The Costs of Power Quality Disturbances for Industries Related Fabricated Metal, Machines and Equipment in Thailand

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***Abstract*—** *The purpose of this paperis to examine industrial customer attitudes relating impacts from power quality events which include voltage sags, undervoltage, overvoltage and voltage interruption. In this study, 63 industries associated fabricated metal, machines and equipment products in Nava Nakorn industrial zoneare selected to estimatemonetary losses from power quality events in 2010. The direct customer survey with questionnaire guideline is introduced in the data collecting process.In the survey questionnaire, customer attitudes are represented in term of impacts levels to manufacturing processes and thier activities. The economic impact level is then transformed into monetary value by using weighting economic factor. The customer survey results show that the impact level from each power quality event is diversified. It is significantly related to conditions of production capacity, product values, manufacturing processes, amount of sensitive devices and plant recovery time. In addition, the manufacturing industries of semiconductors, integrated circuit (IC) and electronic products perceived a large of monetary losses in case of power quality event and as well as voltage interruption.However, power quality monitoring system, a tool for identifying power quality problems, is still not available in some industries. Further, various industries in this survey never perform full assessment of manufacturingimpacts. Therefore,the economic impact calculationis employed based on industrial expert experiances. The results in this studyare information from customer attitudes related to reliability cost which utility planners can be applied in various fields of electric distribution system including operation, maintenance and network improvementplanning. Finally, the assessment is introduced for industries to address issues about the consequnces ofpower quality problems and reliablity of power supply.*

***Keywords*— Power quality, Voltage sag, Voltage interruption, Fabricated metal, machines and equipment industry.**

1. INTRODUCTION

Currently, numerous developments in power system technologies are widely utilized in electric power industry and customers. Various loads equipment based microprocessor controllerand power electronic devices arealso more sensitive to power quality.Further, improvements on overall power system efficiency from both supply and demand sides resulted in growth ofsensitive devices such asautomatic control system, high efficiency machines, adjustablespeed drives (ASD) and shunt capacitors. This is resulting in concerns about the future impact on system capabilities. Moreover, customers have an increased awareness power quality issues which are becoming better informed from driven factors in power system restructuring and deregulation of power utility industry. Therefore, electric utilities in several countries have been collaborated with their customersto evaluate the impacts from powerquality event. The results of customer impact evaluation can be applied for identifying the optimalmigrationalternatives.

Since the key factor ofnational economic growth and social developmentin developing countries,energy utilization in Fig. 1 shows that industrial sector is the largest consumer in Thailand with share 42.40% of total electrical energy consumption in 2009.In addition, value added contribution from nine industrial sectorsin Fig. 2 displays that industries related to fabricated metal, machines and equipment (TSIC38) is the highest contributor of gross domestic product (GDP) for industrial sector, followed by the food industries (TSIC 31) and textile industries (TSIC 32), respectively.Due to a variety of products and value added contribution, this paper intends to estimateeconomic impacts from power quality problems of industries under TSIC 38.

2. LITERATURE REVIEW

The power quality has become an issue of increasing interest in the various segments of end user since the late of 1980s. At that time, the dominated cause of power quality problems is from natural phenomena and then thegrowth of non linear loads in several applications is extended into a power quality of harmonics problem. Table 1 provides information regarding characteristics

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and causes of common power quality problems. Equipment may have different sensitivity to power quality problems which dependon the specific load type, control setting and application. Consequently, it is often difficult to identify characteristics of problems when power quality monitoring system is not installed in a factory.

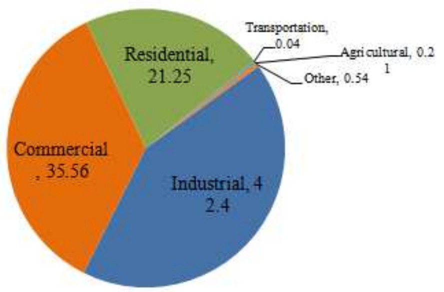

Fig. 1. The electrical energy consumption in 2009.

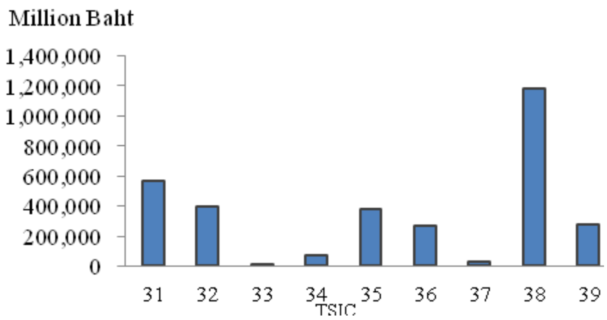

Fig. 2. GDP originating frommanufacturing in 2008.

Table 1.Categories of power quality problems

Characteristics	Causes
Momentary interruption	- Short circuit, operation of protective devices such as breaker and fuse
Temporary interruption	- Short circuit, operation of protective devices
Sustain interruption	- System short circuit, accidents, tree falling
Notch	- Commutated current by operation of power electronic devices
Transient (Impulsive/Oscillatory)	- Lightning, system fault, switching of heavy load such as induction motor starting
Sag	- System faults, switching of heavy load, motor starting
Swell	- Remote system fault, switching off a large load capacitor bank
Undervoltage	- Large load or system switching, faulty connection or wiring and loose connection connections
Overvoltage	- Load switching such as switching off large load or system switching on a large capacitor bank, incorrect tap settings on transformers

In general, power quality problems can be categorized in different standards accordingto development objectives or criteria of typical duration, voltage magnitude and frequency content. For instance, the general proposes of power quality standard development include IEEE standard 1159 [1], the IEEE Standard 519-1992 [2], IEC 61000-4-30 [3] while the SEMI Standard F-47 is developed for specific propose to serve manufacturers and suppliers of hardware, ICT services and software [4].The IEEE Standard 1159 was developed to provide general guidelines forpower standard definitions and quality measurements in different categories of power quality events while the IEEE Standard 519-1992was designed to establish guidelines for harmonic current and voltage distortionlevels on distribution and transmission circuitsand the IEC 61000-4-30 was set up to define the correct measuring algorithms for power quality instruments. In addition, the customer load model can also be used as the method to analyze the power quality events, however load diversify and time-dependent operation makes this approach impracticable. Instead, equipment sensitivity to power quality can be considered in the power acceptability curve. One of thewidely well-known curves is Computer Business Equipment Manufacturers Association (CBEMA) [5].

Since the association reorganized in 1994 and was subsequently renamed the Information Technology Industry Council (ITI), the CBEMA curve was also updated and renamed the ITI curve. Typical loads will likely trip off when the voltage is below the CBEMA or ITI curve like a sample application for setting run/stop of load in Fig. 3. The curve labeled ASD represents an example of voltage sag ride through capability for a device that is very sensitive to voltage sags. It trips for sags below 0.9 p.u. that last for only 4 cycles. The motor contactor curve represents typical contactor sag ride-through characteristics. It trips for voltage sags below 0.5 p.u. that last for more than 1 cycle.

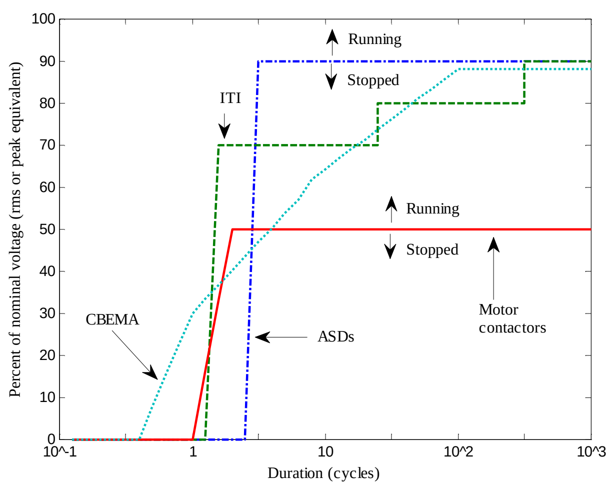

Fig. 3.Equipment voltage sag ride-through capability curves.

In electricity market, power quality is interested by electric utility companies, equipmentmanufacturers and electric power customers. There aremany reasons associated concerns which comprising of economic growth, rising rapidly in electricity demand, modern and advance technology developments of sensitive devices, customer service standard. For these reasons, numerous researches related power quality problems analysis, monitoring systems, mitigation methods, technical standards, and economic impact evaluations are continue to publish. The study results related to power quality issues led to establishment power quality indices in regulation of service standard for worldwide countries [6-11]. In addition, evaluation of power quality cost especially industrial sector was performed at the beginning of the 1990s for comparing with the cost of power quality services. The survey of industrial customers contribute on underlining the power quality disturbances susceptibility of industrial processes and also giving the estimation of annual costs experienced by customers[12]. The cost of a disturbance involves losses from lost production, damaged raw material, idle labors and in certain cases damaged equipment. The IEEE standard 1346–1998 provides some guidelines on how to calculate thecost associated a voltage disturbance which the approach requires participation of management as well as financial,operational, maintenance, and sales staffs [13]. However, some utilities face resources limitation and it is so difficult in practical to interview all participants at the same time. Some first study to assess the power quality cost was performed in USA and Canada [14-15]. The customer damage from power quality events can impact from microeconomic to macroeconomic in these countries. For instance, a feeder with high number of short interruption and voltage sag was estimated losses by 1.8 Million US$ [16]. In Italy, the survey of economic impacts in manufacturers from power quality problems was evaluated in range of 50-250,000 US$ per year per factory [17]. In South Africa, a recent study showed that major industries suffer annual losses of more than 200 US$ million due to voltage sag problems [18]. The survey results of European-wide in 2007 suggested that several companies lost up to 10% of their annual turnover due to poor power quality [19]. For industrial perspectives, the effects of power quality on weaving-knitting, dyeing and finishing processes in textile industry were assessed in term of partial interruption, major interruption and complete breakdown to textile processes. The results of power quality measurement showed that losses were significantly high, being around 15% of the annual net profit of the textile industry [20]. In automotive industry, four-cycle voltage sag can lost over 700,000 US$ in the following 72 minutes due to shut down of process and required rework from malfunction of programmable controllers and drive systems working in a real-time process environment [21]. The high technology machines of semiconductor companies in Taiwan including wafer manufacturing and integrated circuit packing identified that losses due to power quality event was greater than 5 million NT$ per event (1US$=28.66NT$) [22]. Another estimation the losses of semiconductor manufacturing was conducted in Iran [23]. The economic impact caused by voltage sag was shutdown production processes of 23 minutes which the company suffered losses about 138,000 US$. This evaluation may greater losses when include equipment and machines damage costs, reduced product quality, increased maintenance costs. For chemical industry, 20,053 pharmaceutical manufacturing companies in India were investigated economic impacts from poor power quality in 2009. The total cost of complete plant disruption including direct costs, downtime costs and restart processes costs due to all power quality events for worst case scenario was approximately Rs.20 billion (1 US$=26.474 Rs at June 2009). The losses from voltage disturbances alone accounts for 50% of the total cost of downtime due to all events. This results were calculated the cost of downtime due to all events and voltage disturbances alone, account for 10.33% and 5.16% of the national annual production of pharmaceutical companies, respectively [24]. The power quality costs due to voltage sag in various industries were estimated as shown in Table 2 [25]. This literature is also addressed the survey results of Frost and Sullivan, an independent consulting firm specializing in evaluating technology markets, about cost of voltage disturbances alone impact to US industry over 20 billion US$ every year. Since the power quality in Thailand is less attention to study problems, causes and impacts, the paper has been examined the customer attitudes related to manufacturing processes affected from power quality and interruption statistics in 2010. Impacts of voltage sags, undervoltage and overvoltage are presented in this study.

Table 2. Impact of voltage sags on industries

Industry	Losses (US$)
Semiconductor industry	2,500,000
Credit card processing	250,000
Equipment manufacturing	100,000
Automobile industry	75,000
Chemical industry	30,000

3. METHODOLOGY

The research of economic impacts from power quality problems is still less attention especially in developing countries. In addition, power service standardsare defined only power supply reliability indices such as the system average interruption frequency index (SAIFI) and the system average interruption duration index (SAIDI). In this study, the methodology to assess power quality costs from industrial customer perspectives is developed based on customer survey. The questionnaire is developed from several guidelines and publications to fulfill the customer information and relevant data. The contents of survey questionnaire are divided into four parts as following:

Part I: *General manufacturing information*; this part is formed to obtain data includes factory location, manufacturing processes, type of activity, number of employees, operating time in a day and in a week, and data on the electric end-use (voltage level, demand and average electrical energy consumption). In addition, personal contact information such as name of respondent, mobile phone number, fax number, e-mail address isalso defined in this section.

Part II: *List of sensitive devices*; information about sensitiveloads, equipment and machines in industrial processes including programmable logic *controllers* (PLC),automation control system, ASD, soft starters, computerized numerical control (CNC), computers, power electronic devices, switching power supply, power rectifier, magnetic contactors is filled in the survey questionnaire. Further, respondents were asked to describe different impact between power quality problems (voltage sag) and zero-voltage condition (sustain interruption).

Part III: *Cost of power quality problems*; impact level from each power quality categorycomprising instantaneousvoltage sag, momentary voltage sag, temporary voltage sag, under voltage, over voltage and sustained interruption is estimated. Data on each impact level provides qualitative costsat specific impact level (not impact to complete process shutdown). In this case, customer impacts from sustain interruption is assigned as the reference cost. The power quality costs referred to the impact from voltage sags can be calculated by using weighting economic factor.

Part IV: *Power quality events in a year*; the statistic data of power quality problems occurred in 2009provided by monitoring system or manual documentation system is collected.

4. THE SURVEY ORGANIZATION

Due to high density of industrial customer located on the logistic hubfor productsdistribution, the industries operating in Nava Nakornindustrial zone are the target groupof survey.Over 217 industries and more 200,000 employees are currently operating in this industrial zone. The industries utilizeelectricity from distribution utility,namely the Provincial Electricity Authority (PEA). The electricity supply to industries consists of 4 main substations, each connected with 10 feeders. A total capacity from 4 substations was desired at 515 MVA and connected in loop circuit to prevent electric problems. The specification of electric substation system is summarized in Table 3which the distribution utility delivers electricity with the medium voltage of 115 kV and 22 kV.For industrial information, the number of industry in each category is shown in Table 4. The statistic data shows that 120 factories related to fabricated metal, machines and equipment (TSIC 38) is the highest number of industry in Nava Nakhon industrial zone. In this industrial category, several products are the majority contributorto national economy. Considering production process, most of manufacturing industries under TSIC 38 operate with high technology machines and sensitive devices includingautomatic control system, electronic control cards and vary speed drive controlled motors. Poor power quality may damage the system andcause all production lines failures. Thus, the scope of this study is to investigate the economic value of various industries under TSIC 38from power quality disturbances.The study has been carried out by interview expert in the factory to address level of impactin each power quality category. The costs of power quality event can be estimated with the weighting factors in Table 5 that refer to the cost of sustain interruption.

Table 3. Electric substation capacity in Nava Nakorn industrial zone

Substation	Code	Supply capacity (MVA)	Rated voltage (kV)
Nava Nakorn 1	NVA	2x40	115/22
Nava Nakorn 2	NVB	2x40	115/22
Nava Nakorn 3	NVC	2x50	115/22
Nave Nakorn 4	NVD	2x40	115/22

Table 4. Number of industry in Nana Nakorn industrial zone classified by TSIC

TSIC	Description	Number of industry
31	Food, beverage and tobacco	19
32	Textile and apparel	8
33	Wood and wood products	5
34	Pulp and paper	6
35	Chemical and petrochemical products	38
36	Non metallic mineral	3
37	Basic metal	3
38	Fabricated metal, machines and	120
39	Other manufacturing	15
Total		**217**

Table 5.The guideline of qualitative impact level and economic impact weighting of power quality problems

Level of impact	Weighting for economic analysis	Guideline
No effect	0.0	All processes not impact, short process recovery time and there is no raw material damages
Very less impact (sag with minimum voltage between 70% and 90%	0.1	Most processes not impact. However, some processes which not critical may impact during voltage sag
Less impact (sag with minimum voltage between 50% and 70%)	0.3	Some processes have been stopped while othersare still normal operation. However, overall production lines cannot full operation capacity.
Medium to quite large impact (sag with minimum voltage below 50%)	0.5-0.7	Most processes were interrupted. Long recovery times at least half an hour was normally required to check machine breakdown and then restart process.
Large to greatest impact (short and long interruption)	0.8-1.0	Most processes interrupted and consequence of completedproduction lines shutdown. Long recovery time is required to inspect material damages, machines breakdown and then restart processes.
Cannot identified	N/A	Never investigate or not install power quality monitoring system

5. STUDY RESULTS

5.1 General industrial customer survey information

Regarding the highest number of industry in Nava Nakorn industrial zone,120 companies related to fabricated metal, machines and equipment products are selected as the target to estimate costs of power quality event and voltage interruption. The data gathering process was achieved by direct customer interviews in case of industries preference or the questionnaire response in case of an industry does not prefer to reveal plant information. Although survey information is given by experts in manufacturing processes or well-known person about electric power system in the factory, there are some industries which the survey information in questionnaire was not useful or may not represent to the generalized results. After validating responded data, 63industriesare represented in the analysis and evaluation costs associated power quality event. The selected data from customer survey can be classified into sub-category under TSIC 38 as shown in Table 6. Overall response rate is approximately with 52.5% of total industry. In this survey, the industry related to equipment, radio, television and communication products (TSIC38320) have the largest number of respondents, followed by automotive parts and general assembly industry (TSIC 38439). The description and example products under each sub-category can be summarized in Table 7.

Table 6. Sample size and number of responses

TSIC	Population	Respondent	Response rate (%)
38110	5	1	20
38198	5	2	40
38500	5	2	40
38199	5	5	100
32220	5	1	20
38240	5	3	60
38292	5	3	60
38320	30	23	76
38330	10	2	20
38393	10	2	20
38399	5	2	40
38250	10	5	50
38439	20	12	60
Total	120	63	52.5

Table 7. List of sub-category under fabricated metal, machines and equipment industry (TSIC 38)

TSIC	Description	Examples of products
38110	Factories related cutlery tools and appliances made of steel	cutting wheel
38198	Factories related coating, engraving services and related services grew	mold for die casting
38220	Factories related machinery and agricultural equipment	Small diesel engine, walk-behind tractor rice reaper tractor, oil & spare parts
38240	Factories related machinery and special equipment for industrial applications	electric discharged machine, wire-cut, machine centers injection mold machine
38292	Factories related air conditioning systems	parts of air condition (strainer, header assembly, distributor, reducer pipe)
38320	Factories related equipment and radio, television and communication	color television, video, CCTV, VTR ,Satellite Receiver Equipments
38330	Factories related machinery and home appliances that use electricity	electrical appliances (washing machine, cooker, refrigerator, etc.)
38393	Factories related electric lamps and lighting systems	automotive lighting equipment
38399	Factories related other electrical equipments	transformers,heat exchanger,defrost heater,thermostat vend-mechanism and water pump
38250	Factories related theelectronic and computer assembly parts	computer hard-disk , flexible printed circuit board, transistor, diodes,resisters, capacitors, integrate circuits (IC)
38439	Factories related the automotive industry, parts and assembly	gear set for motorcycle
38500	Factories related the equipment measurement and control profession	clamp meter,multi meter,wall clock, alarm clock, table clock
38199	Factories related fabricated metal products which are not classified in the other	

Considering industrial scale by using electrical energy consumption criteria from electricity tariff structure of the Provincial Electricity Authority (PEA), the survey shows that large scale industries which consumed average electricity more than 250,000 kWh a month is the highest participant for this study (33 factories), however medium scale industries (electricity consumption between 100,000-250,000 kWh a month) and small scale industries (less than 100,000 kWh a month) also response significantly as shown in Fig. 4.Distribution of electrical energy consumption is also plotted in Fig. 5 which the two-largest electrical energy consumers are from the manufacturing of semiconductors including various types of IC, passive module, discrete semiconductors and optoelectronics products, followed with hard disk drive manufacturing, respectively. When filtering the two-largest energy consumers out of samples as Fig. 5 (below), a half of remaining industries consume electricity in a range of 100,000-1,000,000 kWh per month with the average of 346,492 kWh per month. Information about electricity consumption reveals that most industries categorized in TSIC 38 and located in Nava Nakorn industrial zone are large general service business sector under electricity tariff structure of PEA.

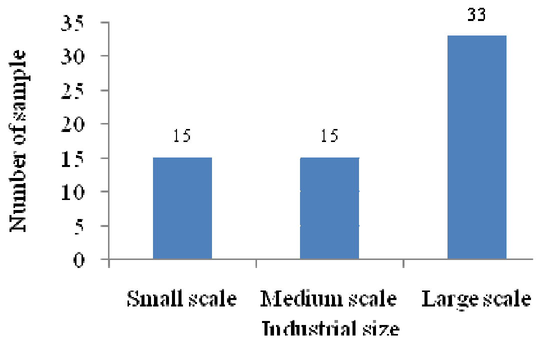

Fig. 4.Industrialrespondents categorized by scale.

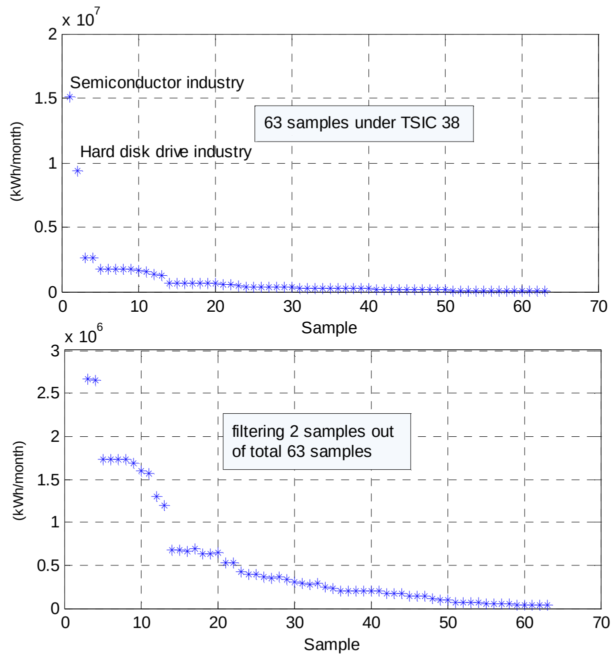

Fig.5. Scatter plot of electrical energy consumption.

To increase respondents understanding of the different impacts between power quality problem and reliability problem, the customers were asked their experiances about power quality problems in a year and how they can identify which problem was from power quality? The guideline for customer survey in this question is “the factory has been set up power quality monitoring or not?” In case the power quality monitoring system was not installed especially in a small scale industry, the customer were asked the experiances about protective devices malfunction such as main circuit breaker tripped from unknow reason while electric network was still in normal condition. In addition, the customers were asked to inform the overal processes impact from power quality and from power interruption. The survey results show that most industrial customersperceived a different impact between sustain interruption and power quality problem while the remaining indicated an equal impact. In general, the factories with continuous processes require a time to restart all processes since most production lines are driven by sensitive devices, machines and equipment. After voltage sag or power interruption has been activated, the production lines need to reset and investigate the material damage before restart process again. Based on survey questionnaire, Table 8providesinformation of installed devices, equipment and machines which sensitive to power quality problemsfor industries under TSIC 38.

Table 8. Installed sensitive devices, machines and quipment of manufacturing in selected industry

Sensitive devices, machines and equipment	Proportional (%)
Power electronics devices (ASD)	58.73
Computer and IT system	65.08
Switching power supply, rectifier, PLC	73.01
Magnetic contactor for motor control	73.01

Due to a variety of products, the results of customer survey show that most process characteristics of industries under TSIC 38were driven based on hand-made operation and inspection. Human resources are essential factor for a factory to make products. However, some industries have a semi-continuous processes that mean some parts of products can be completed by automation system while assembly process and final inspection arestill required human resources. The application of power electronic devices such as VSDnot widely apply in production lines while process automation system and magnetic contactorfor motor operation control are common utilized in most industries.

5.2 Economic impacts of power quality disturbances from industrial expert perspectives

Considering economic impacts from various power quality problems including instantanous sag, momentary sag, temporary sag, undervoltage, overvoltage and sustain interruption, the survey results are summarized in Fig.6 to Fig.11, respectively.

From sensitivity of equipment and process controls, the customer survey conclude that advance technology industry especially the processes of semiconductor fabrications require high levels of power quality. A case of 0.2 second voltage sag, a class of instantanous sag, can activate emergency off on various tools and cause productions lines to go down for hours.From the specifying impact level in case of instantaneousvoltage sag in Fig.6 (the rms voltage decreases to between 0.1 and 0.9 p.u. for a duration time of 0.00833 second to 0.5 second), the highest number of industryis in the level of low impact while 8 industries indicate that instantaous voltage sag affected equal to zero-voltage conditions. However, this event was rarely occurred in the network.

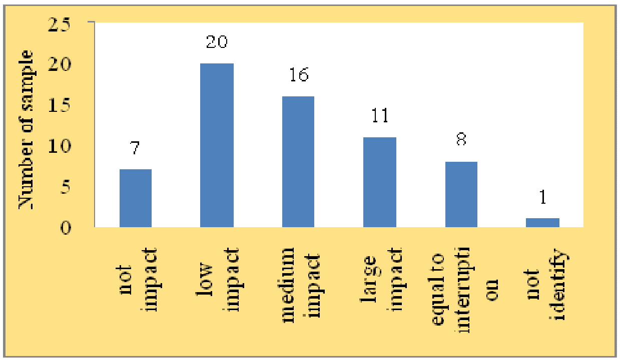

Fig. 6. Impact level of instantaneousvoltage sag.

The specifying impact level of momentaryvoltage sag is shown in Fig. 7 (the rms voltage decreases to between 0.1 and 0.9 p.u. for a time duration of 0.5 second to 3 second). The 20 industries from survey indicate that they haveperceiveda large impact from momentary voltage sag while 11 industries had experiences of losses equal to voltage interruption. Most of a large economic impact is in large scale semiconductor industry.

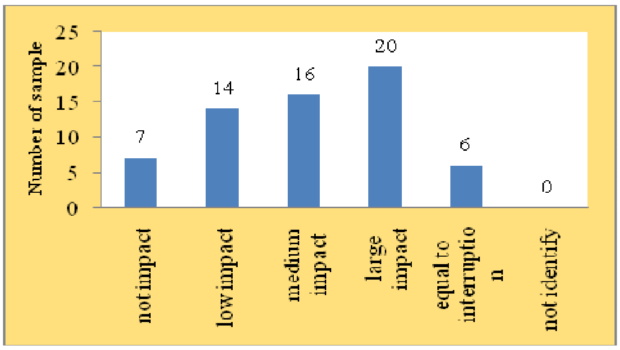

Fig. 7.Impact level of momentaryvoltage sag.

Further, the impact levels of temporary voltage sag are assessed as shown in Fig. 8 (the rms voltage decreases to between 0.1 and 0.9 p.u. for a time duration of 3 to 60 seconds). The survey shows that industries had a large impact when temporary voltage sag wasoccurred. The economic impacts from instantaneous, momentary and temporary voltage sag imply that duration is significant to impact levels. The average value of impact levels from voltage sags is used to estimate the costs of power quality.

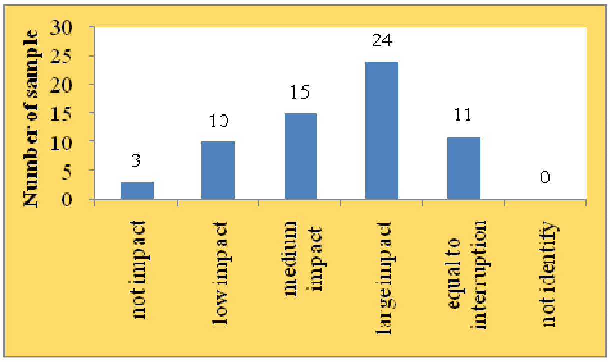

Fig. 8.Impact level of temporary sag.

For the case of undervoltage which rms voltage decreases to between 0.8 and 0.9 p.u. for a period of time greater than 1 minute, distribution of economic impact level from customer survey is shown Fig. 9. Most of undervoltage can be the result of load switching.Consequently,process machines and equipment might have operation malfunction. For instance, typical setting motor controller with 70-80% of norminal voltage cause an increasing heating loss in induction motor during long duration undervoltage. However, in this survey, the power quality event in case of undervoltagewasnot frequently happened since large loads were not applied in the industries. Fig. 10 illustrates customer attitudes about economic impact level from overvoltage which the magnitude of voltage is between 1.1-1.2 p.u. for duration longer than 1 minute. Overvoltage can be the similar causestoundervoltage. It may cause of immediate equipment failure especially electronic devices. Electric transformers and power cable of rotating machines can result in loss of equipment life time. From daily inspection, an overvoltage event ismore attended to concerndue to energy saving program in several factories. Forundervoltage and overvoltage problems, respondents indicate that economic impacts can vary from medium level to the damage equal to zero-voltage conditions. It reveals that most industrial processescan serious impact from undervoltage and overvoltage more than voltage sag.

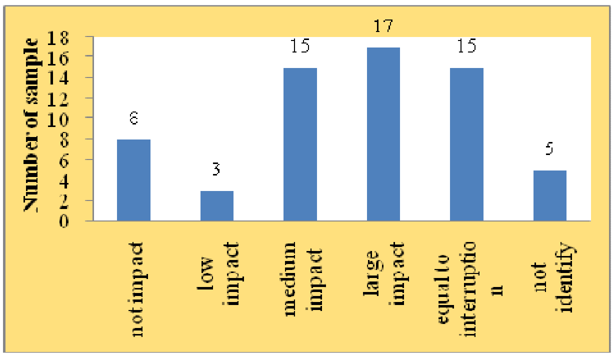

Fig. 9. Specifying impact level of undervoltage.

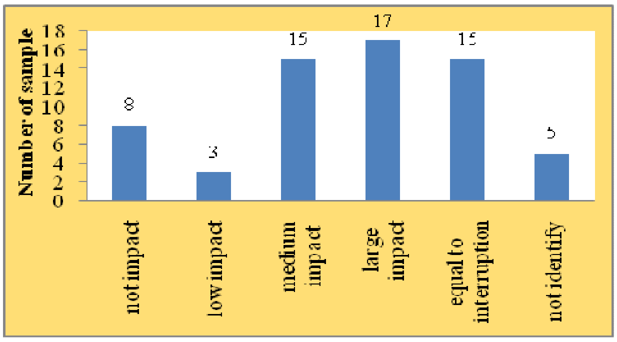

Fig. 10. Specifying impact level of overvoltage.

In addition, the specifying impact levels of sustain interruption (duration longer than 1 minute) are surveyed which the result is shown in Fig. 11. Most respondents informed that unreliable power relating sustain voltage interruption can contribute to a large economic impact. The voltage interruption is caused by the operation of protective devices such as breakers tripping and fusesblown out. In this industrial area, industrial customershadexperiences about 9 sustain interruptions and 18 events of recloser operation. Industrial process interruptions were caused by a wide range of phenomena includingequipment failures, animals, trees, severe weather, and human error. However, the statistic of interruption indicates that the majority of causes are from equipment failures. Regarding power quality and reliability improvement programs, the distribution utility who responsible in this service area has a great challenges opportunity to improve the network performance for minimizing industrial customer impacts and increasing customer satisfaction.

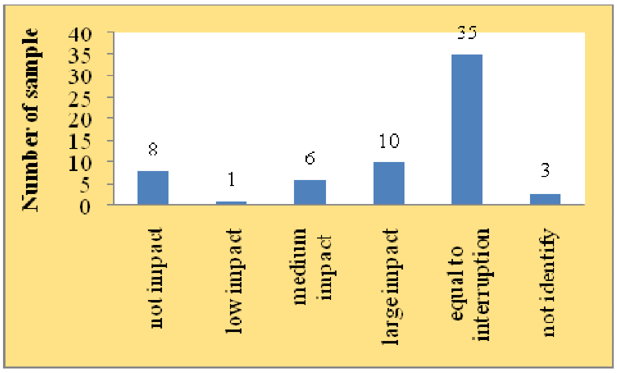

Fig. 11. Specifying impact level of sustain interruption.

5.3 Estimation cost of power quality problems

In order to estimate the costs of power quality problems, the weighting factors in Table 5are applied for calculation which the cost of voltage interruption was used as the reference value.The estimation of costs is divided into three industrial scale comprising small scale industry, medium scale industry and large scale industry, respectively. The calculation results in term of monetarylosses per event and monetary losses per average demand are summarized in Table9 and Table 10, respectively. Power quality costs in case of voltage sag varied from 20,833 to 335,290 Baht per event imply that industrial scale is significant to the losses from power quality.Further, the power quality cost of this survey is approximate 60-70% with respect to the cost of sustain interruption. The calculation results revealed that power quality problems are important issue for industrial customers as well as the voltage interruption.

Table 9. Power quality costs based event of problems

Scale	Voltage sag		Voltage Interruption	
	Baht/event	US$/event	Baht/event	US$/event
Small scale	20,833	637.47	32,667	999.57
Medium scale	37,875	1,158.93	52,000	1591.13
Large scale	335,290	10,259.49	503,935	15419.81

Remark: 1 US$≈32.681 Baht (2010)

Table 10. Power quality costs based customer demand

Scale	Voltage sag		Voltage Interruption	
	Baht/kW	US$/kW	Baht/kW	US$/kW
Small scale	125.64	3.84	207.96	6.36
Medium scale	34.27	1.04	85.53	2.61
Large scale	119.82	3.67	180.09	5.51

Remark: 1 US$ = 32.6810 Baht (2010)

6. CONCLUSION

Modern technology industry has extremely high value productionprocesses which are more sensitive to power quality events.This paperpresents the survey results about power quality costs and voltage interruption costs of 63 advance technology industries related to fabricated metal, machines and equipment products.The selected industries were located in Nava Nakorn industrial zone, Pathumthani province, Thailand. Regarding to thestatistic of circuit breaker and recloser operations in 2010, industries in the areahad experiencedof economic losses from both direct and indirect costs. The levels of customer impact are dependent to significant factors including types of the power quality problems, value of products, manufacturing processes, industrial size or capacity and etc,. High level of customer impact is categorized in large scale industry especially in semiconductors, hard drives and computer components products. The economic impact levels from various power quality categories wereestimated by industrial expert experiences stated inquestionnaire guideline. In case of voltage sag, the average monetary losses are evaluated with 20,833, 37,875 and335,290Bahtper event for small scale industry, medium scale industry and large scale industry, respectively.In addition to reliability aspects, the industrial impact associated sustain voltage interruption can be evaluated with 32,667, 52,000 and 503,935Baht per event for small scale industry, medium scale industry and large scale industry, respectively. The estimation reveals that it is important to consider the impacts of both interruptions and power quality problems. Based on customer survey results, installation monitoring system is the basic measure for industries to deal with power quality and reliability problems. The conditions of quality and reliability of power supply can accelerate or decelerate various opportunities and national economic growth.

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