. Therefore, cost of interruption is evaluated as a basic parameter of economic evaluation in the process of increasing the power system reliability. Reliability of distribution network is an important subject due to increasing demand for more reliable service with less interruption frequency and duration. This paper presents the main cause of power interruption, evaluate the cost of customer interruption by IEEE 1366-2012 guideline distribution reliability indices, and compare the interruption cost of various utility sectors without and with distributed generation (DG).

KEYWORDS: Economic Impacts, Utility sectors, Customer Interruption Cost

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I. INTRODUCTION
The distribution system is an important part of the total electrical supply system, as it is provides the final link between a utility's bulk transmission system and its customers. It has been reported the cause of the interruption, assesses the duration, frequency of power interruption and indicates how much interruption influences the utility economically. Reliability of a power distribution system is the ability to deliver uninterrupted service to customer. Distribution system reliability indices can be presented in many ways to reflect the reliability of individual customers, feeders, and customer-oriented indices. To evaluate the reliability in distribution system, two different approaches are normally used: namely, historical assessment and predictive assessment. Historical assessment involves the collection and analysis of the distribution system outage and customer interruption data. Predictive assessment will perform for a specified amount of time with minimal or no failure or maintenance. Therefore, the interruption cost calculation are carried out based on calculation for interruption time of each feeder, estimation for numbers of customers in each load type, interrupted power rating for each load type, calculation for interruption cost by multiplying interrupted power, corresponding cost and interruption time.

II. Proposed Area for The System
The distribution network selected for the study is Watt Kyee Inn substation at Nyaung Oo District. This is a typical network coming from 66/11kV substation as a source point and having four feeders such as Myo Haung, Nyaung Oo, Ngae Pit Taung, and Taung Zine feeders. It is shown in Table I.

Table I. Parameters of Feeders

SN	Feeder Name	Number of X'mer	Total X'mer Capacity (kVA)	Total No. of Customer	Average Load, La (MW)	Length (km)
1	Myo Haung	55	11725	3125	1.8	9.371
2	Nyaung Oo	54	9600	1561	2.6	21.113
3	Ngae Pit Taung	74	17870	1683	2	9.532
4	Taung Zine	133	25524	11353	3.5	130.741

III. Economic Analysis of Reliability

Electricity is important in economic development of a nation and it cannot be overemphasized as the access to reliable electricity increases the productivity and the public well-being. From the economic point of view, the most of the utility are willing to invest for further improvement of reliability of distribution system. Therefore, economic analysis becomes one of the vital tools for reliability assessment. This research employs a marginal benefit to cost analysis for economic evaluation, focusing on enhancing system performance and reliability through strategic investments. The fundamental objective of any distribution system is to achieve a balance between reliability and cost-effectiveness. The ideal relationship between the system reliability and the costs with respect to the customer interruption and utility investment cost is shown in Figure (1). The sum of the utility cost and its customer gives the total reliability cost. Total utility investment cost includes expenditure on automation, and maintenance to improve the reliability. The lowest point of the curve illustrated below occurs at the intersection of total utility investment costs and interruption costs. At this juncture, the distribution system demonstrates enhanced reliability and cost-effectiveness.

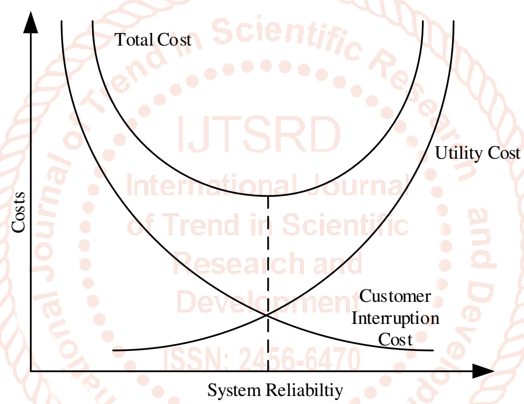

Figure 1. Optimization Curve for Reliability

A. Reliability Survey

The reliability of a power distribution system is characterized by its capacity to provide continuous service to consumers. Electric utilities are increasingly acknowledging the significance of a reliable electric power supply, which plays a crucial role in shaping customers' purchasing choices. The distribution network is inherently complex and susceptible to various factors that may lead to power interruptions. Distribution reliability encompasses both the availability and the quality of the power supply at the customer service entrance. The reliability is measured by how much frequency, how long durations and how many interruption over a year. Many researchers have devised various methodologies aimed at enhancing power reliability, particularly in relation to quality, stability, and the reduction of losses within distribution systems.

The reliability indices are presented the reliability of individual customers, feeders and customer-oriented indices in the distribution system. These studies involve the interruption cost for the various utility sectors. The evaluation on their capacity to endure possible disruptions or failures while maintaining uninterrupted operations are carried out. Reliability surveys can be helpful in the various utility sectors of power system to analysis the interruption cost and increase the reliability of a power system. It is essential for electric utilities to measure actual distribution system reliability and to access the basic function of providing cost effective and reliable power supply to all customer types.

B. Customer Surveys

The customer surveys are the most popular tools chosen and utilized by the electric power society and utilities. In customer surveys, the customer is the best position to assess their interruptions, that is taken as the correspondent. Finding a compromise between reliability and costs, has been a subject of discussion for several decades now and will likely continue for years to come. Customer survey questionnaire is collected the data of load shed, unload shed such as faults, line clears, number of customers, the length (km), number of transformers, total transformer capacity (kVA), average load (MW) of each feeder for a reliable customer interruption cost study. These include the duration and the frequency of the power outage, the season that the interruption is seen in (summer, winter and rainy), the time of occurrence (during or outside working hours) and the character of the outage is given beforehand, unexpected or planned outage.

Most of the studies use the sector customer damage functions by categorizing the customers in the sectors of Agricultural, Commercial or Service, Government and Institution, Industrial, Office and Building, and Residential. Cost-estimation studies are an important tool to be able to estimate an optimal level of continuity of supply. The optimal continuity of supply can be different for different feeders and for different types of customers and will certainly evolve with timer as end user equipment, customer requirements and investment costs change.

C. Distinguish Various Utility Sectors

The electric utilities are responsible for distribution or delivery of electricity to the customers who live in their service area. The customer damage factors include duration, outages time, and customer types. The utilities are divided into customer sectors of (1) Agricultural, (2) Commercial or Service, (3) Government and Institution, (4) Industrial, (5) Office and Building, and (6) Residential regarding their power consumption characteristics.

Table II. Numbers of Utilities Sectors in Each Feeder

Feeder Name	No. of Customers					
	(1)	(2)	(3)	(4)	(5)	(6)
Myo Haung	46	1235	136	31	365	1312
Nyaung Oo	32	375	56	18	205	875
Ngae Pit Taung	52	256	735	13	206	421
Taung Zine	210	3885	213	63	2310	4672

For the interruption cost estimation, the reference interruption duration and cost are taken from IEEE 1366-2012.

Table III. Interruption Duration and Cost Based on Utility Sectors

Sector Name	Interruption Duration (minutes)	Cost ($/kW)	Sector Name	Interruption Duration (minutes)	Cost ($/kW)
(1)	1.00	0.06	(4)	1.00	1.63
	20.00	0.34		20.00	3.87
	60.00	0.65		60.00	9.09
	240.00	2.06		240.00	25.16
	480.00	4.12		480.00	55.81
(2)	1.00	0.38	(5)	1.00	4.78
	20.00	2.97		20.00	9.88
	60.00	8.55		60.00	21.06
	240.00	31.32		240.00	68.83
	480.00	83.01		480.00	119.20
(3)	1.00	0.04	(6)	1.00	0.00
	20.00	0.37		20.00	0.09
	60.00	1.49		60.00	0.48
	240.00	6.56		240.00	4.91
	480.00	26.04		480.00	15.69

IV. Cost of Interruption

The financial implications of an interruption differ significantly among various customers and across different nations. Additional critical factors encompass the length of the interruption, the season, the specific day of the week, the time of day, and the presence or absence of prior notification. Notably, the expense associated with an interruption is greatly influenced by its duration. There are two main aspects when the customer interruption cost assessments are done. The first matter is the methodology of collecting necessary input data and corresponding tools for the estimations and suggestions about the economic correspondence of the customer interruption costs. Short interruptions lead to damaged processors and malfunctioning equipment. Longer interruptions are results in lost production and lost sales. There are many factors determining the economic impacts due to interruptions. These include the duration and the frequency of power outages. The customer interruption cost data are usually collected by Electric Power Corporation (EPC) for different customer sectors.

The interruption cost at an individual customer load point is dependent on the type of customer (customer sectors), the load curtailed, the duration of interruption and the time of interruptions. The expense associated with an interruption is significantly influenced by the length of time it persists. The customer interruption cost is used as a measure of customer's benefits of the distribution system reliability. Accurate customer interruption cost assessments are important for adequate cost-benefit analysis. In addition, the interruption cost also depends on the duration of the interruption, the time of the week and whether customers are informed about the interruption ahead or not. The customer having a good back up of power system is supposedly impacted less. The amount a customer is prepared to invest in enhanced reliability is intrinsically linked to the costs incurred due to interruptions caused by power outages. For the interruption cost estimation, the reference interruption cost data are taken from IEEE 1366-2012.

V. Counts Numbers of Load Shed, Faults and Line Clears

When the generation and the load are not balanced, the customers connected to the system suffer the greatest number of outages and the greatest unavailability. The distribution system is susceptible to irregularities that may include failures, disturbances such as human errors or natural cause effects like lighting and tornadoes and also situations like protection or communication system failures. The reliability of the distribution network system is closely related to the problem of termination of the load or blackout due to interruption time, schedule load shed, unscheduled load shed such as faults and line clear, etc.

Table IV. Total Counts and Hours for Myo Haung Feeder and Nyaung Oo Feeder

Monthly Data (2023)	Feeders					
	Myo Haung Feeder			Nyaung Oo Feeder		
	Counts	Hours	C/H	Counts	Hours	C/H
January	62	13	292	68	14	324
February	57	14	286	65	14	318
March	62	14	320	71	14	354
April	67	14	334	74	15	378
May	64	15	342	72	16	390
June	114	12	360	111	13.5	390
July	74	16	392	71	17	405
August	72	17	409	71	15	372
September	69	15	357	64	16	348
October	66	13	263	69	12	250
November	68	13	269	71	11	252
December	85	13	336	84	12	320
Total	860	169	3960	891	169.5	4101

Table V. Total Counts and Hours for Ngae Pit Taung Feeder and Taung Zine Feeder

Monthly Data (2023)	Feeders					
	Myo Haung Feeder			Nyaung Oo Feeder		
	Counts	Hours	C/H	Counts	Hours	C/H
January	18	7.5	45	139	15	527
February	18	7	43	129	15	526
March	21	8	74	138	16	620
April	33	9	135	131	17	685
May	26	9.5	111	149	16	714
June	28	11	146	203	14	849
July	31	10	140	181	18	1041
August	25	9	93	153	16	726
September	25	9	93	146	17	754
October	26	9	102	131	13	474
November	27	9	99	158	13	568
December	26	8	84	187	13	669
Total	304	106	1165	1845	183	8198

VI. Interruption Cost of Individual Feeder without DG

According to Load Shed and Unload Shed data,

Example of Myo Haung Feeder: [3960 hr/yr, 10.85 hr/day, 651 min/day]

For Agricultural,

According to Electric Power Corporation (EPC) Office data,

(i) No. of Customer = 46

$$\text{(ii)Power (kW)} = 1800 \times \frac{\text{No. of Customer}}{\text{Total No. of Customer}}$$

$$= 1800 \times \frac{46}{3125}$$

$$= 26.5 \text{ (kW)}$$

(iii) Interruption Cost ($/kW) @ 480 min

= 4.12 ($/kW)

(iv) Interruption Cost / day ($/day)

$= \text{Power (kW)} \times \text{Cost (\$/kW)} \times (651/480)$

$= 26.5 \text{ (kW)} \times 4.12 \times (651/480)$

$= 148.1 \text{ (\$/day)}$

Table VI. Interruption Cost of Myo Haung Feeder: [3960 hr/yr, 10.85 hr/day, 651 min/day]

Utility Sectors	(1)	(2)	(3)	(4)	(5)	(6)
No. of Customer	46	1235	136	31	365	1312
Power (kW)	26.5	711.4	78.3	17.9	210.2	755.7
Interruption Cost ($/kW) @ 480min	4.12	83.01	26.04	55.81	119.2	15.69
Interruption Cost/day ($/day)	148.1	80086.6	2766.6	1351.6	33988.4	16081.2

Table VII. Interruption Cost of Nyaung Oo Feeder: [4101 hr/yr, 11.24 hr/day, 674 min/day]

Utility Sectors	(1)	(2)	(3)	(4)	(5)	(6)
No. of Customer	32	375	56	18	205	875
Power (kW)	53.3	624.6	93.3	30.0	341.4	1457.4
Interruption Cost ($/kW) @ 480min	4.12	83.01	26.04	55.81	119.2	15.69
Interruption Cost/day ($/day)	308.3	72803.3	3410.5	2349.5	57150.4	32108.5

Table VIII. Interruption Cost of Ngae Pit Taung Feeder: [1165 hr/yr, 3.19 hr/day, 191 min/day]

Utility Sectors	(1)	(2)	(3)	(4)	(5)	(6)
No. of Customer	52	256	735	13	206	421
Power (kW)	61.8	304.2	873.4	15.4	244.8	500.3
Interruption Cost ($/kW) @ 480min	0.65	8.55	1.49	9.09	21.06	0.48
Interruption Cost/day ($/day)	127.9	8280.1	4142.9	447.0	16411.7	764.4

Table IX. Interruption Cost of Taung Zine Feeder: [1165 hr/yr, 3.19 hr/day, 191 min/day]

Utility Sectors	(1)	(2)	(3)	(4)	(5)	(6)
No. of Customer	210	3885	213	63	2310	4672
Power (kW)	64.7	1197.7	65.7	19.4	712.1	1440.3
Interruption Cost ($/kW) @ 480min	4.12	83.01	26.04	55.81	119.2	15.69
Interruption Cost/day ($/day)	749.1	279207.8	4802.0	3044.1	238393.4	63464.6

VII. Interruption Cost of Individual Feeder with DG

With the application of DGs, the interruption costs of the distribution system are significantly changed. After replacing DGs, Load Sheds are not considered, according to Unload Shed data,

Example of Nyaung Oo Feeder: [3960 hr/yr, 10.85 hr/day, 651 min/day]

For Agricultural,

According to Electric Power Corporation (EPC) Office data,

(i) No. of Customer = 32

$$\text{(ii)Power (kW)} = 1800 \times \frac{\text{No. of Customer}}{\text{Total No. of Customer}}$$

$$= 2600 \times \frac{32}{1561}$$

$$= 53.3\ (\text{kW})$$

(iii) Interruption Cost ($ / kW) @ 60 min

= 0.65 ($ / kW)

(iv) Interruption Cost / day ($ / day)

$= \text{Power (kW)} \times \text{Cost (\$ / kW)} \times (218 / 60)$

$= 53.3\ (\text{kW}) \times 0.65 \times (218 / 60)$

$= 125.9\ (\$ / \text{day})$

Table X. Interruption Cost of Myo Haung Feeder: [1178 hr/yr, 3.23 hr/day, 194 min/day]

Utility Sectors	(1)	(2)	(3)	(4)	(5)	(6)
No. of Customer	46	1235	136	31	365	1312
Power (kW)	26.5	711.4	78.3	17.9	210.2	755.7
Interruption Cost ($/kW) @ 480min	0.65	8.55	1.49	9.09	21.06	0.48
Interruption Cost/day ($/day)	55.7	19665.6	377.4	524.8	14316.1	1172.9

Table XI. Interruption Cost of Nyaung Oo Feeder: [1327 hr/yr, 11.24 hr/day, 674 min/day]

Utility Sectors	(1)	(2)	(3)	(4)	(5)	(6)
No. of Customer	32	375	56	18	205	875
Power (kW)	53.3	624.6	93.3	30.0	341.4	1457.4
Interruption Cost ($/kW) @ 60min	0.65	8.55	1.49	9.09	21.06	0.48
Interruption Cost/day ($/day)	125.9	19403.2	505.0	990.2	26126.9	2541.7

Table XII. Interruption Cost of Ngae Pit Taung Feeder: [1178 hr/yr, 3.23 hr/day, 194 min/day]

Utility Sectors	(1)	(2)	(3)	(4)	(5)	(6)
No. of Customer	52	256	735	13	206	421
Power (kW)	61.8	304.2	873.4	15.4	244.8	500.3
Interruption Cost ($/kW) @ 480min	0.65	8.55	1.49	9.09	21.06	0.48
Interruption Cost/day ($/day)	127.9	8280.1	4142.9	447.0	16411.7	764.4

Table XIII. Interruption Cost of Taung Zine Feeder: [5426 hr/yr, 14.87 hr/day, 892 min/day]

Utility Sectors	(1)	(2)	(3)	(4)	(5)	(6)
No. of Customer	210	3885	213	63	2310	4672
Power (kW)	64.7	1197.7	65.7	19.4	712.1	1440.3
Interruption Cost ($/kW) @ 480min	4.12	83.01	26.04	55.81	119.2	15.69
Interruption Cost/day ($/day)	495.7	184757.7	3177.6	2014.3	157750.0	41995.9

VIII. Comparison of Interruption Cost of Various Utility Sectors without DG and with DG

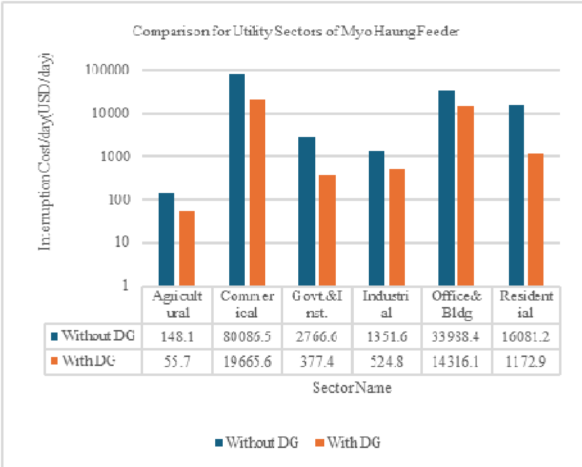

Figure 2. Interruption Cost of Utility Sectors for Myo Haung Feeder

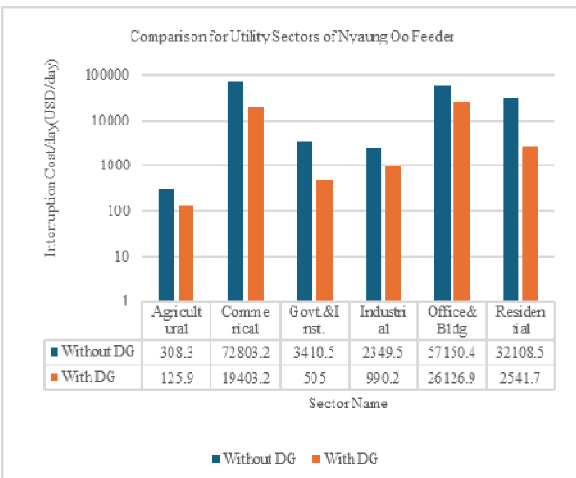

Figure 3. Interruption Cost of Utility Sectors for Nyaung Oo Feeder

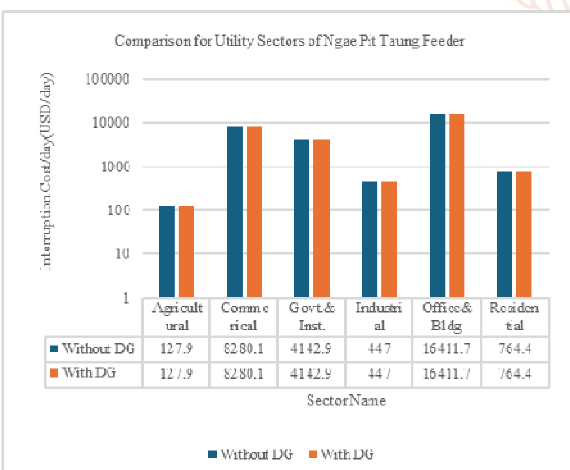

Figure 4. Interruption Cost of Utility Sectors for Ngae Pit Taung Feeder

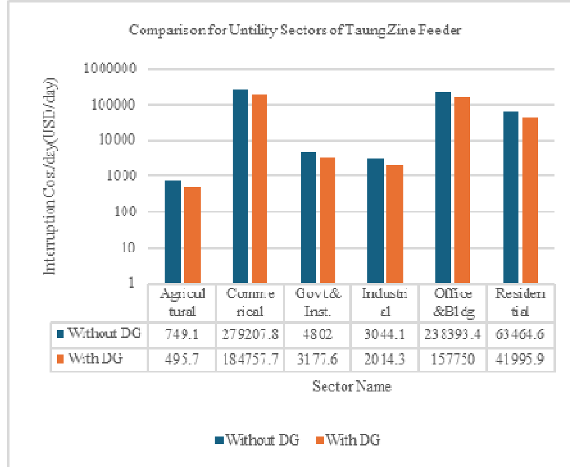

Figure 5. Interruption Cost of Utility Sectors for Taung Zine Feeder

IX. Discussion and Conclusions

This research investigated the costs associated with the power outages on the Proposed Area. In addition residential, commercial, and industrial customers, etc. are affected differently by the power outages. For reliability improvement of the distribution system, the distributed generations (DGs) are connected at the distribution feeders. The location and sizing of DGs are obtained Bus No. 37 and 1.96 MW at Myo Haung feeder, Bus No.36 and 1.87 MW at Nyaung Oo feeder, Bus No.51 and 2.61 MW at Ngae Pit Taung feeder and Bus No.89 and 4.48 MW at Taung Zine feeder. The interruption costs are calculated for without DG and with DG conditions and the results are compared the interruption costs of various utility sectors for per day basic. By integrating DGs, the interruption costs ($/day) of Agricultural, Commerical, Government and Institution, Industrial, Office and Building and Residential are significantly decreased from 148.1 to 55.7, from 80086.5 to 19665.6, from 2766.6 to 377.4, from 1351.6 to 524.8, from 33988.4 to 14316.1 and from 16081.2 to 1172.9 at Myo Haung feeder. By penetrating DGs, the interruption costs ($/day) of Agricultural, Commerical, Government and Institution, Industrial, Office and Building, and Residential are significantly decreased from 308.3 to 125.9, from 72803.2 to 19403.2, from 3410.5 to 505.0, from 2349.5 to 990.2, from 57150.4 to 26126.9 and from 32108.5 to 2541.7 at Nyaung Oo feeder.

By adding DGs at Ngae Pit Taung feeder, the interruption costs ($/day) of Agricultural, Commerical, Government and Institution, Industrial, Office and Building and Residential are the same values for all sectors after installing DG and before installing DG because of VIP line. By penetrating DGs, the interruption costs ($/day) of Agricultural, Commerical, Government and Institution, Industrial, Office and Building and Residential are significantly decreased from 749.1 to 495.7, from 279207.8 to

184757.7, from 4802.0 to 3177.6, from 3044.1 to 2014.3, from 238393.4 to 157750.0 and from 63464.6 to 41995.9 for Taung Zine feeder. Among various sectors, the commercial sector shows the largest value of the interruption cost and the agricultural sector results the smallest value of the interruption cost for the individual feeder. These results are helpful to the local utilities to provide the reliable supply at customer and the cost effective manner. So, the evaluation of interruption costs are provided to make planning for reliability improvement using distributed generations (DGs).

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