Outage Cost of Industries in Thailand by Considering Thailand Standard Industrial Classification

P. Teansri, R. Bhasaputra, W. Pattaraprakorn, and P. Bhasaputra

***Abstract*— *The aim of this paper is to evaluate the planned and unplanned outage cost of the industries in Thailand by considering Thailand Standard Industrial Classification (TSIC). In this study, the 825 surveyed industrial data is collected to represent the outage cost in terms of Baht/event, Baht/kWh and Baht/kW$_p$. In addition, the impact factors such as employee overtime, defected product, machines and equipment damage and etc. are also determined in percentage of outage cost. The results of surveyed data indicate that above half of industries operate the equipment and machines longer than ten years and one-third of industries work without the emergency power system while the industries with the emergency power system has the average capacity only 14.4% of total demand. The analytical results show that the average planned outage costs are 140,444 Baht/event, 74.94 Baht/kWh, and 16.23 Baht/kW$_p$, whereas the average unplanned outage costs are 651,383 Baht/event, 308.41 Baht/kWh, 68.47 Baht/kW$_p$, respectively. Moreover, the highest unplanned outage cost found in the non-metallic mineral industries with the average outage cost of 1,396,680 Baht/event while the lowest unplanned outage cost found in wood and wood products industries with the average outage cost of 216,042 Baht/event. The textile and wood products industries have the highest outage cost in term of energy not supplied that are 387.36 Baht/kWh and 96.80 Baht/kWh for unplanned outage and planned outage, respectively. The pulp, paper and paper products industries have the highest outage cost in term of peak demand that are 92.05 Baht/kW$_p$ for unplanned outage cost and 23.62 Baht/kW$_p$ for planned outage cost. Furthermore, the factor of defected product has the highest percentage of outage impact factors that is 18.9% approximately. Finally, the unplanned outage cost per event from industries' view point can be decreased up to 90% when the optimal outage management has been implemented successfully with cooperation between utility and industries to change unplanned outage to planned outage.*

***Keywords*— Outage cost, Thailand Standard Industrial Classification (TSIC), Metropolitan Electricity Authority (MEA), Provincial Electricity Authority (PEA), Outage impact factor, Power system reliability.**

1. INTRODUCTION

In the year of 2008, the global economic crisis, political uncertainty and fluctuating oil prices were constraints of Thai economic growth, which is considered as the parameter of risk analysis. The consequences of the economic crisis decelerated the energy consumption in most economic sectors. Moreover, the political uncertainty due to changes of government during 2008 delayed the disbursement of government budgets and the implementation of mega-infrastructure projects included improvement on electrical power systems. Furthermore, fluctuating oil prices lead to difficult management in electricity unit prices.

Electricity is an important energy to drive Thai economy especially in commercial and industrial sectors. Although financial problems are constraints for economic expansion, the forecast of electricity consumption in Thailand will grow rapidly after crisis recovery. So, the electric utilities require optimal planning for the expansion and improvement on generation systems, transmission systems and distribution systems with acceptable reliability levels and reasonable prices [1].

1.1 Electrical power system in Thailand

1.1.1 Generating systems

The total installed capacity of power plants in Thailand is 29,211 MW as shown in Fig. 1. The capacity of 14,328 MW (49%) is from the Electricity Generating Authority of Thailand (EGAT) power plants, 12,151 MW (42%) is from Independent Power Producers (IPPs), 2,092 MW (7%) is from Small Power Producers (SPPs) and the last 640 MW (2%) is from neighboring countries, namely Lao PDR and Malaysia [2]. Fig. 2 illustates the percentage of generated power by fuel types. Natural gas has the largest portion of the total installed capacity with 70%, while approximately 21.2% is from coal and lignite and the small portion is from renewable energy with 1.4%. In order to increase Thailand energy security, the roles of renewable energy such as biomass, biogas, municiple solid waste (MSW), solar and wind are expected the rapid growth in the future of electricity markets.

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Although using high volumn of traditional resources such as natural gas, coal and lignite for electricity generation has a benefit of low opearting cost, the combusion of traditional resources contributes the environmental aspects included climate change issues. In addition, the limited traditional resources and high power demand result in unsecured energy reserves. Therefore, the directive energy policies included effective strategies of Thailand power development plan have been launched into all sectors to deaccelerate and reduce power peak demand. For instance, the encouraging of energy efficiency and conservation, supporting renewable energy projects and promoting clean development mechanism (CDM) can enhance the energy security.

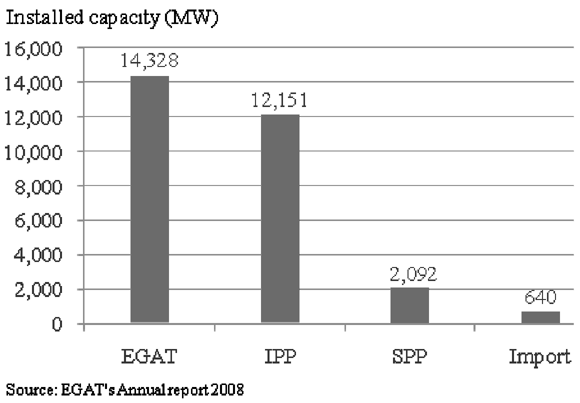

Fig. 1. Installed capacity in Thailand.

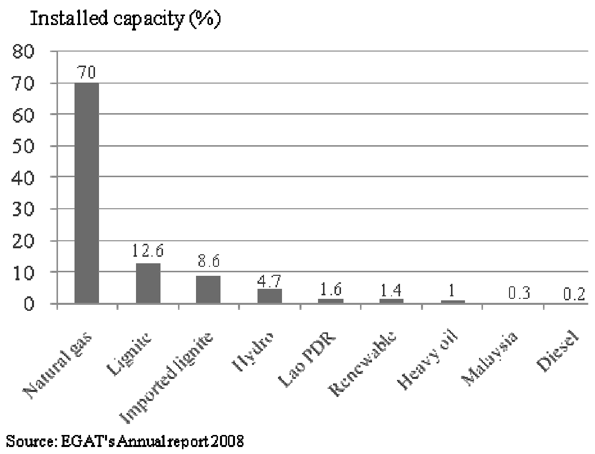

Fig. 2. Percentage installed capacity by fuel types.

1.1.2 Transmission systems

At present, the electricity markets in Thailand are influenced by private sectors that participate in renewable energy projects. Nevertheless, EGAT is still the main responsible authority for transmission systems which cover 30,219 circuit-kilometers of high voltage transmission lines. The standard operating voltage levels of EGAT's transmission lines are 500, 230, 132 and 115 kV at operating frequency of 50 Hz and the number of EGAT's substations are 209 substations. The electricity is transmitted from power plants, transmission lines through 524 delivery points with the total transformer capacity of 72,075.19 megavolt-amperes (MVA). In addition, EGAT has enhanced the energy cooperation with neighboring countries by using the 300 MW Thailand - Malaysia high voltage direct current (HVDC) interconnection system which enable the power exchange between the two countries. The new interconnection system will also allow EGAT networks to reduce the reserve capacity and enhance energy supply security.

1.1.3 Distribution systems

The distribution systems in Thailand are devided in two authorithies. The Metropolitan Electricity Authority (MEA) serves electricity for 2,793,337 customers in Bangkok, Samutprakan and Nonthaburi provinces while the Provincial Electricity Authority (PEA) provides electricity for 14,600,420 customers in 73 provinces that covers 510,000 km^2 or 99.9% of the total country's areas.

1.2 Electricity demands and forecasting

In 2008, the total of electrical energy consumption in Thailand is equal to 134,936.63 GWh. The peak demand was 22,568 MW that occurred on April 21, 2008. The electrical energy consumption of Thailand in 2008 was classified by five customer sectors as shown in Fig. 3. In addition, the electrical energy consumption was divided by distribution authorities (PEA and MEA) as illustrated in Fig. 4 [3]. The situation of electricity demands is clearly that the industrial sector (46.82% of the total demand) is the largest electricity consumption compared with the other groups. The calculated reserve margin of all customers is 24.50% which reveal abundant installed capacity due to the situations and conditions of global economic recession. However, the growth rate of global economy at 3.5-4.7% increasing is predicted which lead to expanding the GDP's index and energy demands in Thailand during 2008-2021.

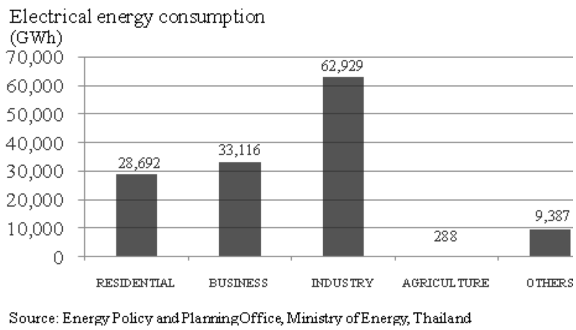

Fig. 3. Electrical energy consumption of Thailand in 2008

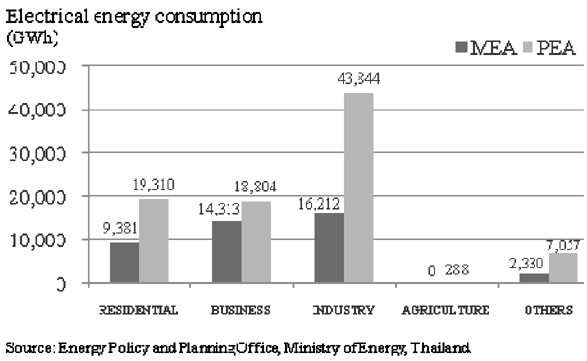

Fig. 4. Electrical energy consumption in 2008 classified by PEA and MEA.

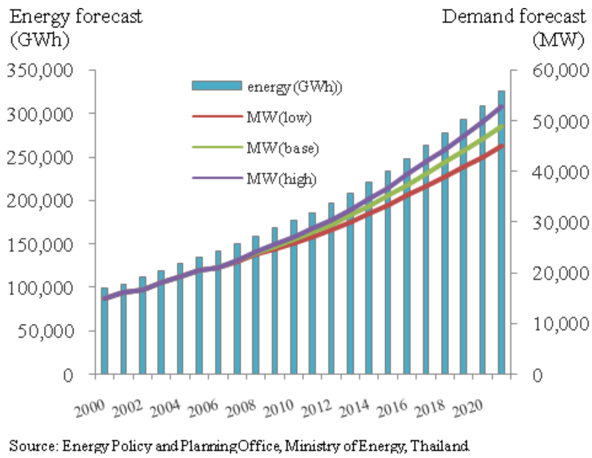

Fig. 5. Electricity load forecasting from 2008-2021.

Actually, there are several factors that affect electricity demand. The key factors are electricity price, number of electricity appliances, income per capita, climate change, and consumer load pattern which differ by regions and consumer groups. The load forecast methodology must correctly measure the effects of the key factors on electricity demand. In Thailand Power Development Plan 2007-2021 (PDP 2007 Rev.2), three main assumptions are used for load forecast. The annual average GDP growth rates are 5.0% and 5.6% during 2007-2011 and 2012-2026, respectively. The growth rate of global economic is 3.5%-4.7% and Dubai Oil Price is 55-60 US Dollars per Barrel. As shown in Fig. 5, the result of electricity load forecast in cases of base, low and high rates of Thailand economic growth during 2007-2021 shows that the expected electricity demand and the energy growth rate are 5.78% and 5.69%, respectively. Although the installed capacity is enough to reserve total customer demand at the time, the utility planners have important tasks to continued study about the reliability of electrical power system in their responsible areas for improving system performances and reaching customers's satisfaction. Consequently, the reliability of power systems depend on both internal and external factors. The improvement of power systems for high reliability level takes a vast investment cost and increases electricity unit prices. Hence, the utility planners must concern the optimum point between total investment cost and reliability target.

1.3 Power system reliability

Ideally, the power system's reliability from the viewpoint of consumers means the uninterrupted supply of power from the generation systems, transmission systems or distribution systems. In contrast with the utility viewpoint, the meaning of reliability is extended from the customer's meaning with the acceptable quality. Therefore, the general definition of power system reliability is the ability of power supply to perform the function of it's designed for under the operating conditions with acceptable quality. In practical, the key indicators of power system reliability for consumers are the frequency and duration of outages at their point of utilization (i.e., their load point) [4]. The indicators normally used to assess power system reliability in Thailand are System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) and Customer Average Interruption Duration Index (CAIDI) [5]. For instance, the quality standard targets of PEA in the year of 2008 are 11.32 times/customer/year and 508 minutes/customer/year for SAIFI index and SAIDI index, respectively [6]. While the actual performance of distribution system collected from the 2002-2007 is illustrated in term of SAIFI and SAIDI statistics as shown in Fig. 6 to Fig. 9. The summarized information has been discussed as following:

i. The SAIFI of MEA especially from 2005 to 2007 are decreased continuously in all customer groups with the rate of 67.37%, 32.75% and 35.21% for industrial, commercial and residential customers, respectively.

ii. The SAIDI of MEA especially from 2005 to 2007 are also decreased with the rate of 64.55%, 31.16% and 35.17% for industrial, commercial and residential customers, respectively [7].

iii. The SAIFI of PEA especially from 2002 to 2007 are decreased with the rate of 22.31%, 34.56%, 10.86%, 26.53% and 24.35% for industrial, commercial, town municipal, district municipal and rural customers, respectively.

iv. The SAIDI of PEA especially from 2002 to 2007 are decreased with the rate of 47.08%, 42.76%, 29.08%, 42.62% and 39.48% for industrial, commercial, town municipal, district municipal and rural customers, respectively.

v. The CAIDI of MEA's industrial customer in 2007 is equal to 13.81 minutes/event/customer, but in business and residential group are equal to 23.19 and 23.67 minutes/event/customer, respectively. Correspondingly, the CAIDI of PEA's industrial group in 2007 is equal to 21.29 minutes/event/customer, in business and rural areas are equal to 35.86 and 46.83 minutes/event/ customer, respectively.

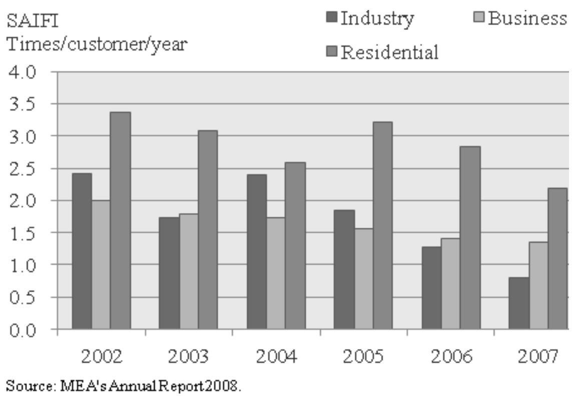

Fig. 6. SAIFI of MEA from 2002-2007.

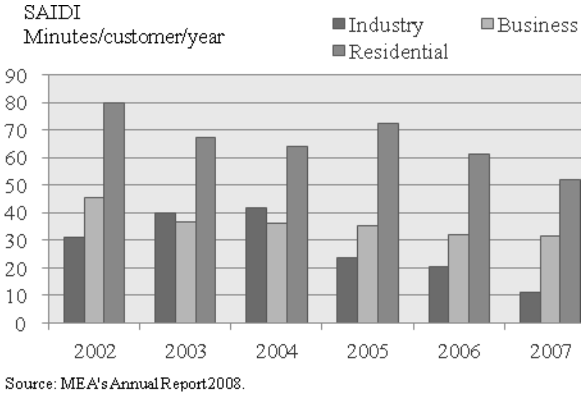

Fig. 7. SAIDI of MEA from 2002-2007.

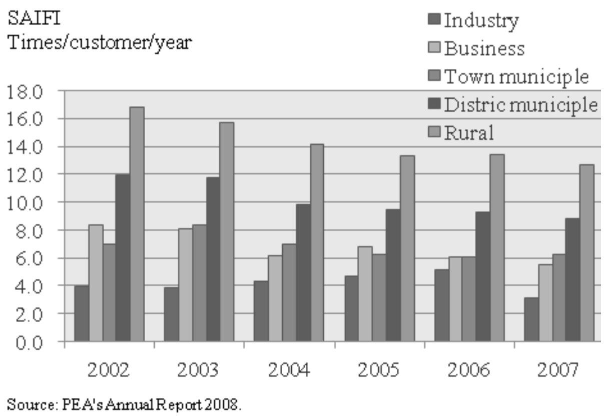

Fig. 8. SAIFI of PEA from 2002-2007.

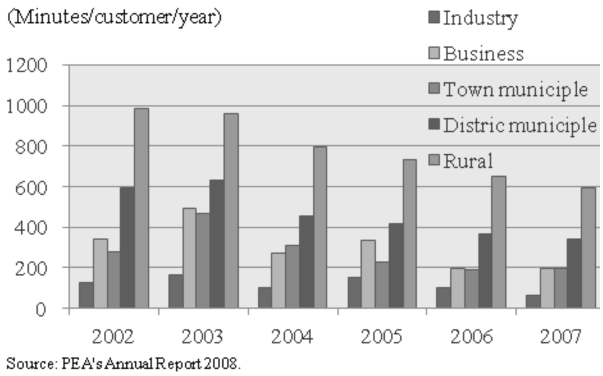

Fig. 9. SAIDI of PEA from 2002-2007.

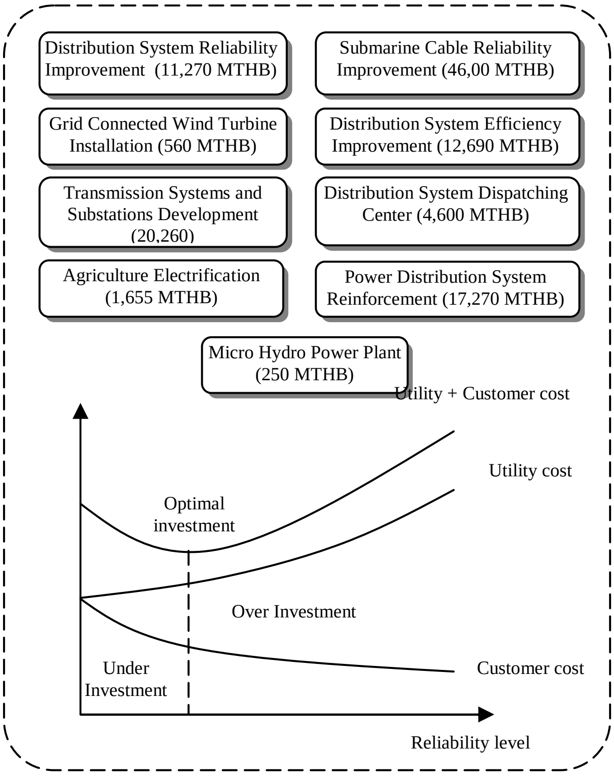

Fig. 10. Optimal reliability invesment concept by considering utility and customer cost with the implementation projects of PEA during 2002-2009.

The actual performance indicators above are important information in power system planning and expansion especially in distribution systems. When the power outage indicated by reliability indices is happened, there are several losses from utilities and customer view points. The utility lost the revenue from delivering electrical energy to the customers. The industrial customers lost the oppotunity in finished product and equipment might be damaged from power outage. The commercial customers lost in electronic data and equipment jamming. The residential customers have a significant and direct effect on the lives of private citizens. Although the trend of distribution reliability is continuely improved over the period, the constraints of utilities in Thailand especially PEA's area is the reliability management in a wide area with an actual limited budget to achieve sufficient customer's satisfication.

The total numbers of PEA's electric-circuit are 8,673, 283,028, and 450,425 km-circuit for transmission, distribution and low voltage distribution, respectively. Therefore, the investment cost of distribution system is very high and customers' requirement for more reliability and stability is impossible. Fig. 10 illustrates the PEA's investment of 73,115 million Baht for 9 projects during 2002-2009 to expand and improve reliability and efficiency of distribution networks. The vast investments are considered the optimal reliability point between the utility cost and customer cost. Despite the project investments contribute benefits into customers and society, the customer cost is also an important data that is necessary to judge in planning process. Thus, the major challenges of utilities are to increase the market value of services with the right amount of reliability and to decrease the cost of operation, maintenance and construction to provide customers electricity at the reasonable prices [8]. Therefore, the optimum investment of distribution reliability improvement must integrate both the cost of customers together with utility viewpoints [9-10]. The investment portfolios, least-cost planning framework, business customers costs of outages should be examined in various engineering options. This information can be meaningfully applied to a wide range of areas including transmission line design, substation and distribution circuit design, equipment rating and maintenance schedules [10].

1.4 Cost of energy not supplied

During power outage, there are the cost of energy not supplied both utility and customer. The cost of energy not supplied which normally is estimated from economic cost and social cost. The economic cost can be estimated with the various customer activities while social cost can be evaluated by using figures from government agencies. Although power distribution systems have received less attention in study than generation and transmission systems, the analysis of the customer failure statistics shows that distribution systems contribute as much as 90% towards the energy not supplied to the customers. In addition, utilities are encountering the increasing uncertainties in economical, political, social and environmental constraints [11]. These results are required for more extensive justification of new system facilities and increased emphasis on optimizing the operational cost and reliability of the distribution system. The study of outage cost is so valuable information that needed to be continuity updated in the planning period such as every 3-5 years. There have been extensive studies in reference [12-14]. In 2007-2008, the energy not supplied of PEA's residential customers is 2.4 times higher than industrial customers as shown in Fig. 11. The reason of difference is that the residential group has a large of customers approximately 90.1% of total PEA's customers. However, it was significant decreased by 8.35% from 2007-2008 as same as the distribution reliability indices. In contrast, the utility losses in industrial area are increased by 9.84 % from 2007 to 2008 as shown in Fig. 12. The reason is that the total energy consumption in industrial customer is continuous increased. In addition, productive performance has also improved. However, the damage cost of equipment failure and maintenance cost from electric restoration are not included in the cost of utility losses. For the industrial customers that consumed a large of energy more than other customers groups, the outage cost is a key issue in the cost-effective management of electric utilities. These costs may take in the form of lost sales, poor relationships with customers because of delivery issues, loss of finished product or intermediate inputs, lost wages or additional overtime payment and damage of sensitive equipment.

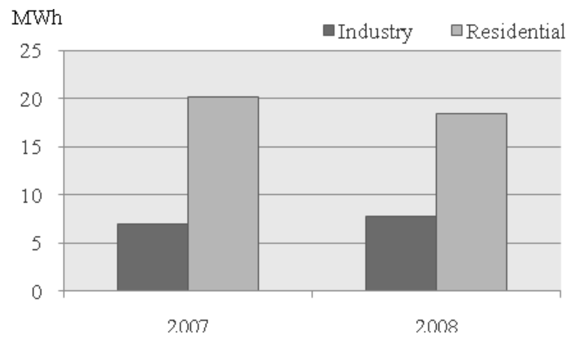

Fig. 11. Loss of load statistics in year 2007-2008.

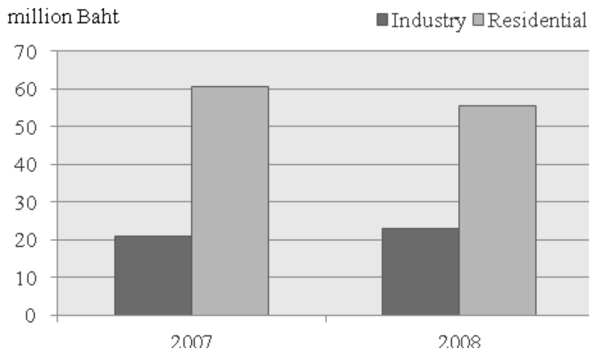

Fig. 12. The cost of energy not supplied in 2007-2008

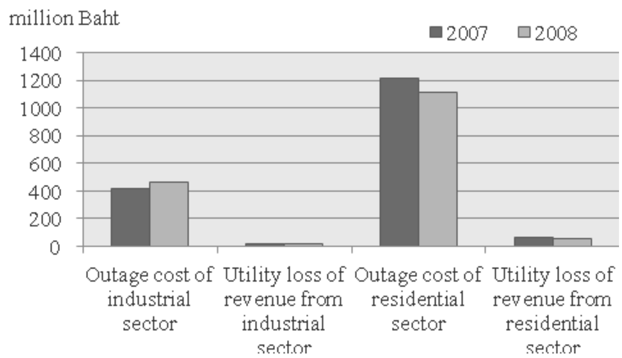

Fig. 13. Outage cost in customer and utility's viewpoints

As the previous outage cost study of Thailand in 2000 [15], the loss of customer's viewpoint was approximately 60.348 Baht/kWh. The latest updated outage cost data of PEA (in 2007 and 2008) as shown in Fig.13 is used for reliability target setting. When the value of customer's viewpoint is compared to the value of utility's viewpoint, the customer's outage cost is 20 times higher than utility's outage cost. There are several studies related to outage cost evaluation. For example, the outage cost of Chilean industries studied by Pablo S. and Gabriel F. in 1989 was $7.7 per kWh [16]. After that, Ashok S. determined customer outage cost in the northern region of India to study the reliability of generation-resource plan in 1990. The study found that customer outage cost is 2.30 Rupees (Rs.) per kWh [17]. Priyantha D.C. and M.S. Jayalath estimated the economic impacts of energy not supplied for planned outage and unplanned outages of Sri Lanka and Bangladesh in 2001-2003 are $0.66, $1.08, $0.34 and $0.83 per kWh, respectively [18-19].

Furthermore, Thomas H. F. studied the outage cost caused by snakes on the Island of Guam, which are around $3,000,000 in the lost of productivity from 1978-1997 with more than 1,600 times [20]. However, the outage cost can vary all the time, depending on many factors such as high production cost, change of technology. In this paper, the outage cost of large industrial customers of the PEA's areas is evaluated in terms of Baht/event, Baht/kWh and Baht/kWp. The rational difference between planned and unplanned outage cost is expected in the field of distribution system planning and equipment target setting issues. In addition, the outage impact factors are also determined in order to investigate each industrial characteristic and to study current performance of distribution system reliability in the customers' viewpoints.

2. METHODOLOGIES

The outage cost is typically based on survey method. The survey captures information from industrial customers about the economic losses such as tangible costs and opportunity costs. Tangible costs include defected product, employee's overtime, machine and equipment damage. The opportunities costs include lost production and lost sales. In order to evaluate the outage cost, the reliability of proposed methodology can be generalized into six steps as shown in Fig. 14. The outage cost of medium and large scale industries is defined as the research objective. The sampled industries are the designated factories according to the Energy Conservation and Promotion Act B.E. 2535(1992) from 3,489 registered industries in Thailand. The outage cost questionnaire is developed and distributed to designated factories for collecting the outage cost data. The key definition of the questionnaire is concerned only the electrical power quality problems that defined in term of "sustained interruption" according to IEEE standard 1366-2003 (interrupted more than one minute). The process characteristic of each industrial type, the size of industry in term of energy consumption, the outage duration, the process recovery time, the emergency action plans in industries for outage management and the capacity of emergency power supply are research assumptions which used to verify the reliability of surveyed data. In data analysis, the general information such as electrical cost, customer outage statistics, aging of electrical equipment and machines, the available of backup power system is presented. In addition, the outage cost impact factors including the employee's overtime, the defected product, the machine and equipment damage, the cost of process recovery, the opportunity loss during low electricity rates, the product delayed delivery, the profit loss and other factors are also analyzed. The unplanned outage cost and plan outage cost in term of Baht/event, Baht/kW$_p$ and Baht/kWh are calculated and analyzed for each industrial type. Finally, the recommendations for utility and industrial sector are also presented in the conclusion of research.

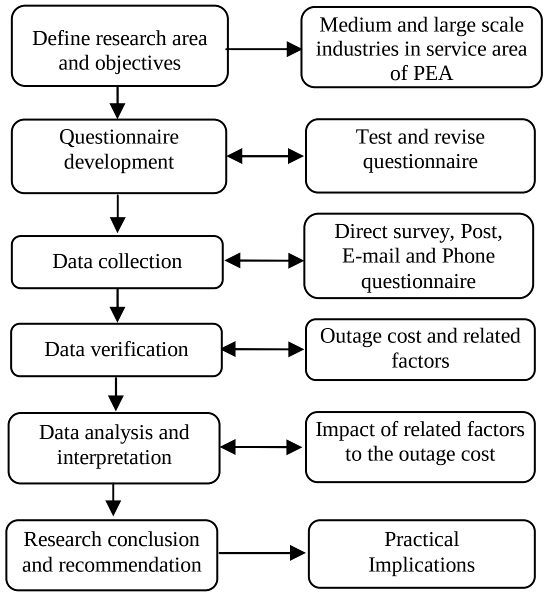

Fig. 14. Outage cost study flowchart.

3. STUDY RESULTS

In this study, the 825 feedback respondents from 9 industrial groups are received, approximately 23.58% of total distributed questionnaires. From the sampling theory by Taro Yamane, the data analysis error of these respondents is less than 4% with the confidential level of 95%. The number of respondents in 9 industrial groups is shown in Fig. 15. The summarized information is described in the following subsections.

3.1 Electrical cost**:** the overview of energy usage in the 825 designated industies is represented in term of the average electrical cost and energy consumption that are 4.34 million Baht/month, 1,336,263 kWh/month, respectively. The maximum of average electrical energy cost found in basic metallic industrial group by 11,477,278 Baht/month while the pulp, paper and paper products industrial group has the minimum of average electrical cost by 1,723,984 Baht/month.

3.2 Aging of electrical machines and equipment**:** above 50% of respondents indicate that electrical machines and equipment have been operated for more than 10 years with average preventive maintenance of 1.7 time/year. Some respondents concerned about over life cycle of electrical equipment and consequence of major damage from the power outage. In addition, most of respondents had an inefficient corrective maintenance especially in spare part management.

3.3 Power outage experiences: the main findings of outage frequency and duration for 825 industries are: 37% of respondents evaluated that the outage duration is 30-60 minutes/event; haft of respondents observed that the outage frequency is less than 6 times/year (average 4.92 times/year), and the average of process recovery time is 46.6 minutes/event. In addition, 36% of respondents indicated that most of outage occurred during 15.00-18.00.

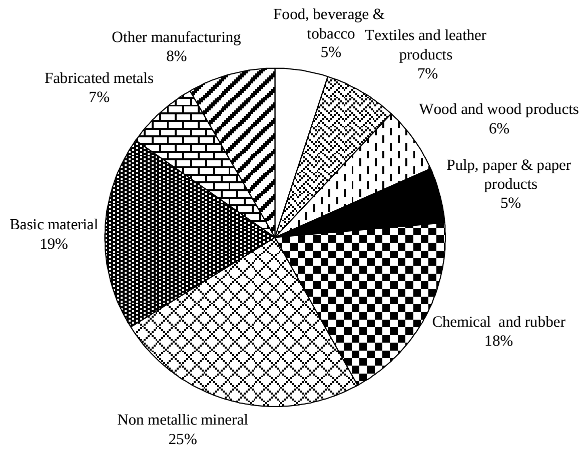

Fig. 15. Percentage of respondents classified by TSIC

***3.4 Emergency power supply*:** there are several processes that require emergency power supply in case of the outage to supply necessary system. For instance, the computer files need to be saved, lifting system needs to operate for safety reason, sensitive equipment such as electronic boards require a power to regulate functions during outage. The results of this study show that the emergency power supply is available for 529 designated industries (64%) and the average of installed capacity is 14.4% of total demand as shown in Table 1.

Table 1. Emergency power system of 825 industries

TSIC	Emergency Power System (Respondents)		Available capacity(% of demand)
	Available	Not Available	
31	80	25	16.5
32	30	34	17.0
33	16	18	9.0
34	11	3	18.8
35	62	35	12.0
36	44	20	17.6
37	19	10	14.2
38	77	44	11.4
39	190	107	12.8
total	529	296	14.4

***TSIC 31, 32, 33, 34, 35, 36, 37, 38 and 39** represent for the industries of food, beverage & tobacco, Textiles and leather products, Wood and wood products, Chemical and rubber, Non metallic mineral, Basic material, Fabricated metals, Other manufacturing, respectively.*

3.5 *Impact factors of outage cost*: in order to investigate the impacts of industries during the power outage; eight factors are selected from reliability research literatures [21-24] and used as concerned parameters. The outage impact factors of 9 industrial groups are shown in Table 2. The important issues are discussed as following:

- The employee overtime; this factor impacts the industries that operated less than 24 hours/day. There are no responsible persons to perform the machines and equipement reset during the outage as the industry's outage management procedures. The average employee's overtime cost is 16.9% of outage cost.
- The defected product; when the outage happened, some intermediate and finished product were damaged and were not able to re-produce. In the customer's response found that the average cost of defected product is 18.96 % of the outage cost especially in food, beverage and tobacco that is 21.6% of the outage cost.
- The machines and equipment damage; there are several types of failure such as malfunction, life ending, interruption and catastrophe. The sensitive equipment can be damaged or malfunctioned during power outage while the emergency power supply was not available in plant. The computer can be damaged and important files are lost while supply voltage drop below minimum neccessary operation and uninterrupted power supply is not connected. The cost of computer maybe take account into a part of outage cost. The overview of survey shows that the average cost of machine and equipment damage is 12.1% of outage cost. The basic metallic industries indicated that the machines and equipement damage is the most impact factor with 15.5% of the outage cost.
- The cost of process recovery; some processes in a plant cannot immediately recover after outage which is necessary to reset all processes to initial condition and in some cases; the recovery time is more than 24 hours. This factor is not significant with different industrial groups, that the average is 15.3% of outage cost.
- The opportunity loss during low electricity rates; Most industries prefer to operate processes during off peak period of TOU (time of use) tariff (22.00-9.00 in week day and weekend because the energy rate is only one-third of on-peak period of TOU tariff. The opportunity loss might be the considerible cost for such industry. The surveyed results show that the non-metallic industrial group comprised with cement, glass and ceramic industrial customers are the most effect with average 12.1% of outage cost.
- The product delayed delivery; some products had reserved ordering. When the delivery was delayed as order commitment, supplier might be charged by client. The surveyed results show that 9 industrial groups have no different impact with average 10.7% of outage cost.
- The profit losses; the damage in case of electrical outage makes processes stop, lead to production lost and cause lost in profits. The average of this impact is 14.8% of outage cost while the most impact found in other industrial group with 17.5% of outage cost.

3.6 The outage cost evaluation

The results of outage cost by 825 designated industrial data show that the average unplanned outage cost is 651,383 Baht/event while the average planned outage cost is 140,444 Baht/event. The outage cost in each industrial group is shown in Table 3. In the study, there are three major industries which are impacted from outage; the unplanned outage cost per event of non-metallic mineral, chemical and rubber and basic material industries are higher than average unplanned outage cost by 2.14, 1.80 and 1.70 times, respectively. Moreover, the outage cost in term of peak demand (Baht/kW_p) and energy not supplied (Baht/kWh) can be calculated by using the data of electrical energy consumption, working days, working hours, outage duration and outage frequency. The average unplanned outage cost of 825 industries in term of peak demand and energy not supplied are 68.47 Baht/kW_p and 308.41 Baht/kWh while the average planned outage cost are 16.23 Baht/kW_p and 74.94 Baht/kWh, respectively. The lowest outage cost in term of peak demand is found in the non-metallic mineral industries which the unplanned outage cost and the planned outage cost are 39.00 Baht/kW_p and 10.31 Baht/kW_p, respectively. The lowest outage cost in term of energy not supplied for unplanned outage is found in basic material with 221.03 Baht/kWh and for planned outage is found in other manufacturing industries with 43.21 Baht/kWh. The outage cost in term of Baht/kW, Baht/kW_p and Baht/kWh for unplanned outage and planned outage are also summarized in Table 4 and Table 5, respectively. Finally, the planned outage cost and unplanned outage cost per event of 9 industrial groups are shown in Fig. 16.

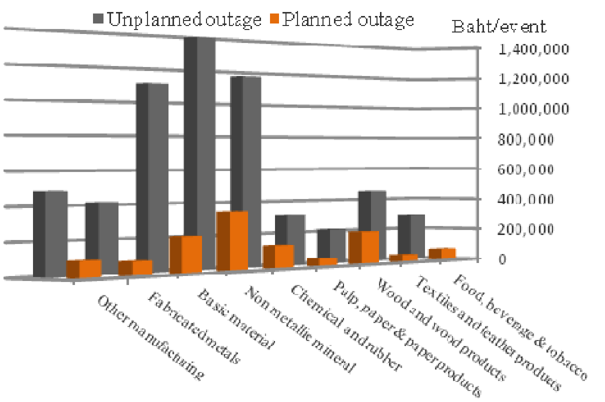

Fig. 16. The planned and unplanned outage cost of 9 industrial groups.

4. CONCLUSION AND DISCUSSION

According to the current situation of electrical energy in Thailand, the reserve margin of total installed capacity is about 24.5 % of peak demand, which indicates the adequate energy supply security. In addition, the focal point of sustainable policy for utility is the improvement on power system reliability, stability and security. In this study, the assessment method is proposed to determine the performance of distribution system in term of customer outage cost. The 825 designated industries in PEA service area have been evaluated the cost of both planned and unplanned outage. The results show that the case of unplanned outage, the non-metallic mineral comprising with cement and glass industries have the highest average outage cost with 1,396,680 Baht/event while the lowest average outage cost is found in wood and wood products with 216,042 Baht/event. In case of planned outage, the highest average outage cost is also found in non-metallic mineral industries with 352,891 Baht/event but the lowest average outage cost found in textile and leather products industries with 45,938 Baht/event. In addition, the major outage impact factor is the defected product which is 18.9% of outage cost. The other impact factors are 16.9%, 15.3%, 14.8%, 12.1%, 10.7%, 10.7%, and 0.2% of outage cost for employee’s overtime, the process recovery, profit losses, machines and equipment damage cost, opportunity lost of low electricity rates, product delayed delivery and other, respectively. The results of outage cost study can be concluded that overall economic losses due to unplanned and planned outage impact to industrial customers in Thailand both direct and indirect cost.

Although PEA has continually improved reliability performance of distribution system, the outage cost of industrial sector is significantly higher than previous study. In addition, the wide service area with limited budget of PEA is the main constraints for reliability improvement. For this reason, the large gap between unplanned outage cost and planned outage cost is the challenge issue for PEA and industrial customers. The optimal cooperated management between PEA and industrial customers can be substantially decreased the economic losses from power outage. From customer point of view, the industrial sector should study more details for critical processes that are sensitive to power outage and provide the sufficient backup power system. Furthermore, the effectiveness of outage management with outage statistic record and outage cost assessment should be integrated into the quality management standard system such as ISO 9001 for negotiation benefits with utility. Moreover, the power quality monitoring system should be available in plant for providing adequate information to troubleshoot the power quality problem. From the utility point of view, the reliability investment should be focused the project prioritization to balance the cost and benefits between utility and customer. However, the outage cost of residential and commercial sector is required to further study and use in practical planning process.

In competitive market of power system, the outage cost is the important parameter that is necessary for decision making process of power system planning and operation. The proposed outage cost methodology described in this article is not restricted only industrial sector in Thailand. It can be applied the concept for the GMS’s countries to determine the optimal investment strategy under the conditions of power system in the region, the service area of utility and the characteristic of electricity customer.

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Table 2. The percentage of impact factors to the outage cost (classified by TSIC)

TSIC	Outage cost impact factors							
	Employee overtime	Defected product	Machine and equipment damage	Cost of process recovery	Opportunity loss during low electricity rates	Product delayed delivery	Profit losses	Other
Food, beverage &	18.3	21.6	11.3	16.3	11.4	8.4	12.4	0.3
Textiles and leather products	18.6	18.2	9.9	14.8	9.9	11.8	15.9	0.5
Wood and wood products	14.7	21.3	12.5	15.4	12.1	8.5	15.0	0.8
Pulp, paper & paper products	18.4	18.1	13.1	16.4	9.4	11.0	13.7	0.0
Chemical and rubber	16.6	19.0	13.4	14.2	11.5	10.8	14.4	0.3
Non metallic mineral	16.1	19.7	10.4	14.4	12.1	11.7	15.5	0.2
Basic material	15.5	18.6	15.5	16.4	11.1	10.2	13.4	0.0
Fabricated metals	17.1	17.7	12.4	14.5	10.4	11.8	16.0	0.2
Other manufacturing	17.3	16.9	11.1	15.6	9.1	12.3	17.5	0.3
Average	16.9	18.9	12.1	15.3	10.7	10.7	14.8	0.2

Table 3. The planned and unplanned outage cost of 825 industrial customers in unit of Baht/event

TSIC	Average electrical cost	Outage cost (Baht/event)						% of deviation		
	(Baht/ month)	Unplanned outage			Planned outage					
		min	avg	max	min	avg	max	min	avg	max
Food, beverage & tobacco	2,287,878	138,912	292,520	530,160	37,040	70,000	119,000	73.34	76.07	77.55
Textiles and leather products	2,872,665	238,141	452,930	763,047	28,313	45,938	68,281	88.11	89.86	91.05
Wood and wood products	5,006,555	126,750	216,042	330,417	102,083	204,375	278,333	19.46	5.40	15.76
Pulp, paper & paper products	1,723,984	147,000	314,167	574,667	29,067	48,333	74,333	80.23	84.62	87.06
Chemical and rubber	1,821,266	752,677	1,173,828	1,639,792	62,135	137,891	259,583	91.74	88.25	84.17
Non metallic mineral	7,660,796	806,328	1,396,680	2,174,531	165,781	352,891	644,844	79.44	74.73	70.35
Basic material	11,477,278	663,281	1,110,078	1,672,500	99,719	217,734	404,688	84.97	80.39	75.80
Fabricated metals	1,998,792	220,008	419,979	709,874	50,134	85,672	132,185	77.21	79.60	81.38
Other manufacturing	4,236,486	279,292	486,220	760,533	50,904	101,160	176,959	81.77	79.19	76.73
Average	4,342,856	374,710	651,383	1,017,280	69,464	140,444	239,801	75.14	73.12	73.31

Table 4. The unplanned outage cost of 825 industrial customers in the Baht/kW, Baht/kWp, Baht/kWh

TSIC	Unplanned Outage Cost		
	Baht/kW	Baht/kW$_p$	Baht/kWh
Food, beverage & tobacco	83.74	58.62	244.23
Textiles and leather products	101.38	70.97	387.36
Wood and wood products	99.28	69.50	343.38
Pulp, paper & paper products	131.51	92.05	352.77
Chemical and rubber	112.14	78.50	328.64
Non- metallic mineral	55.71	39.00	276.08
Basic material	75.92	53.14	221.03
Fabricated metals	120.64	84.45	365.92
Other manufacturing	100.00	70.00	256.25
Average	97.81	68.47	308.41

Table 5. The planned outage cost of 825 industrial customers in the Baht/kW, Baht/kWp, Baht/kWh

TSIC	Planned Outage Cost		
	Baht/kW	Baht/kW$_p$	Baht/kWh
Food, beverage & tobacco	30.84	21.59	89.12
Textiles and leather products	21.53	15.07	87.87
Wood and wood products	26.90	18.83	96.80
Pulp, paper & paper products	33.75	23.62	82.38
Chemical and rubber	23.98	16.78	63.22
Non- metallic mineral	14.74	10.31	72.46
Basic material	15.64	10.95	45.40
Fabricated metals	24.07	16.85	94.00
Other manufacturing	17.21	12.05	43.21
Average	23.18	16.23	74.94