Development Industrial Interruption Cost Model by Adaptive Neuro-Fuzzy System
Part II: Evaluation Interruption Cost of High Energy Consumption

P. Teansri, N. Uthathip, P. Bhasaputra, and W. Pattaraprakorn

Abstract— *According to development interruption cost model of industrial customer which explained in part I of this article, this paper presents the sector customer damage function (SCDF) of industrial sector providing high contribution of gross domestic production (GDP) including food, beverage and tobacco industry (TSIC31), textile industry (TSIC32), petrochemical and chemical products industry (TSIC35) and fabricated metal products, machines and equipment industry (TSIC38). First, the contribution of GDP's industrial sectors in 2008 is reviewed. Second, the customer survey information including manufacturing processes and critical machines is summarized. Then, interruption cost models of the industrial sector are developed by adaptive neuro-fuzzy inference system (ANFIS). The SCDF of small scale, medium scale and large scale industries are investigated. Third, interruption cost is evaluated by using the data set of the designated factories which defined as the large energy consumer. The estimation represents the impacts in the level of macroeconomics point of view. The simulation results show that the interruption costs of large scale industries contribute the financial losses from 0.41%-1.49% of manufacturing's GDP. These results reveal that the interruption cost from industrial sector can affect to the contribution of manufacturing's GDP. The key factors to reduce the economic impact from interruption are the optimal management strategy on interruption frequency and duration especially in high density area of large scale industrial sector.*

Keywords— **Interruption cost, industrial customer, gross domestic production (GDP), adaptive neuro-fuzzy inference system.**

1. INTRODUCTION

Even the uncertainty situation of global economy, industrial sector from the countries around ASEAN including China, India, Vietnam and Thailand has been growing rapidly. For Thailand, the economic structure has transformed from a complete agriculture-based economy into more diversified economy. The industrial sector is one of the key successive players of nation economy. Several factors including fundamental infrastructures, facilities, human resources, logistic and government supports has been continuing developed for investment from internal and external investors. In 2008, the manufacturing sector was the largest economy contributor at 34.93% of Gross National Product (GNP). Modern power system as a part of fundamental infrastructure with requirement of high reliability from large scale customer plays important roles in the developing countries to enhance the growth of economy. In order to improve the system performance and expand the networks of electrical power system with least-cost planning, not only the planners require the investment cost which directly obtained from utility perspective, but information of customer cost and social benefits is also included during making a decision process. The interruption cost incurred from customer viewpoint provides challenges and opportunities for utility planners to set up alternative capital investments and optimal operating procedures that affect electrical power supply reliability and quality [1-4]. Numerous researches and practices in the interruption cost evaluation have been carried out. In general, the evaluation is first categorized into subgroups or sectors and the results are then calculated with the network reliability indices to obtain the interruption cost of nationwide scale. Since high contribution to country economic growth, industrial sector is one of the common target groups from both developed countries and developing countries to perform the interruption cost evaluation. In 2003, the United State of America, the world largest economy at that time, estimated losses arising from massive electric power blackout in the northeastern United States and Canada on August 14-15, was between US$ 26 billion to US$ 400 billion which excluded the power quality events [5]. For developing countries, the study focusing on the effects of power interruption in Pakistan estimated the direct costs of load shedding to 843 industries during 1987 and coupled with the indirect multiplier effects on other sectors. It resulted in 1.8% reduction of GDP and 4.2% reduction of the volume of manufactured exports. In India, the numerous sectors including pharmacy and biotech were evaluated the interruption cost with US$ 9.2 billion in 2008 caused by earthing, cabling and lack of viable infrastructures. Similarly, power rationing in Colombia was estimated to reduce overall economic output by 1% of GDP in 1992 [6]. In Nepal, 285 industries in 15 categories based on North American Industry Classification Standard (NAICS) were surveyed to identify scope for investment in system planning and reinforcement [7]. The outages result in an economic loss

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in Nepal's industrial sector amounting to US$ 24.7 million a year. This translates into 4.43% of the industrial sector GDP or 0.47% of the national GDP in 2001 [8]. For Bangladesh, the substantial economic loss from interruption is calculated in industrial sector amounting to US$ 778 million a year. This translates into 11.54% of the industrial sector GDP or 1.72% of the national GDP in 2000-2001[9]. In Nigeria, World Bank estimated the adaptive costs of electricity failure on the Nigerian economy at US$ 390 million, divided between consumer backup capacity (US$ 250 million), operating and maintenance cost of diesel auto-generator (US$ 250 million) and fuel and lubrication (US$ 50 million) [10]. In Korea, the customer interruption cost is taking into consideration of macro economy. The results of evaluation show that customer interruption cost of Korea as a whole is about 30-35 times the average revenue per electric energy sold [11]. In Sri Lanka, the economic loss of industrial sector associated planned and unplanned interruption was estimated in 2000/2001. Under 300 hours for planned interruption, the interruption cost were estimated to be in the range of US$ 47-117 million, which is 0.4-0.9% of the country's GDP in that year, while the loss from 100 hours for unplanned interruption was estimated to be US$ 30-58 million, which approximately 0.25-0.46% [12]. In Netherland, the reliability of the electricity supply during 1999-2004 was relatively high with SAIDI index of 30 minutes per year. This high level of reliability was from network improvements by installation 97% of the cables in underground system, reconfiguration network in mesh topology and using advanced system of safety facilities. The pricing power outage estimated in 2003/2004 showed the reliability cost of Dutch society for all households and SME firms at an about 48 million under one outage of two hours every four years [13]. In China, the impact of electric energy unserved of Shanghai was estimated a macroeconomic cost in 2006 by using Cobb-Douglas with 50.91×10^8 CNY, approximately 0.57% of the GDP [14].

In this article, the economic impacts from unreliable power supply of high energy consumed industrial sector in Thailand are simulated with actual performances of distribution utility. The paper is divided into 5 sections. The economic contributions in 2008 from 16 economic activities and from 9 manufacturing sectors have been reviewed in section 2. To illustrate the development results by using ANFIS concept in part I of this article, the customer interruption cost models of four industrial sectors contributed more than 10% of GDP are presented in section 3. To estimate unreliable cost incurred to industrial sector, the 3,521 large scale industries are examined to evaluate the interruption cost in a year. The results of calculation under three scenarios are obtained by customer interruption cost models with past performance indices comprising customer average interruption duration index and system average frequency interruption index, respectively. The financial loss from the power supply interruption in each scenario is compared to the GDP value and the results can be referred to macroeconomic impacts point of view.

Table 1. Gross National Product at Current Market Prices by Economic Activities in 2008 (Millions Baht)

No.	Economic Activities	Value	%
1	Manufacturing	3,169,629	34.93
2	Wholesale and Retail Trade; Repair of Motor Vehicles, Motorcycles and Personal and Household Goods	1,282,989	14.14
3	Agriculture, Hunting and Forestry	950,861	10.48
4	Transport, Storage and Communications	643,244	7.09
5	Hotels and Restaurants	437,705	4.82
6	Public Administration and Defence; Compulsory Social Security	400,439	4.41
7	Education	377,755	4.16
8	Financial Intermediation	350,290	3.86
9	Mining and Quarrying	314,823	3.47
10	Electricity, Gas and Water Supply	262,123	2.89
11	Construction	260,717	2.87
12	Real Estate, Renting and Business Activities	216,601	2.39
13	Health and Social Work	169,364	1.87
14	Other Community, Social and Personal Service Activities	123,294	1.36
15	Fishing	105,977	1.17
16	Private Households with Employed Persons	9,682	0.11
	Gross Domestic Product	**9,075,493**	**100**

Source: Office of the national Economic and Social Development Board, 2008.

Table 2. Gross Domestic Product Originating from Manufacturing at Current Market Prices (Millions Baht)

No.	Industrial sectors	Value	%
1	Fabricated Metal Products, Machinery and Equipment, Office, Accounting and Computing Machinery	1,181,348	37.27
2	Food Products and Beverages and Tobacco Products	566,079	17.86
3	Textiles, Wearing Apparel, Leather Products and Footwear	391,696	12.36
4	Refined Petroleum Products, Chemicals and Chemical Products	376,006	11.86
5	Funiture; Manufacturing n.e.c.	277,322	8.75
6	Rubber and Plastic Products 'Other Non-metallic Mineral Products	268,891	8.48
7	Paper and Paper Products Printing and Publishing	69,397	2.19
8	Basic Metals	26,669	0.84
9	Wood and Wood Products	12,221	0.39
	Total Value Added	**3,169,629**	**100**

Source: Office of the national Economic and Social Development Board, 2008.

2. ECONOMIC CONTRIBUTION BY SECTOR

In 2008, Thailand was directly affected from the global economic slowdown in the fourth quarter. Most of Thailand's economic indicators were high at the beginning of 2008, but they started declining in October. However, the economic indicator by gross national production (GNP) in Table 1 shows that manufacturing sector contributes the highest GNP sharing of 3,169,629 million Baht, which account for 34.93% of country's GNP. The gross domestic productions (GDP) growth rate of Thailand's industrial sector was 6.1% in the third quarter of 2008. To focus on the revenue from industrial sector, the GDP of nine industrial sectors are summarized in Table 2. The statistic data illustrates that the industries classified in fabricated metal products, machinery and equipment, office, accounting and computing machinery contribute the highest of GDP in manufacturing sector at 1,181,348 million Baht, account for 37.27% of GDP in manufacturing sector. Then the industries of food, beverages and tobacco products provide the GDP at 566,079 million Baht (17.86%) followed with manufacturing of textiles, wearing apparel, leather products and footwear by contributing the GDP at 391,696 million Baht (12.36%). The manufacturing of refined petroleum products, chemicals and chemical products contribute the GDP at 376,006 million Baht (11.86%). Four industrial sectors are provided at least 10% of the GDP from manufacturing sector.

Regarding high GDP's contribution, this paper is intended to investigate the economic impact of large scale industries under four industrial sectors from power supply interruption. The economic impact in this study refers to interruption cost which industry perceived in a year. First step, the data from industrial customers covering interruption cost and relevant data is collected. Then, the adaptive neuro fuzzy inference system (ANFIS) principle is introduced to formulate the interruption cost model. The summary of steps to develop the interruption cost model by ANFIS has been discussed in part I of this article. Next step, the interruption cost models of four industrial sectors are compared within the industrial group by three scales including small scale, medium scale and large scale industry. In addition, the customer survey data is also presented in each part of four industrial sectors. Finally, in order to calculate the impact of power interruption to the large scale industrial sector, the information of 3,521 factories under the Energy Conservation and Promotion Act which classified as the large energy consumers is used to estimate the interruption cost with three scenarios. The interruption cost in scenario 1 is assessed by using the overall actual performance of the provincial electricity authority (PEA) in 2008. In this case, the large industries are assumed in the PEA service areas covering inside industrial zones and outside industrial zones. In the scenario 2, interruption cost is calculated with the actual performance of electric utility in industrial areas. The scenario 3, interruption cost is assessed with the reliability criteria in power service standard. The financial loss from power interruption of 3,521 designated factories is compared to the GDP of manufacturing sector. Finally, the interruption cost rates of nationwide is calculated with the actual interruption statistics which provided from utility database.

3. SECTOR CUSTOMER INTERRUPTION COST FUNCTION

According to development concept of interruption cost by using adaptive neuro-fuzzy in previous article (Part I), the four input variables provided from customer survey are used to formulate the interruption cost model. The surveyed industries were classified based on the Thailand Standard Industrial Classification (TSIC). The data compiled from these surveys lead to the formulation of sector cost function, which refer as the sector customer damage function (SCDF). The SCDF presents the sector interruption cost as a function of interruption durations. The interruption cost associated with an interruption at any point in the system involved the combination of costs associated with all customer types affected by that interruption. In this paper, the SCDF of four industrial sectors which contribute the high sharing of manufacturing's GDP (>10%) is presented. In each SCDF model, the interruption cost is divided into three industrial scales. The summarized information from customer surveyed is discussed in each industrial sector.

3.1 Interruption cost model of food, beverage and tobacco industries (TSIC 31)

The food, beverage and tobacco industries (TSIC 31) is one of the top ten industrial sector which provided the value added for Thailand economy during a past decade. It contributes the GDP in manufacturing sector with 566,079 million Baht, account for 17.86%. The total energy consumption in this sector is 7,294 ktoe which the sharing of commercial energy and renewable energy are 26.90% and 73.10%, respectively. There are a variety groups in food, beverage, and tobacco industry. These include the factories related to food, meat, fruit, vegetable, grains, starch, ice, milk, dairy products, sugar, liquor, non alcoholic drinks or soft drink and feed products. Table 3 shows the number of surveyed respondents categorized in sub-group under food, beverage and tobacco industry.

Table 3. Respondents of industry in TSIC 31

TSIC	Type of food industry	Respondents	%
31149	Processed foods	65	20.00
31212	Ice making	37	11.38
31164	Food from flour	37	11.38
31181	Sugar	28	8.62
31220	Animal feeds	26	8.00
Other	Factories ralated to food manuafcturing	132	40.62

The average of SCDF which refers to interruption cost function of industries in TSIC 31 is shown in Fig. 1. In the survey of 325 industries, the average electrical energy consumptions are 1,070, 171 and 36 MWh per month for large scale, medium scale and small scale industry, respectively. Due to the raw materials to produce the food and beverage products distribute in the wide spread area, 80% of industries in TSIC 31 are located outside the industrial estates or industrial zones. The time which impacts to the industries after an interruption occurred is approximately 15 minutes. At that time, the interruption cost of large scale industries can larger up to 8.4 times and 15.2 times of medium and small scale industries, respectively. The reason to support the interruption cost model is the process characteristic of most industries in food and beverage especially in large scale industries are operated with continuous process. The sensitive machines including vary speed drive, relay, switching power supply and automatic control system may operate with malfunction during an interruption event. Therefore, most of large scale industries prepare a standby power supply system to serve the electrical energy for critical machines and equipment which can reduce the impact of an interruption. In addition, a standby power supply is utilized in safety reason for workers or employees in hazardous areas. Furthermore, most of industries which a backup supply system is not available in processes are classified in small scale industries and typically operate with average 8 hours per day while most of large scale industries run production lines with 16-24 hours per day. The time of day has also significant impact to the interruption cost as reported by industrial respondents in food and beverage industries. Interruption cost of small scale industries in regular office hours from 09:00-12:00 a.m. and from 01:30-06:00 p.m. is higher than night time. In contrast, the impact of large industries in the regular office hours is lower than night time because the measure of off-peak tariff rate improves energy utilization efficiency and shifts a peak load from the day time period into night time period.

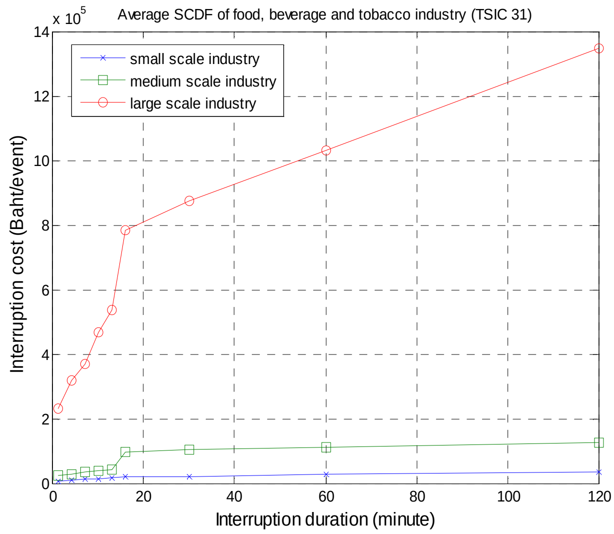


Fig. 1. Interruption cost of food, beverage and tobacco industries.

3.2 Interruption cost model of textile, wearing apparel, leather products and footwear industries (TSIC 32)

Regarding to the 3rd of largest manufacturing's GDP, industries in sector of textile, wearing apparel, leather products and footwear (TSIC 32) contribute the value of 391,696 million Baht of GDP in manufacturing sector, account for 12.36%. At the present, the number of manufacturing in this sector registered with the department of industrial work (DIW) is fully operated at approximately 5,217 factories. Trend of energy consumption in this sector is continuously increased for a last decade. However, the proportions of energy consumption are 9.11%, 7.03%, and 4.10% for the year of 1981, 2000 and 2008, respectively. During the year 2004-2008, the total energy consumption in textile industries varied in a range of 948-1191 ktoe which most of utilization provided from commercial energy. The sharing of electricity is largest portion with 60.78% of commercial energy demand, followed with solid fuel portion is 25.78%, liquid fuel portion is 12.64%, and natural gas portion is 0.80%. The number of respondents from customer survey in Table 4 shows that there are variety groups of products in textile industries. When considering manufacturing processes, the structures of textile industry consist of three manufacturing industries which are upstream industry, midstream industry and downstream industry.

The upstream industry is related to the natural and synthetic fiber manufacturing. In general, most of raw materials in synthetic fiber manufacturing including nylon, polyester, rayon and acrylic are provided from petrochemical industry. The textile industry classified as upstream manufacturing is required high investment in process equipment and machines. In addition, the energy consumption in this sector is relatively higher than midstream and downstream manufacturing. The simple flowchart of a melt spinning polymer from chip which is an upstream industry is shown in Fig. 2. During the power interruption, all processes are interrupted and the recovery time at least 2-3 hours is required for extraction the damaged material, cleaning, and restarting processes.

The midstream industry is related to factories weaving fabric, lace or apparel with yarn or fiber, or bleaching and dyeing or finishing of fabric, lace or apparel woven with yarn or fiber. The textile industry in midstream manufacturing can create the value added of products from upstream industry by 2-3 times before delivering raw materials to the downstream industry.

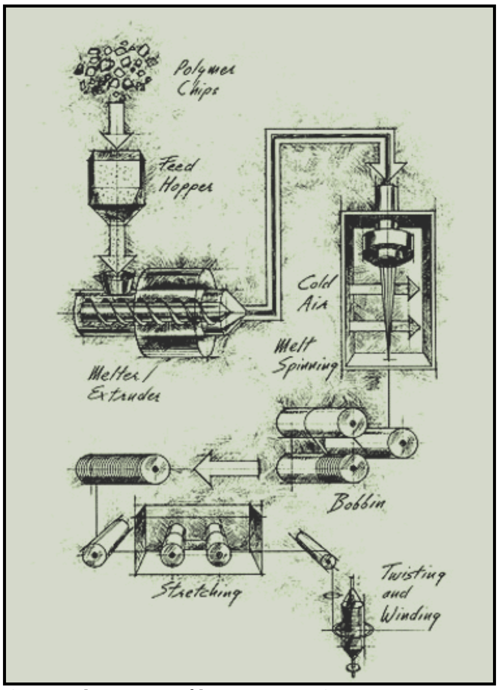
The downstream industry is related to apparel and clothing accessories factories which raw materials are provided from upstream and midstream industry, respectively. In general, the downstream industry is categorized in small to medium industry. The key driven factor to produce textile products is from a large number of employees. In addition, the machine and equipment to support the downstream processes is less sensitive to the power quality than upstream and midstream industry.

To investigate the industrial customer attitude about the cost and damages from power interruption, the data of 193 industries in textile industrial sector is collected in survey study. The number of respondents categorized as sub-group of TSIC 32 is shown in Table 4.

Table 4. Respondents of industry in TSIC 32

TSIC	Type of textile industry	Respondents	%
32115	Weaving, preparing warp-threads for weaving	38	19.69
32113	Spinning	19	9.84
32400	Shoes or parts of shoes	18	9.33
32202	Apparel	17	8.81
32120	Manufacturing products or parts of products	11	5.70
Other	Factories ralated to textile products	90	46.63

The results of survey for textile industries show that the average electrical energy consumption in the industries are 1,470, 172, 41 MWh per month for large scale, medium scale and small scale of textile industry, respectively. Considering the industrial location, the survey results illustrate that 60% of textile industries are located outside industrial area. In addition, 40% of industries install standby supply system. Most of these prefer a standby supply system to maintain the function of automatically critical machines. A backup supply capacity can serve the critical load approximately 5-10% of peak demand. Moreover, 60% of industries operated by continuous process with 24 hours a day, 7 days a week especially in upstream manufacturing industry. After the surveyed data is verified, the data set of input-output variables is assigned in the ANFIS to formulate the interruption cost model by ANFIS. The SCDF provided from ANFIS output which refers to interruption cost function of industries in TSIC 32 is shown in Fig. 3. The result of model development can conclude that the interruption cost of textile industry is sensitive to the scale of factory. During interruption duration from 5-15 minutes, the trend of interruption cost of large scale industry has seen a rapid increased in interruption cost.



(Source: http://www.fibersource.com)

Fig. 2. A sample flowchart of upstream manufacturing for textile industry (melted spinning polymer).

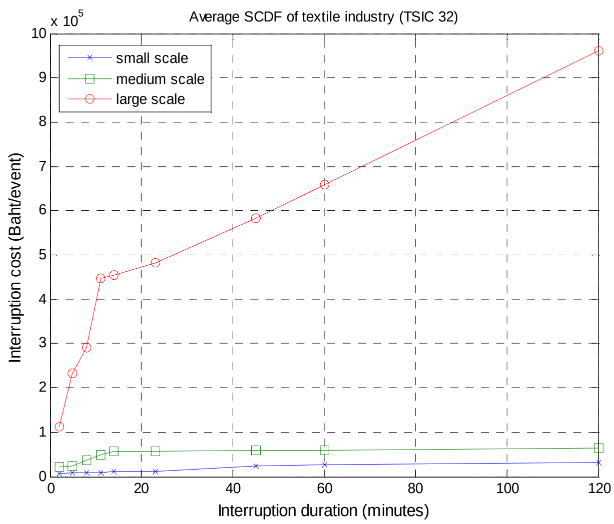


Fig. 3. Interruption cost of textile industries.

3.3 Interruption cost model of chemical, petrochemical and chemical products industries (TSIC 35)

Based on the large investment in the chemical, and petrochemical industries especially in eastern area of Thailand, this sector is the primary raw material for a numerous business opportunities. Most of chemical and petrochemical products are used in other major industries. The factories in this sector related to chemical products, chemical substances, chemical materials, fertilizers, synthetic resin, elastomer, plastic, medicines, soap, cosmetics, beautifications, petroleum refinery, tyre and rubber. In 2008, this industrial sector can contribute 11.86% of manufacturing's GDP, accounting value added of 376,006 million Baht. The total energy consumption in this sector is 2,059 ktoe which the sharing of commercial energy and renewable energy are 88.34% and 11.66%, respectively. The renewable energy sources consist of agricultural waste and fuel wood with share 36.67 and 63.33%, respectively. The commercial energy consumption in this year is 1,819 ktoe. The sharing of electricity is largest portion with 40.17% of commercial energy demand, followed with natural gas (27.05%), liquid fuel (19.08%) and solid fuel (2.04%), respectively. The results of survey data from 354 industries in TSIC 35 show that the average electrical energy consumptions are 1,286, 153 and 38 MWh per month for large scale, medium scale and small scale industry, respectively. About 58% of sampled industries located outside industrial areas. In addition, 55% of industries operated with continuous processes. Petroleum refinery plant is one of the businesses classified in continuous process since most of machines and equipment are sensitive to the power quality problems. In case of voltage dip, short interruption or sustain interruption, at least 6 hours to 24 hours is necessary for process recovery until product capacity is in normal level. In the study, a half of industry operated with 24 hours a day, which normally classified in large scale industry. The SCDF of industries in TSIC 35 provided from ANFIS is shown in Fig. 4. The economic impact from power interruption for large scale industry very differs from small scale and medium scale industry.

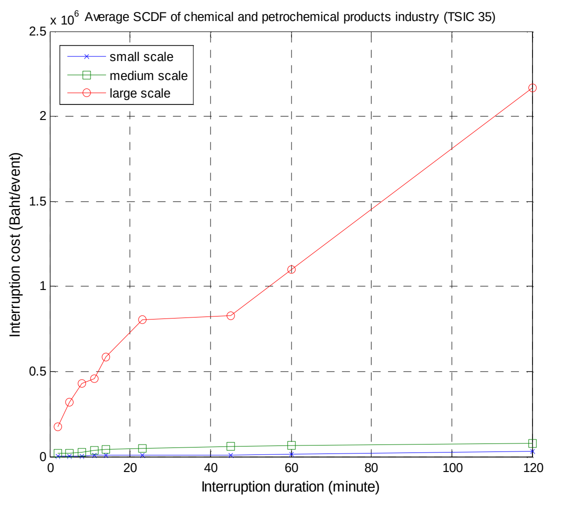


Fig. 4. Interruption cost of chemical, petrochemical and chemical products industries.

3.4 Interruption cost model of fabricated metal products, machinery and equipment, office, accounting and computing machinery (TSIC 38)

In this survey, the data of 652 companies in the TSIC 38 is used to develop interruption cost model by ANFIS principle. From total respondents, 174, 135 and 343 industries are classified in small scale, medium scale and large scale industry, respectively. There are several kinds of following businesses related to fabricate metal products, machine and equipment. Each factory may operate very differently from another. However, the major industrial groups under TSIC 38 are listed as follows:

- The industries related to automobile, automobile assembly and parts,
- The industries related to semiconductors and IC products,
- The industries related to computer peripherals, electronic parts and assembly, storage equipment, network equipment, power supplier, connector and electronic component;
- The industries related machinery assembly and equipment;
- The industries related medical and precision instrument.

Note that different industrial groups can be combined to form a larger group. The data from survey for industries in TSIC 38 can be concluded as follows; the average electrical energy consumption are 1,496, 152, 44 MWh per month for large scale, medium scale and small scale industry, respectively. The locations of 473 industries (72%) are situated in industrial areas, including industrial promotion zone, free trade area and industrial estates while 213 industries (28%) are located outside the industrial areas. For the production activity, the manufacturing of 453 industries is operated based on continuous process while 206 industries are batch process. It can imply that an interruption can contribute the losses of products and opportunities for the industries in TSIC 38, especially in continuous process industry. Based on the responses, 70% of industries operate without backup power supply and 35% of industries can be utilized standby power supply with only 5-10% of peak demand. From this point, improving productivity and reliability of industrial process can be achieved by installation a proper backup power supply system which the reliability cost and worth should be analyzed before investment. After performing data validation, the input data set from customer survey is assigned to develop the interruption cost model by ANFIS principle. The output of interruption cost model for industries in TSIC 38 is shown in Fig. 5.

The results from interruption cost model show that interruption duration is also significant impact to the industries. For example, the interruption cost of large scale industries in TSIC 38 is approximately 42.7 times and 91.0 times of the interruption cost of medium and small scale industries at the interruption duration of half an hour, respectively. The integrated circuit (IC) chips and semiconductor manufacturing processes are the examples of industries in TSIC 38 which installed high technology and sensitive machines and equipment such as CNC machines, robotics and automatic control system. In case of a sustain interruption or voltage dip, the customer damage cost in this industry can diverse vary from a few thousand to millions Baht since the expensive product value is definitely destroyed although an interruption duration is occurred in a short periods.

From SCDF of four industrial sectors discussed above, the issues of quality and reliability of power supply in modern power system should be addressed interruption costs in planning and decision making process. To illustrate the important of economic losses from industrial sector, the simulation of interruption cost evaluation based on large scale industry is presented in the next section.

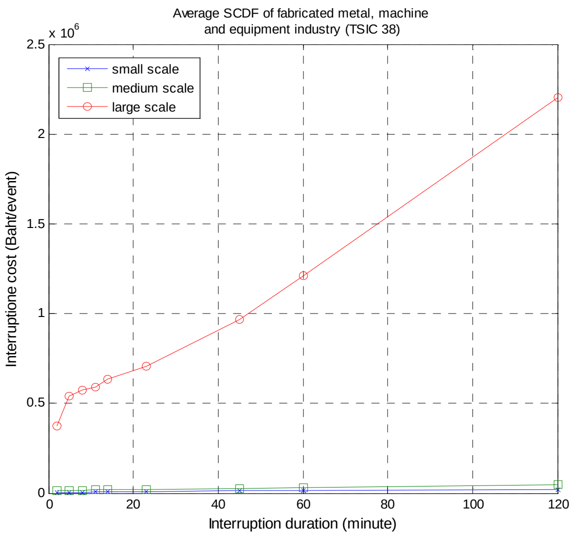


Fig. 5. Interruption cost of fabricated metal, machine and equipment industries.

4. EVALUATION INTERRUPTION COST OF HIGH ENERGY CONSUMPTION INDUSTRY

In order to evaluate interruption cost of the high energy consumption sector, the analytical approach is divided into two sub-sections. First, interruption cost models by ANFIS principle is applied with past actual performances of the electric distribution utility to calculate total interruption cost based industrial GDP's contribution. The estimation of industrial customer impact from power supply interruption can be implied to the macroeconomic point of view. Next, interruption cost rates of nationwide area are assessed to compare with industrial perspective. The results are obtained based on the event of interruption and the energy not supplied.

4.1 Interruption cost based industrial GDP's contribution

In fact, concerning of power quality and reliability of electricity in Thailand has been continuously improved to a better performance. For instance, the actual performance indices in term of the system average interruption frequency index (SAIFI), the system average interruption duration index (SAIDI) and the customer average interruption duration index (CAIDI) during 2005-2008 of PEA in Table 5 show that reliability level of electricity delivered to customers is developed. However, under complexity and uncertainty conditions of economic growth in Thailand, the reliability of power system should be emphasized in investment planning especially in distribution networks. In order to examine the economic impact from unplanned power interruption, the estimation customer interruption cost of high energy consumption industries are assessed. In this paper, interruption cost model of nine industrial sectors is developed from ANFIS principle. Four input variables of ANFIS system consist of electrical energy consumption, process characteristic, interruption duration time and process recovery time are employed from the utility database and customer survey. The interruption cost model of nine industrial sectors represented by SCDF is illustrated in Fig. 6.

Table 5. Actual performance indices of distribution utility

Year	SAIFI	SAIDI	CAIDI
2008	8.1	341.8	42.0
2007	11.3	508.2	44.9
2006	11.8	552.7	46.7
2005	12.0	630	52.5

Source: PEA annual report (2005-2008)

To analyze the national economic impact from interruption, 3,521 large scale industries in nine industrial sectors are calculated interruption cost based on ANFIS model. All of the large scale industries are designated factories according the Energy Conservation Promotion (ECP) Act. The criteria of factories in the Act that become designated factories are:

1. using a power meter; or installation the transformer for one or several sets in total of over 1,000 kW or 1,750 kVA;
2. using electricity from the distributor system; or heat from steam of the distributor; or depleted energy from energy supplier or of self-generation, either one of such those or the overall, since 1st January up to 31st December of the previous year and having of total energy consumption in term of electricity equivalent to over 20 TJ.

In this paper, the interruption duration and interruption frequency are obtained from actual performances including CAIDI and SAIFI of PEA in 2008, respectively. The calculation is divided into three scenarios. First, the financial losses of large scale industry based industrial's GDP is estimated under the actual performance of CAIDI and SAIFI indices of PEA. Second scenario is assessed based on CAIDI and SAIFI indices of the industrial area which the reliability is expected to be a high level and the third scenario is determined by using the CAIDI and SAIFI indices of industrial area according the criteria in power quality service standard. The results of economic impact analysis under three scenarios are presented in Table 6 to Table 8, respectively.

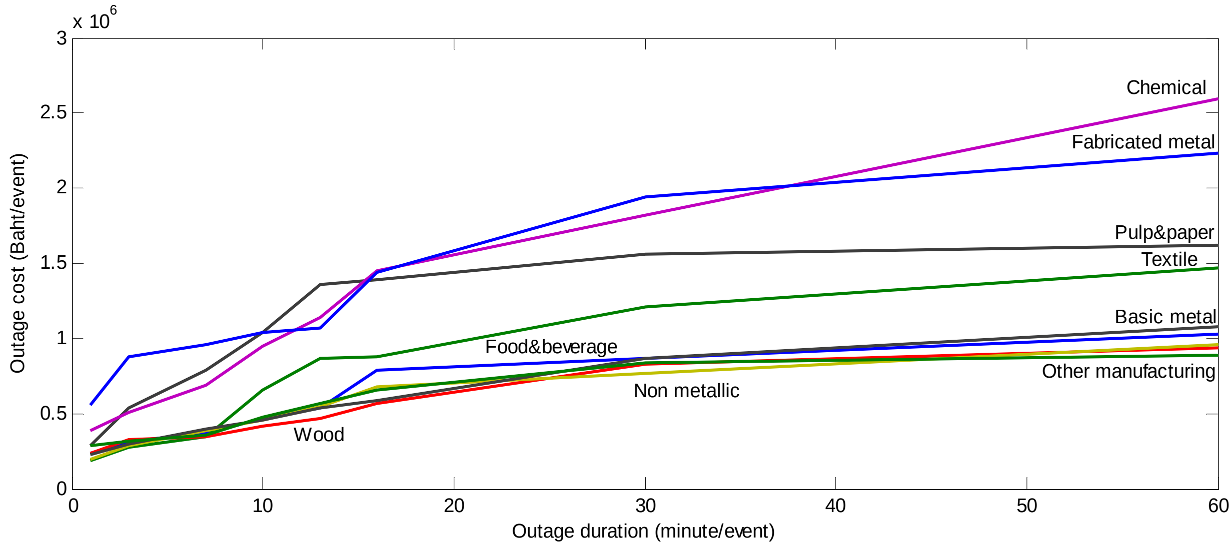


Fig. 6. The interruption cost models of large energy consumption for nine industrial sectors in Thailand.

Table 6. Interruption cost of high energy consumption industry under the SAIFI and CAIDI of PEA in 2008 (8.1 times/customer/year, 42 minute/event)

Industrial group	Number of designated industries	Interruption cost (million Baht/event)	Interruption cost (million Baht/year)
TSIC 31	727	725.5	5,905.6
TSIC 32	364	491.6	4,001.8
TSIC 33	105	94.3	767.9
TSIC 34	109	161.3	1,313.2
TSIC 35	756	1,632.4	13,288.1
TSIC 36	164	136.6	1,112.5
TSIC 37	215	217.5	1,771.0
TSIC 38	1,011	2,311.8	18,818.8
TSIC 39	70	61.4	499.8
Total interruption cost			47,479
The total interruption cost / GDP			1.49%

Table 7. Interruption cost of high energy consumption industry under actual SAIFI, CAIDI indices of industrial area in 2008 (2.69 times/customer/year, 26.46 minute/event)

Industrial group	Number of designated industries	Interruption cost (million Baht/event)	Interruption cost (million Baht/year)
TSIC 31	727	618.85	1,664.71
TSIC 32	364	421.93	1,135.00
TSIC 33	105	77.32	207.99
TSIC 34	109	171.98	462.62
TSIC 35	756	1,317.68	3,544.57
TSIC 36	164	123.42	332.00
TSIC 37	215	172.45	463.88
TSIC 38	1,011	1,828.22	4,917.90
TSIC 39	70	61.4	136.64
Total interruption cost			12,865.31
The total interruption cost / GDP			0.41%

Under the actual performance of distribution utility in 2008 with SAIFI index of 8.1 times per customer per year and CAIDI index of 42.0 minutes per event, the interruption cost of designated factories can be estimated by using the SCDF model. The calculation results are shown in Table 6. The total interruption cost under this assumption is 47,479 million Baht per year. The industries in fabricated metal, machines and equipment group (TSIC 38) have the highest interruption cost by 18,818.8 million Baht per year, account for 39.6% of total interruption cost in designated factories followed with the sector of chemical and petroleum products (TSIC 35) which the interruption cost 13,288.1 million Baht per year. In addition, the total interruption cost of designated factories is approximately 1.49% of the manufacturing's GDP. To compare the interruption cost with other scenarios, the interruption cost in Table 6 is used as the base case of interruption cost for large industrial customer.

Another scenario is calculated the interruption cost under the assumption that most designated factories located in the industrial estates or the areas which provide high reliability level of power supply. The actual performances in industrial areas (industrial estate, industrial promotion zone, free trade area) are replaced to calculate the financial losses. For industrial area, the SAIFI index in 2008 is 2.69 times per customer per year while CAIDI is 26.46 minutes per event. After applying the indices into the SCDF model, the total interruption cost of designated factories under this assumption is shown in Table 7. The total interruption cost of designated factories is 12,865.31 million Baht per year, account for 0.41% of GDP from manufacturing sector. When compare the interruption cost with the base case, this scenario provides the total interruption cost below the interruption cost from base case with 34,614 million Baht, which account for 72.9%. For the reliability perspective, if we assumed that most of large scale industries operated with continuous process and normally sensitive to the interruption frequency, the industry located inside an industrial area has a lower risk of financial losses compared with an industry located outside industrial area. Since the criteria of network design for industrial area is concerned about the high reliability of power supply, therefore, the financial losses from power supply interruption is one of the concerned factor for investor to make a decision about the location of their business.

Table 8. The interruption cost of high energy consumption industry under the SAIFI, CAIDI of industrial area according power quality service standard (4.85 times/customer/year, 49.02 minute/event)

Industrial group	Number of designated industries	Interruption cost (Million Baht/event)	Interruption cost (Million Baht/year)
TSIC 31	727	677.98	3,288.217
TSIC 32	364	511.45	2,480.56
TSIC 33	105	98.48	477.67
TSIC 34	109	173.92	843.54
TSIC 35	756	1,729.11	8,386.21
TSIC 36	164	142.60	691.62
TSIC 37	215	224.79	1,090.23
TSIC 38	1,011	2,219.05	10,762.41
TSIC 39	70	62.13	301.34
Total interruption cost			28,289.08
The total interruption cost / GDP			0.89%

Last scenario, the simulation applies the service quality standard which the electric distribution utility has been controlled. This standard has been identified that the SAIFI index for an industrial area is set at 4.85 times per customer per year while the CAIDI index is allowed to 49.02 minutes per event. The interruption cost evaluation of designated factories under the quality service standard can be calculated as shown in Table 8. Total interruption cost is estimated at 28,289 million Baht per year, account for 0.89% of the manufacturing sector's GDP. The total interruption cost in this case differs from the case of actual performance of distribution utility by approximately 40%. This implies that optimal industrial location is one of the important factors to enhance industrial performance. Based on calculation assumption, although the analysis of industrial customer impacts assumed that similar industrial processes or production lines should have a similar characteristics during power interruption, however, responses about interruption cost from actual customer survey may differ from an industry to the other industries. An industry may sensitive to interruption frequency or interruption duration while the others may face a great monetary loss from both interruption duration and frequency aspects. The major objective of this section intends to apply the ANFIS model to estimate the range of macroeconomic impact from power interruption. However, some variable inputs such as process characteristic and recovery time are defined according the results of customer survey data while the electrical energy utilization is assumed that all designed factories consume higher than 250,000 kWh/month.

The simulation results of interruption cost evaluation for 3,521 designated factories under three scenarios indicate that the issue of power quality and reliability is an important for planning and making the decision about system expansion and improvement. In addition, under the globalization and liberalization of international trade of goods, the investors prefer to locate their business on the high quality infrastructures. If the large scale industries are situated in the area of power supply with low reliability level. It can diverse affect to their business profits. Although the evaluation results in this study are emphasized for the sustain interruption. In fact, the actual customer damage costs include the impacts from various types of power quality problems. Therefore, the assessment the unreliable cost of power supply especially in industrial sector is important to enhance the benefits of customers, electric utilities and society.

4.2 The interruption cost rates of nationwide and industrial customer perspective

To illustrate the calculation of interruption cost rates of nationwide and compare with industrial perspective, the individual customer damage functions (ICDF) based on obtained survey data and TSIC category is first developed by using ANFIS principle. ICDFs can be compiled and calculated for the Sector Customer Damage Function (SCDF) by using customer category based on electricity tariff structure. Consequently, the Composite Customer Damage Function (CCDF) is formulated using SCDF for the customer mix at an interested nationwide area. In this example, the CCDF of nationwide from 1 minute to 120 minutes is estimated as shown in Table 9. Interruption cost rates divided into two units which based on interrupted event and energy not supply (ENS). The steps to calculate interruption rate of nationwide are:

Step 1: create ICDFs in the unit of Baht/event from ANFIS principle by using customer survey data.

Step 2: determine average SCDF(t) in the unit of Baht/event from ICDF(t) according industrial classification. Step 3: normalize SCDF(t) with respect to average demand of each customer sector (Baht/kW).

Step 4: multiply the proportional of electrical energy consumption in each customer sector with SCDF(t) to obtain CCDF(t) in the unit of Baht/kW

Step 5: calculate interruption cost rate based energy not supplied or Interrupted Energy Rate (IER) from Eq. (1)

Step 6: evaluate interruption cost rate based event called "Interruption Cost per Event (ICPE)" from Eq. (2)

Table 9. Estimated CCDF(t) of nationwide area

Duration (minute)	1	10	15	30	60	120
(Baht/kW)	44.6	89.0	139.1	190.0	239.0	440.5

$$IER = \frac{\sum_{j=1}^{n} CCDF(t_j) \times P_j}{\sum_{j}^{n} P_j \times t_j} \quad (1)$$

$$ICPE = \frac{\sum_{j=1}^{n} CCDF(t_j) \times P_j}{n} \quad (2)$$

where:

CCDF Composite Customer Damage Function, t_j is interruption duration of j[th] interruption,

P_j Estimated load loss of j[th] interruption, and

N a number of interruption during interested period.

Relationship between lost load and duration at the interruption j[th] in interested period is plotted in Fig. 7. The IER and ICPE of nationwide area are shown in Table 10. The IER is approximately 305.75 Baht/kWh while the ICPE is 252,414 Baht/event. It can be seen that the IER from customer perspective is very higher than utility perspective which estimates as electricity unit price (average of 3.11 Baht per kWh in 2010). Therefore, the IER is not compared in practical planning. The high value of ICPE is also related to the IER which industrial customer is the most sector affected to interruption.

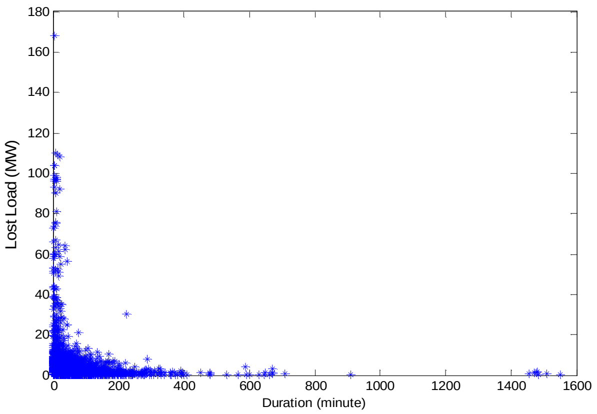


Fig. 7. Relationship between loss load and interruption duration statistic for interested nationwide.

Table 10. IER and ICPE of nationwide area

Interruption cost rate	IER (Baht/kWh)	ICPE(Baht/kWh)
Nationwide	305.75	252,414

In addition, the IER estimated from average monetary losses (Baht) and average energy not supplied (kWh) is obtained from customer survey. The IER is divided according industrial category and scale. The analytical results are shown in Table 11. It can be seen that scale of industry which derived from energy consumption relates to the IER. The IER of small scale industry is lower value than medium scale and large scale industry, respectively. Similarly, ICPE of industry obtained from customer survey in Table 12 implies that most of customer impact to the ICPE of nationwide is from large scale industry.

Table 11. IER based on obtained industrial customer survey

Industrial category	IER (Baht/kWh)		
	Small scale	Medium scale	Large scale
TSIC 31	125.85	188.22	393.99
TSIC 32	164.58	224.15	324.64
TSIC 33	168.39	206.01	181.64
TSIC 34	156.03	225.46	267.49
TSIC 35	134.17	201.36	335.81
TSIC 36	173.93	252.51	123.47
TSIC 37	155.48	207.03	78.05
TSIC 38	114.10	202.62	306.91
TSIC 39	135.83	201.71	328.79

Table 12. ICPE based on obtained industrial customer survey

Industrial category	ICPE (Baht/event)		
	Small scale	Medium scale	Large scale
TSIC 31	3,210.91	23,879.25	282,493.58
TSIC 32	2,883.71	18,745.40	245,513.64
TSIC 33	3,021.18	21,402.50	255,265.56
TSIC 34	3,278.09	23,312.38	234,997.84
TSIC 35	3,286.74	22,804.83	272,134.93
TSIC 36	3,408.50	17,385.92	218,426.30
TSIC 37	3,084.79	24,472.67	258,487.20
TSIC 38	3,308.75	22,896.89	270,139.94
TSIC 39	3,194.50	22,741.00	257,905.46

When compare the IER of nationwide in Table 10 which is calculated from mixed customer sectors and the IER in Table 11 provided from industrial customer survey, the results illustrate that the IER of nationwide (305.75 Baht/kWh) is in a range of the IER of large scale industrial customer (78.05-393.99 Baht/kWh). The IER of industrial customer perspectives is directly related with several factors including interruption cost model, electrical energy consumption and value added contribution of each sector.

5. CONCLUSION

The article demonstrates the analytical approach for interruption cost evaluation which estimated from ANFIS model. In this study, the industrial customer data collected from survey approach is used for building the interruption cost models. The ANFIS output can be transformed to obtain the sector customer damage function (SCDF). In the simulation, four industrial sectors which contribute at least 10% of the manufacturing sector's GDP are presented. The proposed model for four industrial sectors indicates that the industrial scale is significant factor to impact the interruption cost. In addition, 3,521 designated factories under the Energy Conservation and Promotion Act are used as the samples to estimate the financial losses from power supply interruption. The information of designated factories and actual performance data (SAIFI, CAIDI) are used to calculate the interruption cost with the SCDF in each sector. The simulation results show that the financial losses of the large scale industrial sector based on 3,521 designated factories is 1.49% of the manufacturing sector's GDP under the actual performance of SAIFI of 8.1 times/customer/year and CAIDI of 42 minutes/event. Moreover, the interruption cost can be reduced by 72.9% of base case under the actual performance both SAIFI and CAIDI for industrial areas. Further, interruption cost rates of nationwide area both the IER and the ICPE are assessed and compared with the value from industrial perspectives. In the nationwide area, the IER can be estimated with 305.75 Baht/kWh while ICPE is 252,414 Baht/event. The analytical results imply that interruption cost rates of nationwide are affected mainly on the large industrial sector. As the highest of energy consumer and national economic contributor, this study concludes that impacts of power interruption can decelerate GDP especially the large scale industrial area. Assessment financial loss from supply unreliability is an essential task for electric utility planners which the value added and economic growth of country can be enhanced.

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