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Analysis of Customer Interruption Cost with Reliability Indices on Distribution System

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Abstract: The reliability of electric power systems plays a vital role in ensuring continuous and high-quality electricity supply to consumers. This study presents an analysis of customer interruption costs (CIC) in relation to reliability indices such as System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI), etc. according to the IEEE Standard 1366. The main objective is to quantify the economic impact of power interruptions on different customer categories: residential, commercial, and industrial, etc. and to evaluate how system reliability performance affects these costs. Using reliability data and customer survey information, customer interruption cost are developed to estimate the financial losses associated with various outage durations and frequencies. If the even minor improvements in reliability indices lead to significant reductions in customer interruption costs, emphasizing the importance of targeted investments in reliability enhancement programs. The findings of this study provide valuable insights for utility planners, regulators, and policymakers in optimizing system reliability while balancing economic and customer satisfaction considerations.

Keywords: Distribution System, Reliability Indices, Scheduled and Unscheduled Load Shed, Various Utility Sectors, Customer Interruption Cost.

Research Paper

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I. INTRODUCTION

Electric power systems are essential infrastructures that support economic development and enhance the quality of life. The reliability of these systems is a key performance measure, as any interruption in power supply can cause significant inconvenience and financial losses to consumers. With the growing dependence on electricity for both industrial processes and daily activities, maintaining a highly reliable power supply has become a primary objective for utility companies and regulatory bodies. Power system reliability is commonly assessed using quantitative indices such as the System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI). These indices provide a statistical overview of outage frequency and duration, helping utilities monitor performance and identify areas for improvement. However, while reliability indices describe the technical performance of the system, they do not directly reflect the economic and social impacts experienced by customers during power interruptions. To bridge this gap, the concept of Customer Interruption Cost (CIC) has been introduced. CIC represents the economic value that customers place on reliable electricity supply and quantifies the financial losses incurred during service interruptions.

These costs vary depending on the customer category-residential, commercial, or industrial-as well as factors such as outage duration, time of occurrence, and the nature of customer activities affected. Understanding the relationship between reliability indices and customer interruption costs is crucial for effective reliability planning and investment decision-making. By integrating technical reliability measures with economic impact analysis, utilities can prioritize maintenance and improvement projects that yield the greatest benefit to customers. Moreover, regulators can use this information to design incentive-based reliability standards that encourage utilities to deliver cost-effective reliability improvements. This study focuses on analyzing the relationship between customer interruption cost and reliability indices to provide a comprehensive assessment of the economic consequences of power interruptions. The results aim to support decision-makers in optimizing system reliability, minimizing customer losses, and promoting sustainable power system development.

II. DISTRIBUTION SYSTEM RELIABILITY

The primary function of distribution systems is to deliver electricity to consumers for carrying out activities that necessitate electrical power. Assessment of the distribution system to determine the extent to which electricity is made available to the customers without interruption provides a measure of system reliability. Distribution reliability is especially important in this competitive climate because the distribution system feeder customers directly. Transmission and generation events are cause interruption customers, but events on these systems are much less likely to affect customers than the distribution system. Reliability is the ability of the system to provide electricity without interruptions. Since the interruption is less than five minutes, which is the cut-off between the momentary and sustained interruptions. Reliability plays a vital role regarding scheming of distribution system. The reliability of distribution system ensures to operate in such an economical manner that the interruption at customer loads will minimum. Reliability for a power system is quantified in terms of the number of power supply outages. Generally, at the generation level, this signifies capacity inadequacy; at the transmission level, it usually means outage of a line or terminal; and at the distribution level, this means interruption of service to the customer. It is at the distribution level that reliability is most relevant from a customer's viewpoint and a utility's reliability performance is normally quantified at this level in the eyes of both the customers and of the regulatory agencies. Electrical distribution systems play a crucial role in the overall electrical power system.

III. RELIABILITY INDICES

The choice of methods for analyzing a distribution system depends on the characteristics of the system and the scope of the analysis. Three fundamental reliability parameters typically assessed are: the average failure rate (λ), the average repair time (r), and the average annual outage time (U). Based on these parameters, common load-point reliability indices can be calculated as follows:

$$\lambda_s = \sum_{i} \lambda_i \qquad \text{-------(1)}$$

$$U_s = \sum_{i} \lambda_i N_i \qquad \text{-------(2)}$$

$$r_s = \frac{\sum_{i} \lambda_i N_i}{\sum_{i} \lambda_i} \qquad \text{-------(3)}$$

Equations (1), (2), and (3) are used to evaluate load-point reliability indices. These metrics are commonly applied to calculate distribution system reliability indices such as Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average Service Unavailability Index (ASUI), Average Service Availability Index (ASAI), Average Energy Not Supplied (AENS), and Expected Energy Not Supplied (EENS). The most frequently used indices are averages that treat all customers equally. They provide measures of outage duration, outage frequency, system availability, and response time.

IV. PROPOSED AREA OF THE SYSTEM

The distribution network selected for this study is the Watt Kyee Inn Substation, located in Nyaung Oo District. This substation operates at 66/11 kV, 20 MVA and serves as the main supply source for four distribution feeders: Myo Haung, Nyaung Oo, Ngae Pit Taung, and Taung Zine. The Myo Haung feeder consists of 55 load points, supplying approximately 3,125 customers, including residential, commercial, and government or institutional consumers. The feeder spans a total length of 9.371 km. The Nyaung Oo feeder contains 54 load points, serves 1,561 customers, and has a length of 21.113 km. The Ngae Pit Taung feeder comprises 74 load points, supplies 1,683 customers, and covers 9.532 km in length. Finally, the Taung Zine feeder is the largest, with 133 load points, 11,353 customers, and a total length of 130.714 km.

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

V. FAILURE COUNTS AND HOURS OF LOAD SHED AND UNLOAD SHED

An imbalance between power generation and load demand leads to frequent outages and reduced reliability in the distribution system. Various factors such as equipment failures, human errors, natural events, and protection or communication system malfunctions can disrupt power supply. Both scheduled interruptions, like maintenance or load shedding, and unscheduled outages, such as faults or line clearances, affect network performance. Therefore, maintaining a proper balance between generation and demand is crucial for ensuring reliable electricity service to customers.

Table II: Total Failure Counts and Hours for Four Feeders

Months	Feeder Names							
	Myo Haung Feeder		Nyaung Oo Feeder		Ngae Pit Taung Feeder		Taung Zine Feeder	
	Failure Count	Total Hours	Failure Count	Total Hours	Failure Count	Total Hours	Failure Count	Total Hours
January	62	292	68	324	18	45	139	527
February	57	286	65	318	18	43	129	526
March	62	320	71	354	21	74	138	620
April	67	334	74	378	33	135	131	685
May	64	342	72	390	26	111	149	714
June	114	360	111	390	28	146	203	849
July	74	392	71	405	31	140	181	1041
August	72	409	71	372	25	93	153	726
September	69	357	64	348	25	93	146	754
October	66	263	69	250	26	102	131	474
November	68	269	71	252	27	99	158	568
December	85	336	84	320	26	84	187	669
Total	860	3960	891	4101	304	1165	1845	8198

Table III: Evaluation of Basic Reliability Parameters for Four Feeders

Basic Reliability Parameters	Myo Haung Feeder	Nyaung Oo Feeder	Ngae Pit Taung Feeder	Taung Zine Feeder
λ (f/yr)	15.64	16.5	4.11	13.84
r (hours)	72	76	15.74	61.64
U (hr/yr)	1125.79	1254	64.67	853.21

According to Scheduled load Shed and unscheduled load shed such as faults and line clear counts, the basic reliability parameters are calculated for four feeders.

Table IV: Evaluation of Customer-Orientated Indices for Four Feeders

Reliability Indices	Myo Haung Feeder	Nyaung Oo Feeder	Ngae Pit Taung Feeder	Taung Zine Feeder
SAIFI (interruption/ customer)	15.44	16.5	4.11	13.84
SAIDI (hours/ customer yr)	1125.79	1254	66.33	846.97
CAIDI (hours/ customer interruption)	72.91	76	15.74	61.19
ASAI	0.871	0.857	0.997	0.903
ASUI	0.129	0.143	0.003	0.097
ENS (MWh/yr)	2026.43	3260.4	129.34	2986.23
AENS (MWh/ customer yr)	0.65	2.09	0.08	0.26

The customer-orientated reliability indices of the distribution system are evaluated for each feeder on the a above Table III.

VI. VARIOUS UTILITY SECTORS FOR DISTRIBUTION FEEDER

Electric power customers are categorized into six sectors: (1) Agricultural, (2) Commercial or Service, (3) Government and Institution, (4) Industrial, (5) Office and Building, and (6) Residential. The selected distribution area includes both the cultural heritage zone of Bagan and surrounding agricultural lands with river pumping systems. As a result, all six load sectors are present in this area. Customer sectors are classified through separate meter billing for each load type. Based on these billing records, the load types and corresponding customer numbers are identified and compiled for each distribution feeder. The distribution utilities maintain logbooks to record network data according to Electric Power Corporation (EPC) office standards.

Table V: Numbers of Utility Sectors in Each Feeder

Feeder Name	Number of Customers					
	Agricultural	Commercial or Service	Government and Institution	Industrial	Office and Building	Residential
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

VII. EVALUATION OF CUSTOMER INTERRUPTION COST

In the competitive power market, calculation of interruption cost is very significant as interruption, i.e. supply reliability will be an important factor for decision making for both the supplier and the user. For the interruption cost estimation, the reference interruption cost data are taken from IEEE Standard 1366-2012. The interruption costs are segregated according to the load types (six category) and the interruption durations cost (five phases). The customer interruption cost calculations are carried out with the following steps:

- 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 customer interruption cost by multiplying interrupted power, corresponding cost and interruption time.

$$\text{Customer Interruption Cost / day} = \text{Power (kW)} \times \text{Cost (\$ / kW)} \times \frac{\text{Outage time}}{\text{Interruption duration}}$$

Calculation for Agricultural at Myo Haung Feeder: [3960 hr/yr, 10.85 hr/day, 651 min/day]
Number of Customer = 46

$$\text{Power (kW)} = 1800 \times \frac{\text{Number of Customer at Each Sector}}{\text{Total Number of Customer}}$$

$$= 1800 \times \frac{46}{3125} = 26.5\ \text{(kW)}$$

$$\text{Interruption Cost (\$ / kW) @ 480 min} = 4.12\ \text{(According to Customer Interruption Cost for Various Load Types)}$$

$$\begin{aligned}\text{Interruption Cost / day (\$ / day)} &= \text{Power (kW)} \times \text{Cost (\$ / kW)} \times (651/480)\\ &= 26.5\ \text{(kW)} \times 4.12 \times (651/480)\\ &= 148.1\ \text{(\$ / day)}\end{aligned}$$

The customer interruption costs are calculated for four feeders according to scheduled and unscheduled load sheds such as fault and line clear counts.

VIII. RESULTS OF CUSTOMER INTERRUPTION COST FOR FOUR FEEDERS

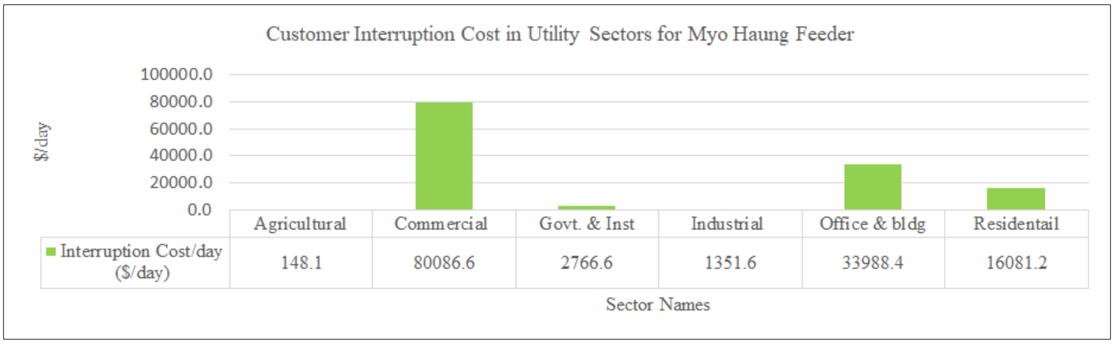

Fig. 1: Customer Interruption Cost of Utility Sectors at Myo Haung Feeder

Fig. 1 shows the customer interruption cost of utility sectors form Myo Haung feeder. The customer interruption cost ($/day) of Agricultural, Commercial, Government and Institution, Industrial, Office and Building, and Residential are 148.1, 80086.5, 2766.6, 1351.6, 33988.4 and 16081.2 at Myo Haung feeder.

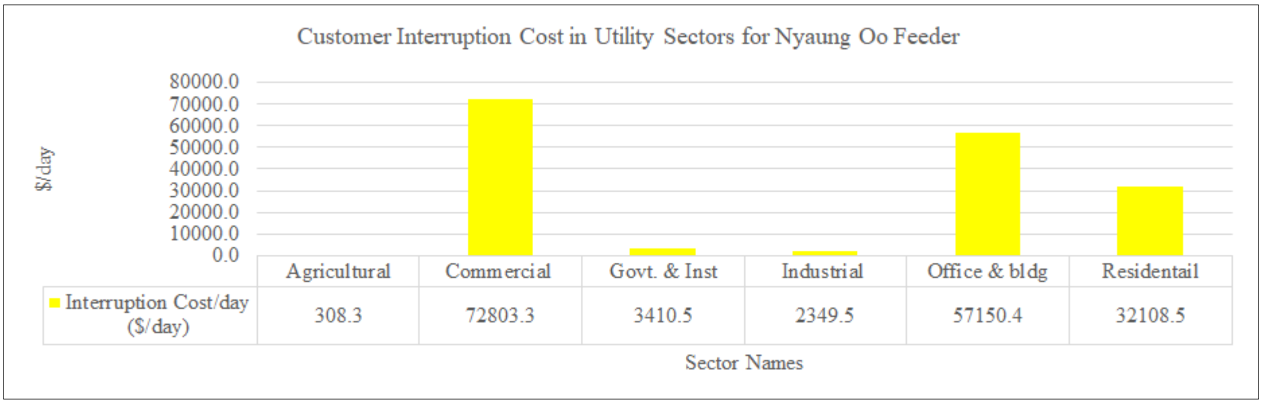

Fig. 2: Customer Interruption Cost of Utility Sectors at Nyaung Oo Feeder

Fig.2 illustrates the customer interruption cost of utility sectors for Nyaung Oo feeder. The customer interruption cost ($/day) of Agricultural, Commercial, Government and Institution, Industrial, Office and Building, and Residential are 308.3, 72803.2, 3410.5, 2349.5, 57150.4 and 32108.5.

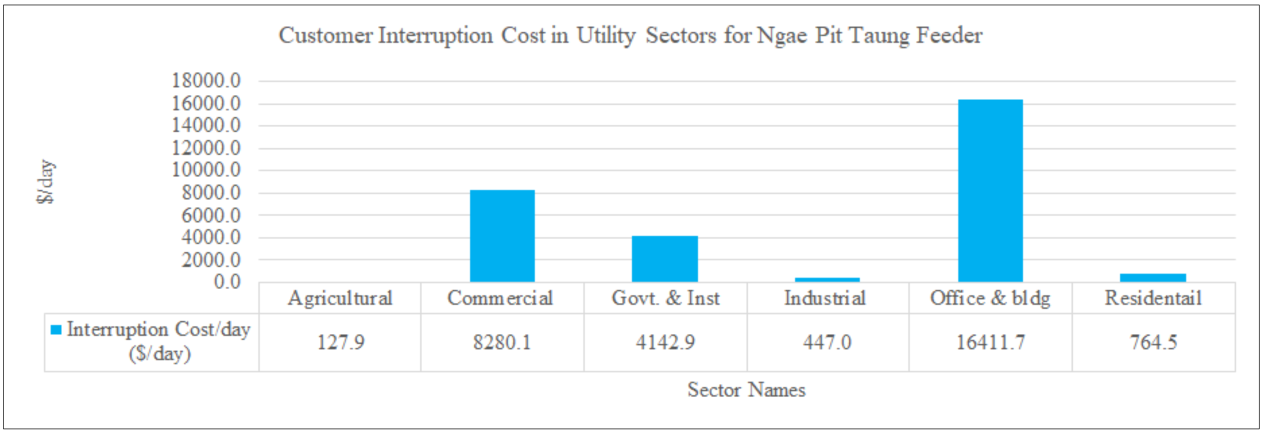

Fig. 3: Customer Interruption Cost of Utility Sectors at Ngae Pit Taung Feeder

Fig.3 presents the customer interruption cost of utility sectors for Ngae Pit Taung feeder. The customer interruption cost ($/day) of Agricultural, Commercial, Government and Institution, Industrial, Office and Building, and Residential are 127.9, 8280.1, 4142.9, 447.0, 16411.7 and 764.5.

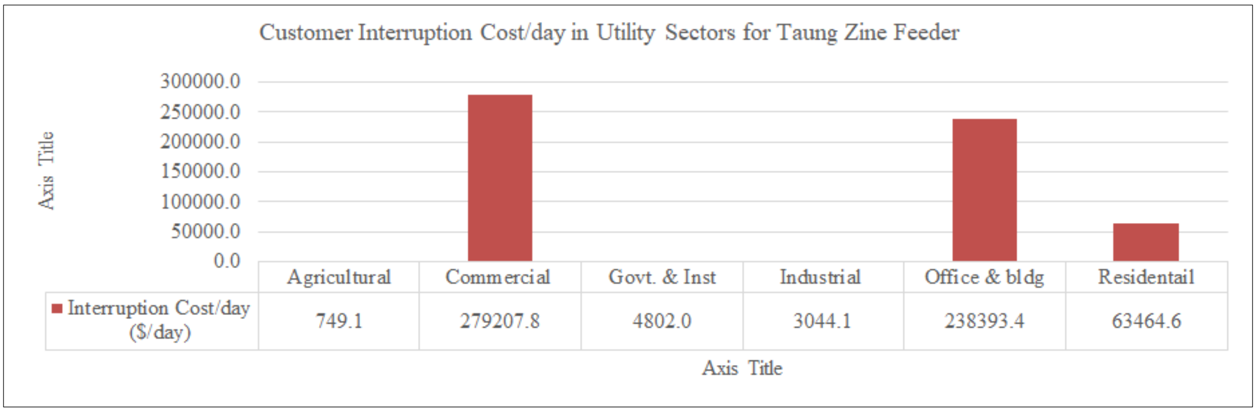

Fig. 4: Customer Interruption Cost of Utility Sectors at Taung Zine Feeder

Fig.4 demonstrates the customer interruption cost of utility sectors for Taung Zine feeder. The customer interruption cost ($/day) of Agricultural, Commercial, Government and Institution, Industrial, Office and Building, and Residential are 749.1, 279207.8, 4802.0, 3044.1, 238393.4 and 63464.6.

IX. CONCLUSION

The customer interruption cost (CIC) for various utility sectors are evaluated using reliability indices obtained from the Myo Haung, Nyaung Oo, Ngae Pit Taung, and Taung Zine feeders of the Watt Kyee Inn distribution network. The analysis provided the estimated interruption costs ($/day) for different customer categories, including Agricultural, Commercial, Government and Institutional, Industrial, Office and Building, and Residential sectors. Among various sectors, the commercial sectors show the largest value of the interruption cost that expect at Ngae Pit Taung Feeder. The agricultural sectors result the smallest value of the interruption cost for all conditions. The results demonstrate how reliability performance directly affects the economic impact on each customer group, emphasizing the importance of improving feeder reliability to minimize interruption costs and enhance overall service quality.

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