Development Composite Customer Damage Function Using the Customer Survey Based Method for Power System Reliability Planning

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ABSTRACT

The optimization in reliability cost-benefit analysis for distribution investment planning has been more attended on energy delivery services in Thailand. In this research, the reliability costs for the customer point of views represented as the interruption costs are presented. The data for analysis is provided from customer survey-based method during 2008-2009. Due to the direct and indirect impacts for electric customer in each category are different, the concept and methodology for data collecting based on customer survey is described. According to interruption costs are different for each sector, the customer survey results are classified into four customer sectors. In each sector, the individual customer damage function derived from survey is aggregated to develop sector customer damage function. The composite customer damage function utilized in regional reliability investment planning is also presented. In addition, the reliability cost evaluation in term of interrupted energy assessment rate for the selected industrial estate is determined in order to investigate industrial customer impact at the level of microeconomics scale. Application areas of reliability cost indices to enhance the effectiveness planning and operation of power distribution system are also recommended.

Keywords: Interruption Cost, Industrial Estate, Interrupted Energy Assessment Rate (IEAR), Reliability Cost Evaluation

1. INTRODUCTION

Electrical power system is a typical example of system requiring high reliability due to both high infrastructure investment and failure cost. In traditional, the first priority function of electric power utilities is to satisfy the system load and energy requirement as economically as possible with a reasonable assurance of continuity and power industry in each quality [1-2]. After conditions of well-developed networks system and low load growth, the system and operation improvement is normally required to meet service standards [3]. However, power industry has undergone the significant restructuring throughout the world since the 1990s. In particular, its traditional vertically monopolistic structure has been reformed into competitive markets in pursuit of increased efficiency in the electricity production and utilization. Therefore, power system planning to determine a minimum cost for expansion of generation, transmission and distribution system is an essential task for utility planner in order to enhance an adequate supply within a set of technical and economic constraints. In developed countries, power system planning is emphasized the issues of network reliability and stability while developing countries focus on network expansion to achieve electricity accessible performance. Consequently, planning criteria in different area are selected based on an acceptable reliability level for the customer while the level of investment is limited to obtain a reasonable electricity price. These criteria practically define reasonable risk level for unsupplied electricity as interested performance. Thus, priority of investment should be considered in decision-making process to satisfy load requirement and to achieve optimal reliability level. The criteria for power system reliability planning may be determined by:

- Judgment based on experiences;
- Establishing relations with other indices for which criteria are already available;
- Determining the optimal value of the reliability indices through cost benefit analysis.

In tradition planning, the judgment based on utility experience or best practices approach is well established. However, several factors including introduction of competitive and deregulated electricity markets, uncertainty operation of a large scale power sys-

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tems lead the electric utility to apply the cost-benefit analysis involving reliability consideration. This concept of reliability consideration is based on the optimal balance between benefits achieved from higher reliability level and cost of providing as diagram describing in Fig. 1.

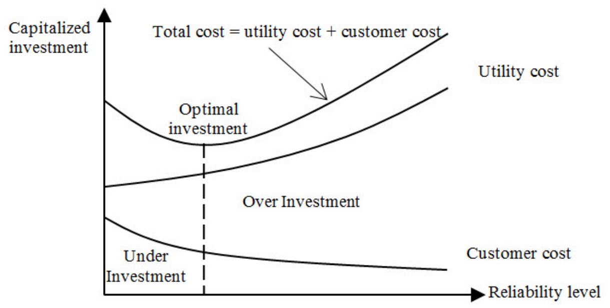


Fig.1: *Cost-benefit analysis of reliability investment*

To achieve optimal reliability level in each area, interruption or outage costs incurred by customer viewpoints are intended to assess and used to support system operation, planning, and design, together with the reliability evaluation. It is expected that the utilization of customer interruption costs will increase in the future, as the restructuring and privatization of the electricity supply industry in many parts of the world have increased commercial pressures on electric utilities and other market participants [4]. Perceived costs of customer interruption or interruption can be utilized to determine the worth of electric service reliability [5]. Although the structure of power system in Thailand is still based on monopolistic policy, the assessment the cost of unsupplied power was also performed over a decade ago. The first fully assessment of interruption costs in Thailand had performed during 1995-1996, and followed in 2000-2001. However, the several conditions related to the customer interruption cost including national microeconomics and macroeconomics system, technology improvement, environment concerns and political constraints were changed. Using the representative customer interruption cost from the ten-year results especially customer interruption costs of commercial and industrial sector may quite impropriate for investment planning. In this paper, the interruption costs of customers in service areas of rural distribution utility namely Provincial Electricity Authority (PEA) is evaluated by survey-based method. The target respondents to survey the interruption costs are classified into four sectors under electricity tariff structure which consists of residential, general service (commercial and industrial), specific business, and government sectors. To investigate the impact of power interruption in different size of customer in each sector, the interruption costs are presented in small, medium and large customer. The monthly energy consumption (kWh) defined in electricity rate of PEA are used as criteria to identify the size of each customer. The reliability cost methodology by customer survey is introduced in Section 2. The data obtained from customer survey leads to formulation of the individual customer damage function (ICDF). All the ICDFs of a given sector (i.e. commercial, industrial, residential, etc.) are combined into the sector customer damage function (SCDF). Then, the composite customer damage function (CCDF) is obtained by weighting the SCDFs with the electrical energy utilized by each customer group. The values of SCDF, CCDF for regional planning are presented in Section 3. Furthermore, reliability worth assessment for industrial distribution system is demonstrated from SCDF and actual interruption statistic information in the selected industrial area. Discussion, applications and conclusion of reliability worth assessment are presented in Section 4 and Section 5, respectively.

2. RELIABILITY COST BY CUSTOMER SURVEY APPROACH

Understanding the nature and variety of customer impacts resulting from power interruption is the essential preliminary step before assessing the reliability cost from customer point of views [6]. The methods to evaluate the impacts experienced by customers due to interruptions can be grouped into three categories [7-9]: 1) indirect analytical methods, 2) case studies of blackouts, and 3) customer surveys. In recent years, the customer survey-based method has come to dominate the literatures since the distribution of interruption costs across customers covered whole service area of electric utility. The customer impacts are represented as the reliability cost which may be classified as direct or indirect, economic or social perspectives. Direct economic impacts include scraped products and raw material, lost production, idle time, process recovery costs, cost of machines and equipment damage while costs of restoring brand equity, losses market share, and business opportunity losses from investors can be referred as the indirect economic impacts.

In order to obtain a sufficient and an accurate data for analysis while respondents are flexible to fill information, the interruption costs questionnaire had adopted the questions from several literatures. The contents of survey questionnaire were designed into 5 parts as listed in Table 1.

3. THE STUDY RESULTS

In this section, interruption costs of four customer sectors provided from survey approach are presented. In each sector, the SCDF defined in (1) is developed to represent the average interruption costs associated with interruption duration. The definition of SCDF is similar to the CCDF but generally refers to a sector rather than entire customer mix. In contrast, the

Table 1: *Contents of survey questionnaire*

Part I	Respondent and organization information
	- Respondent name, position and contact information - Organization name, location, industrial category, operating voltage, electricity consumption
Part II	Manufacturing processes
	- Type of process, critical processes, process recovery time, information about finished products, raw material, working time and working day
Part III	Components of customer interruption cost
	- Overtime payment, machine and equipment damage cost, scraped products and raw material cost, process recovery cost, fuel cost for standby generation units, penalty charge for delayed delivery and profit loss
Part IV	Power supply system
	- Aging of power supply system, emergency power supply system, frequency of power supply inspection, interruption frequency and duration statistics
Part V	Costs of power interruption
	- Interruption cost in case unplanned interruption such as an accident, tree falling, animal and lightning - Interruption cost in case planned interruption such as maintenance activities, network system improvement

CCDF expressed in (2) is used to describe mixed customer interruption cost. It can be derived from the annual electricity consumption ratio and the SCDF of four customer sectors in interested area. The CCDF is normally proposed for reliability

$$SCDF_s(t) = \frac{1}{m}\sum_{i=1}^{m} IC_i(t) \qquad \text{(Baht/event)} \quad (1)$$

$$CCDF(t) = \sum_{s=1}^{S} SCDF_s(t) \times W_s \quad \text{(Baht/event)} \quad (2)$$

where $IC_i(t)$ is the interruption cost for respondent i at interruption duration of t, m is the number of respondents in sector s, W_s is the weighting ratio of electrical consumption in each sector and S is the number of sector.

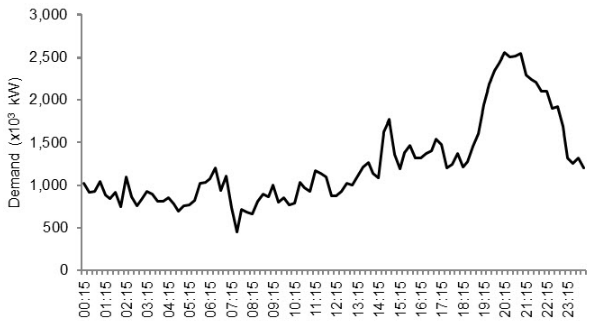
3.1 The interruption costs survey from residential customers

Although residential customers are generally able to report the actions during interruptions, they have difficulty quantifying the value of interruption cost. The load profile in Fig. 2 shows that an interruption event directly impacts to interruption costs especially peak demand periods. The survey responses from residential customers were aggregated to develop residential SCDF as shown in Fig. 3. The CDF for residential customers are the same as their ICDF as there are no other sub-groups [10]. The expected customer interruption cost for the residential sector, therefore, remains unchanged in the different customer composition considered for the load point or feeder level. However, the residential scale is still significant different to the customer interruption cost. For instance, the interruption costs at the duration of 60 minutes are 3.8788 and 161.4246 Baht per event for small and large residential customers, respectively. In addition, interruption costs for residential customers are also presented in term of Willingness to Pay (WTP) and Willingness to Accept (WTA).

WTP: Customers are asked to state the maximum of acceptable level that they would like to pay to the electric utility for avoiding the planned interruption;

WTA: Customers are asked to state the minimum amount of compensation that they would require to be indifferent interruption to suffering the specific interruption.

Over 3,000 respondents in survey, WTP and WTA are 5.4% and 8.6% of electricity unit price, respectively.



Source: Load profile study in PEA service area (2009)

Fig.2: *Load profile of small residential sector*

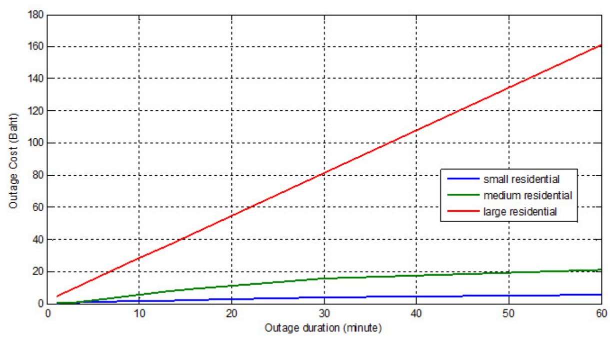


Fig.3: *SCDF of residential sector*

3.2 The interruption costs survey from commercial and industrial customers

To formulate SCDF under tariff structure, interruption costs of commercial and industrial customers (C&I) are aggregated into three categories that consist of small business, medium business and large business, respectively. The SCDF of C&I from 2,590 customers provided from survey approach is shown in Fig. 4. The results imply that large scale business of commercial and industrial customers are dominated. The operating time of production line in small industrial customer is less than 12 hours per day while the large industrial customers have an operating time from 16-24 hours per day. Thus, the risks and impact levels of large business sector are normally higher than small and medium business sector.

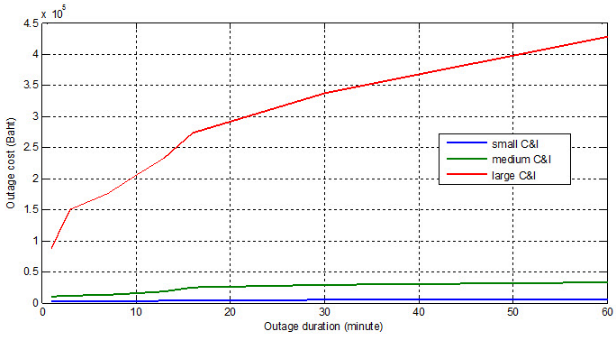


Fig.4: *SCDF of commercial and industrial sector*

3.3 The interruption costs survey from specific business

In this study, the hotel, one of the most competitive sectors in Thailand, is represented as the specific business in electricity tariff. The hotel sector had an overall 5% contribution to the nation gross domestic product (GDP) in 2010. Not only providing room services, seminar facilities and restaurants are included in the facilities. Power interruption issues can causes booking and reservation system failure, client without electricity, safety system out of service, cancellation of meetings, receptions, and conferences. This results directly in loss of clientele and damages the hotel's reputation. It is essential for services with reliable power supply to operate smoothly for comfort, efficiency and value. In this study, the SCDF of specific business sector obtained from 52 sampled hotels is illustrated in Fig. 5. It reveals that the hotel will be affected after interruption duration of 15 minutes. The interruption costs at the duration of 60 minutes are estimated with 6,187.38 and 32,087.76 Baht per event for small and large scale hotels, respectively.

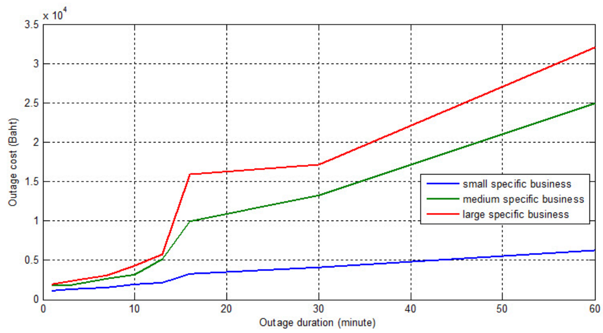


Fig.5: *SCDF of specific business sector*

3.4 The interruption costs survey from government, institutional and non-profit organizations

The government, institutional and non-profit organizations in the survey includes schools, colleges, government buildings, district administration offices. In addition to the mailings survey questionnaire, customers also received permission letter in order to release the record of their organization's consumption history. It was sent to representatives in the organization. The results of customer survey show that most of customers in the sector work with 8-hour in daily and use the electricity less than 250,000 kWh per month. In general, impacts of power interruption are intangible values. However, the approximated interruption costs from the customer perspectives are not widely different. The SCDF from government representatives can be estimated as shown in Fig. 6. At duration of 60 minute, interruption costs are 4,062.98, 5,589.49 and 5,901.79 Baht per event for small, medium and large scale customer.

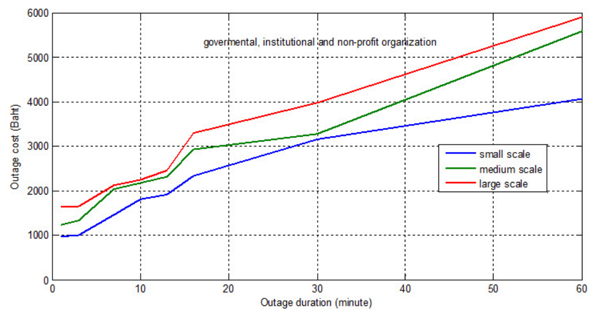


Fig.6: *SCDF of government and non-profit organizations*

In this study, SCDF in each customer sector is developed based on monetary losses per event of interruption. However, some applications such as reliability indices target setting (SAIFI, SAIDI) or load shedding scheme prefer to utilize customer cost with respect to performance of each activity. Therefore, SCDF normalized with peak demand (Baht/kW-peak) is also established. Fig. 7 illustrates SCDF of four customer sectors based on monetary losses normalized with peak demand that each sector is classified by three scales.

3.5 The Composite Customer Damage Function (CCDF)

Although reference [11] indicated that generating a CCDF can be obtained at many points within the electrical power network depending on the intended applications. This paper considers the interruption costs of PEA and large regions which divided into four service areas. The results of SCDF of residential, general service, specific business and government sectors provided from previous section are weighted with

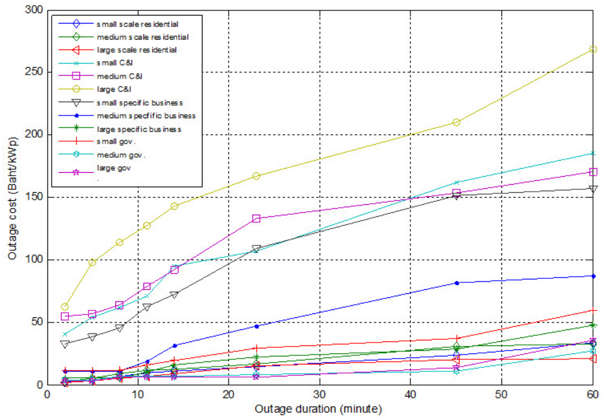


Fig.7: *SCDF expressed in Baht/kW-peak*

electrical energy consumption to obtain the CCDF. The weighting factors for different customer sectors of four regions in PEA service area are listed in Table 2. Weighting factors of each sector depend on number and characteristic of customers which can be varied on interested or specific area. The CCDFs in the units of Baht/event and Baht/kW-peak obtained by SCDFs and weighted by electrical energy consumption are shown in Fig. 8 and 9, respectively. Due to high energy consumption in general service sector especially in large scale industrial and commercial customer, the CCDF for central area is higher than CCDF of PEA and other areas. In this region, the large scale customers contribute 57.2% of total electricity consumption. In contrast, the CCDF for northeastern area is lower than other areas since the high portion of electrical energy consumption is in residential sector, the sector which has lowest impact from power interruption. If customer average interruption duration is estimated by a half-hour per event, the customer interruption cost of PEA are 264,118 Baht/event and 120.01 Baht/kW- peak, respectively. The primary applications of CCDF are related to utility operating and planning activities. For power distribution reliability planning under financial and investment constraints, the results of CCDF in four PEA service areas can be concluded that the electric networks in central area should be set as the first priority for improving the system reliability when considering reliability cost evaluation from customer point of view. In addition to the results of CCDF, information about number of industries shows that over 37 of 45 industrial estates under the Industrial Estate Authority of Thailand (IEAT) and private investor's management are fully operated in the central area. Therefore, strategic planning of power system distribution in regional level should be focused in the key important customer area especially in industrial estates. However, other important or relevant factors for making a decision in network reliability improvement such social and economic benefits should be addressed in practical planning.

Table 2: *Proportional electrical energy consumption of customers under regional service area of PEA*

Sector	Size	North	Northeast	Central	South	PEA
Residential	Small	0.149	0.215	0.025	0.104	0.082
	medium	0.108	0.102	0.044	0.113	0.073
	large	0.063	0.052	0.054	0.077	0.059
General service	Small	0.130	0.127	0.057	0.112	0.086
	medium	0.150	0.141	0.199	0.190	0.183
	large	0.270	0.227	0.572	0.258	0.426
Specific business	Small	0.002	0.001	0.001	0.002	0.001
	medium	0.019	0.014	0.015	0.044	0.021
	large	0.004	0.002	0.007	0.019	0.030
Government	Small	0.054	0.058	0.012	0.042	0.030
	medium	0.044	0.048	0.013	0.034	0.026
	large	0.004	0.009	0.001	0.005	0.003
Other*		0.003	0.004	0.000	0.000	0.002

Note:* the other sectors are not considered for this study

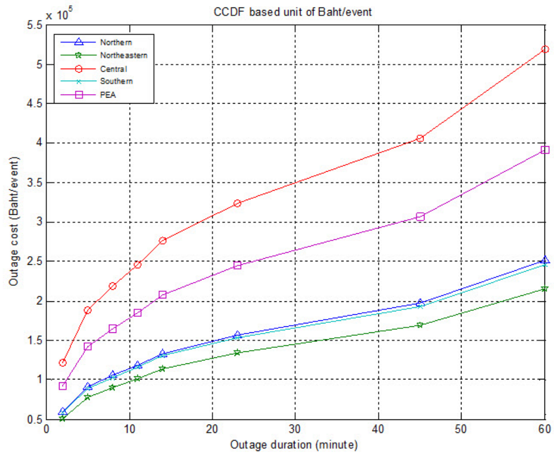


Fig.8: *CCDF (Baht/event) for PEA service area*

3.6 Reliability cost evaluation in industrial estate area

As the present status of Thailand power system, the main utility of generation and transmission systems is able to supply electricity with an adequate capacity and network security while the two electric utilities of distribution systems are able to deliver electricity to their customer with a specific reliability level. Although most utility planning for distribution system is still performed based on tradition approach, however, investment for numerous projects attempt to adapt customer interruption cost as one of the concerned factors. Since the industrial customer sector is sensitive to both interruption frequency and duration, and consequence, the losses are relative to high monetary value when compared with the other sectors. In addition to the estimation results in reference [12] that the macroeconomics impact from power interruption of large scale industries in Thailand was assessed, therefore, this section particularly intends to assess monetary losses of industries located in the

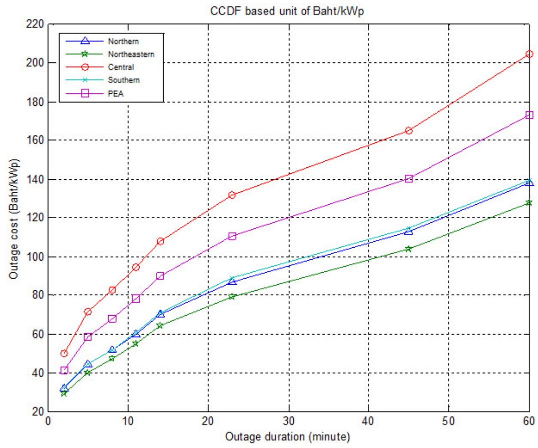


Fig.9: *CCDF (Baht/kW-peak) for PEA service area*

industrial estate from power interruption in order to investigate customer impact in the level of microeconomics. Similar concept to calculate SCDF is applied to estimate customer interruption cost for industrial estate. The reliability cost evaluation of distribution feeders and electric substations in industrial estate is presented. As common used for assessing customer reliability indices, the expected cost of interruption ($ECOST$), the energy not supplied (ENS), the interrupted energy assessment rates ($IEAR$) and the interruption cost per event ($ICPE$) are determined. The $IEAR$ is one of the common reliability cost factor to represent the adequacy of power system while ENS is the commonly used as severity index. The $IEAR$ can be evaluated by suitably combining the customer damage functions with the probabilistic reliability calculation [13]. It is a factor that aggregates monetary costs incurred by customers for each unit of unsupplied energy due to electric power interruptions while $ICPE$ is proposed to represent the average of customer impact based on an event of interruption or outage. According to functional zones of power system that divided into three hierarchical levels (HL), several approaches are used to evaluate the $IEAR$ for generation system (HLI), generation and transmission or composite system (HLII) and overall electric power systems (HLIII) [14-19]. To calculate the $IEAR$ in each hierarchical level, well database system of each electric utility to collect and evaluate the system performance is required. For instance, the basic reliability indices in a distribution system for assessing past performance and future performance target of system components including the average annual interruption time (U), the failure rate (r) and the average duration of failure (r) must be obtained. However, the electric distribution utilities without sufficiently collecting these data will not be able to reasonably evaluate the reliability indices. This section is extended the concept of $SCDF$ and $CCDF$ development from previous section for assessing reliability cost indices of industrial area in term of $ENS, ECOST, IEAR$ and $ICPE$, respectively. Calculation procedures in the study are similar concept of reference [20] which is performed based on actual interruption statistics instead of system reliability indices. The proposed concept allows utility planners to make a decision relating investment options under value-based reliability planning (VBRP).

In the selected industrial area, there are three electric substations which supply electricity for over 250 factories. Each electric substation contains with ten main distribution feeders. Fig. 10 illustrates information about power demand during peak period and light load period for all main distribution feeders. It can imply that most of factories utilized electricity for full operation in the off peak tariff rate. In general, electricity for industrial area is provided from high reliability sources; however, the events of interruption as shown in Fig. 11 were occurred in the study area from several causes including system operations, equipment failures, animals and unknown reasons. In the data analysis, the system operating information over the year 2010 was obtained from distribution utility. A sustain interruption with duration time from 1 minute were collected while the statistics from reclosers operation are not included in the calculation. The following procedures are used to estimate the ENS, $ECOST$, $IEAR$ and $ICPE$ at each feeder and electric substation:

Step 1. Develop SCDF of industrial sector based on substation level using (3) and normalize the value into Baht/kW with average power of each industrial scale. The results of $SCDF$ for industries under substation level are shown in Table 3.

$$SCDF(t) = \sum_i ICDF(t) \times w_i \qquad (3)$$

where w_i is the weighting factor of electrical energy consumption classified by industrial scale i (small scale, medium scale and large scale industries).

Step 2. Consider actual interruption data in each feeder comprising lost load P (MW) and interruption duration t (hours). Calculate feeder interruption cost (FIC) at the interruption duration from $SCDF(t)$ in Table 3 by using interpolation method. The $ECOST$ of feeder f at interruption event n can be expressed in (4). Based on the period of interruption statistic, the total $ECOST$ of feeder f can be aggregated by (5).

$$ECOST_{f,n} = FIC_n \times P_n \qquad (4)$$

$$ECOST_f = \sum_n^j ECOST_{f,n} \qquad (5)$$

Step 3. Calculate $ENS_{f,n}$ from the interrupted load P and duration t and determine total ENS of feeder f in interested period as defined in (6)

$$ENS_f = \sum_{n}^{j} ENS_{f,n} = \sum_{n}^{j} P_n \times t_n \qquad (6)$$

Step 4. Evaluate $IEAR$ and $ICPE$ based on the actual interruption event by using (7) and (8), respectively.

$$IEAR = \frac{ECOST_f}{ENS_f} \qquad (7)$$

$$ICPE = \frac{ECOST_f}{j} \qquad (8)$$

where j is the total interruption event under calculation period.

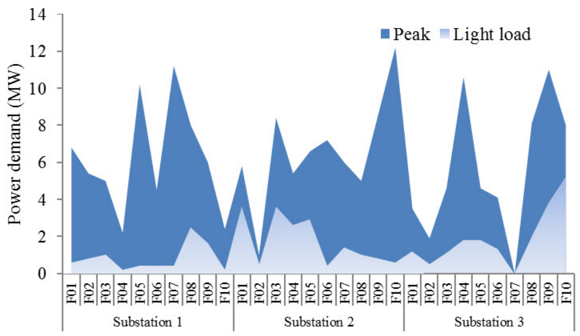


Fig.10: *Peak and light load for three electric substations*

Table 3: *Industrial customer damage function of selected industrial estate at the electric substation level*

Substation	Interruption duration (minute)				
	1	5	10	30	60
	(Baht/event)				
Substation 1	193,276	282,084	339,844	577,827	670,425
Substation 2	271,928	425,820	494,665	773,627	1,073,980
Substation 3	170,512	242,998	266,664	485,041	601,346
	(Baht/event)				
Substation 1	81.51	118.54	143.68	247.43	285.58
Substation 2	93.58	145.42	169.42	265.89	367.62
Substation 3	99.55	139.03	153.99	280.63	345.67

The $SCDF$ in Table 3 shows that the interruption event impacts to industries since short duration. According to actual interruption statistics in Fig. 11, the reliability cost indices represented as $ECOST, ENS, IEAR$ and $ICPE$ at electric substation level can be estimated as shown in Table 4. The total industrial customer interruption cost is about 48 million Baht during interested period. The results of survey also show that over 80% of total electricity consumption in the study area was utilized in

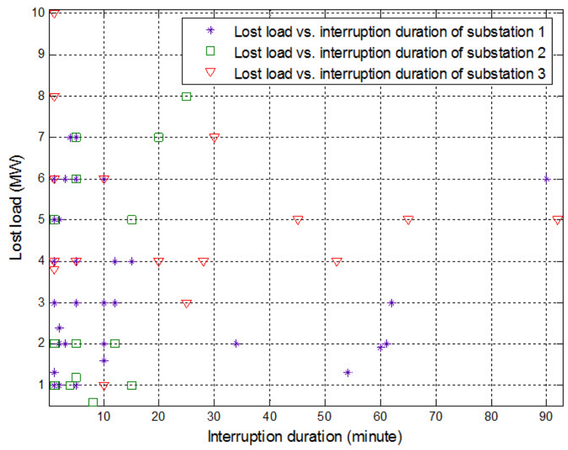


Fig.11: *Relationship between actual performance comprising lost load and interruption duration of interested area*

the large scale manufacturing processes. At the distribution feeder level, the calculation results of each feeder for three electric substations can be obtained as shown in Table 5. The $IEAR$ in (7) indicates that the variable of interrupted load P is not directly affected to the $IEAR$. In contrast, interruption time significantly impacts as the relationship between $SCDF$ and duration time. In addition, the total ENS is relative to the $ICPE$. In order to improve customer service satisfaction, the distribution utility can be applied the assessment results as the customer factor for operation and reliability planning. For instance, the $ICPE$ can be used as the strategic investment indicator for preventing the interruption. The higher value $ICPE$ at feeder F06 and F09 of electric substation 2 and F05 and F09 of substation 3 indicate that reliability improvement measures to eliminate interruption should be defined. Further, the $IEAR$ can be applied for customer restoration strategy. When an interruption is occurred, the distribution operators may set the feeders 4 and feeder 5 of substation 1, feeders 3 and feeder 8 of substation 2 and feeder 8 of substation 3 as the first priority for the sequential restoration procedure.

Table 4: *Reliability cost indices at electric substation level of the selected industrial estate area*

Substation	$ECOST$ x10^6Baht/year	ENS (MWh/year)	$IEAR$ (Baht/kWh)	$ICPE$ (Baht/event)
Substation 1	20.3	28.84	706.09	452,501
Substation 2	8.5	9.23	927.34	570,621
Substation 3	19.2	30.78	624.31	835,483

4. DISCUSSIONS AND RECOMMENDATIONS

Reliability cost indices in the study are represented by $ECOST, ENS, IEAR$ and $ICPE$ which obtained

Table 5: *Feeder reliability cost indices of the selected industrial estate area*

Feeder	ENS (MWh/year)	$ECOST$ Bath/year	$IEAR$ (Bath/kWh)	$ICPE$ (Baht/event)
Substation 1				
F01	3.00	4,796,633.06	1,598.88	811,524
F02	0.33	287,357.20	862.07	373,640
F03	1.7	1,952,621.33	1,115.78	405,330
F04	0.10	281,562.30	2,815.62	180,235
F05	0.91	2,410,025.74	2,638.71	440,759
F06	15.46	4,455,870.26	288.25	762,589
F07	0.10	204,646.00	2,046.46	132,931
F08	-	-	-	-
F09	3.00	3,129,645.93	1,043.22	683,215
F10	4.18	2,844,218.43	679.89	725,938
Substation 2				
F01	-	-	-	-
F02	-	-	-	-
F03	0.08	467,908.50	5,614.90	492,500
F04	0.18	285,279.60	1,584.89	154,128
F05	-	-	-	-
F06	1.83	2,014,211.90	1,098.66	1,120,191
F07	0.42	494,774.80	1,187.46	274,247
F08	0.12	426,162.00	3,652.82	152,990
F09	6.17	4,330,785.99	702.29	1,610,190
F10	0.43	540,195.13	1,246.60	296,100
Substation 3				
F01	-	-	-	-
F02	1.25	752,586.43	602.07	803,010
F03	-	-	-	-
F04	-	-	-	-
F05	3.50	1,964,410.00	561.26	2,062,340
F06	0.17	153,990.00	923.94	186,820
F07	-	-	-	-
F08	1.40	1,895,046.67	1,353.60	728,122
F09	13.22	4,654,180.00	352.14	1,717,824
F10	11.25	9,795,912.57	871.01	723,722

Note: F07 of substation 3 is the feeder for redundant circuit. There are no interruption for F08 of substation 1, F01, F02, F05 of substation 2, F01, F03, and F04 of substation 3.

from two databases. The $ECOST$ is provided by $SCDF$ or $CCDF$ which directly impact from the reliability of customer survey results. The major limitation in applying $SCDF$ and $CCDF$ are mostly due to inaccuracies of the cost function. The estimates of customer predictions for their losses are very subjective. The survey data collected from one utility may not be applicable to other utilities. Fewer amounts of respondents in each customer sector contribute inaccuracy results of $SCDF$ and $CCDF$. For instance, the number of hotel and government sectors in the study should be more surveyed. In addition, understanding of interruption problem to all customer sectors can also enhance the validating customer survey data. Although most reliability of information is obtained from direct customer interview, however, some customer sectors distributed in a wide area are very difficult to interview. The appropriate approach for data collecting is achieved from post-mail. The responded information must be performed data validating. Another issue that the planner should concern is interruption records between customer and utility perspective. The ENS is derived from interrupted load and duration that is normally collected from utility database. If the measurement interruption system is inadequate, the interruption is recorded by manual operation which results may sometime provide inaccurate information.

5. CONCLUSIONS

This paper has presented the formulating composite customer damage function which is proposed to apply in regional service area relating reliability planning. Customer interruption costs based survey approach is collected to develop ICDF, SCDF and CCDF respectively. In addition, the industrial customer damage function in industrial estate and actual network performance indices (customer lost load and interruption duration statistics) are determined to evaluate the reliability worth indices comprising $IEAR$ and $ICPE$. Due to reliability worth is assessed in distribution system of industrial estates area, the results of calculation both in substation and feeder levels can be applied as a user-observable parameter in various fields of reliability planning including network configurations, maintenance policies or schedules, modifying load shedding and restoration sequences, operating policies and emergency strategies. Furthermore, the reliability cost study is extended to use in constructing new or expanding the existing distribution system for achieving effectiveness both socio-economic and engineering point of views.

References

[1] R. Billinton, "Evaluation of reliability worth in an electric power system," *Reliability Engineering and System Safety*, Vol. 46, pp. 15.-23, 1994.

[2] E. P. Raesaar, J. E. Tiigimagi and J. Valtin, "Assessment of electricity supply interruption costs under the restricted time and information resources," *Proceeding of International Conference on Energy & Environment Systems (IASME/WSEAS 2006)*, pp. 409-415, 2006.

[3] "Electricity Interruption Cost Study," http://www.eppo.go.th/power/ERI-study-E/ERI-ExeSummary-E.html, 19 November 2005.

[4] Z. Bozic, "Customer interruption cost calculation for reliability economics: practical considerations," *Proceeding of International Conference on PowerCon 2000*, Vol. 2, pp. 1095 - 1100, 2000.

[5] L. Goel and R. Billinton, "A procedure for evaluating interrupted energy assessment rate in an overall electric power system," *IEEE Transactions on Power Systems*, Vol. 6, No. 4, pp. 1396-1403, 1991.

[6] Math H. J. Bollen, *Understanding Power Quality Problems: Voltage Sags and Interruptions*, IEEE Press (Power Engineering Series), 2000.

[7] R. Billinton, G. Wacker and E. Wojczynski, "Comprehensive bibliography on electrical service interruption costs," *IEEE Transactions on*

Power Apparatus and System, Vol. PAS-102, No. 6, pp. 1831-1837, 1983.

[8] G. Tollefson, R. Billinton and G. Wacker, "Comprehensive bibliography on reliability worth and electrical service consumer interruption costs: 1980-90," *IEEE Transactions on Power System*, Vol. 6, No. 4, pp. 1508-1514, 1991.

[9] R. Billinton, G. Wacker and G. Tollefson, "Assessment of reliability worth in electric power systems in Canada," Final Report for NSERC Strategic Grant STR0045005, June 1993.

[10] R. Billinton, S. Ali and G. Wacker, "Rural distribution system reliability worth evaluation using individual customer interruption cost characteristics," *International Journal of Electrical Power & Energy Systems*, Vol. 26, pp. 235-240, 2004.

[11] G. Wacker and R. Billinton, "Customer cost of electric service interruptions," *Proceedings of the IEEE*, Vol. 77, pp. 919-930, 1989.

[12] N. Uthathip, P. Teansri, P. Bhasaputra and W. Pattaraprakorn, "Development Industrial Outage Cost Model by Adaptive Neuro-Fuzzy Part II: Evaluation Outage Cost of High Energy Consumption Industry," paper No. E-44, *Proceeding of the 5th GMSARN International Conference on Sustainable Development and Climate Change: Challenges and Opportunity in GMS*, Luang Prabang City, Lao PDR, 17-19 November 2010.

[13] R. Billinton and R. N. Allan, *Reliability Evaluation of Power Systems.* Pitman Books, New York/London, 1984.

[14] P.L. Noferi , L Paris and L Salvaderi, "Monte Carlo methods for power system evaluation in transmission or generation planning," *the Annual Reliability and Maintainability Symposium*, 1975.

[15] L. Salvaderi and R. Billinton, "A Comparison between two fundamentally different approaches to composite system reliability evaluation," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-104, pp. 3486-3492, 1985.

[16] R. Billinton, J. Oteng-Adjei and R. Ghajar, "Comparison of two alternate methods to establish an interrupted energy assessment rate," *IEEE Transactions on Power Systems*, Vol. 2, pp. 751-757, 1987.

[17] J. Oteng-Adjei and R. Billinton, "Evaluation of interrupted energy assessment rates in composite systems," *IEEE Transactions on Power Systems*, Vol. 5, pp. 1317-1323, 1990.

[18] L. Goel and R. Billinton, "Evaluation of interrupted energy assessment rates in distribution systems," *IEEE Transactions on Power Delivery*, Vol. 6, pp. 1876-1882, 1991.

[19] L. Goel and R. Billinton, "Determination of reliability worth for distribution system planning," *IEEE Transactions on Power Delivery*, Vol. 9, pp.1577-1583, 1994.

[20] B. Eua-arporn, "Fuzzy interrupted energy assessment rate based on actual system performance," *IEEE Transactions on Power Systems*, Vol. 20, pp. 156-163, 2005.

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