DEVELOPMENT OF POWER QUALITY CONTROL PROCEDURES AND STANDARDS TO CONTROL THE CONNECTION OF NON-LINEAR LOADS IN ELECTRIC POWER SYSTEMS

Ignatius RENDROYOKO
PT PLN (Persero) – Indonesia
Ignatius.rendroyoko@pln.co.id

Muhammad RUSLI
PT PLN (Persero) - Indonesia
m.rusli@pln.co.id

ABSTRACT

The rise of new electric customers with type of load of iron smelting electric furnace has made PLN prompted to prepare adequate power supply, improved reliability of electricity supply and fix the rules of on standards and control procedures of electric power quality on customer's side. Load type iron electric furnace or iron smelters, has been known to cause power quality problems, especially harmonics, which may cause disturbance to other consumers or to electrical power system. Therefore, procedures to supervise and to control customer's electrical load which causing power quality problems need to be developed and implemented to maintain the power system from voltage and current harmonic distortion problem and the influence of other power quality problems. Also, power quality standard as the major rules regarding the limitation of power quality distortions has to be established and consistenly implemented including on the letter of power purchase agreement between utility and electricity customer.

This paper shows the efforts of PLN to develop supervision and control procedures and power quality standards for limiting the distortion power quality and also the preparatory steps for applying the rule on each electric power customer's. Implementation strategies for applying the power quality limitation rule to both news customers and existing customers are described in detail.

Index Terms — power quality, harmonics, non-linear loads, standards, assessment, supervision & monitoring

INTRODUCTION

The announcement of a ban on export of unprocessed metals and non-metallic minerals in the Minister of Energy and Mineral Resources ("MEMR") Republic of Indonesia, Regulation No. 7 of 2012 regarding the Improvement of Mineral Added Values Through Mineral Processing and Refining has made numbers mineral mining company began planning to build mineral processing plants into advanced products. The plan has sparked a growing demand for electric power supply for operation of the metal ore smelting plant in numbers of areas that rich in mineral resources. Recently, there are already 10 potential customers have applied for electricity connection in south east Sulawesi, West Kalimantan, Ternate and East Nusa Tenggara region.

In order to serve electricity connections to supply metal ore smelting plant loads, PLN, the one and only state owned electricity company, has to prepare two main things, firstly the availability of adequate power supplies, and second, ensuring the reliability of supply and power quality. In particular, the readiness of the utilities to ensure the quality of electric power is very important because regions where the plant will be built are mostly consist of weak power system. The other important things, the electricity load of mineral smelter plants are categorized as non linear load which may generate power quality problems such as harmonics. In order to anticipate the upcoming problems, utility has to begin to develop their power quality limitations and its control and supervision procedures. The new electricity customers should be able to meet the criteria and required power quality limits before connecting to electrical power systems.

This paper discusses steps undertaken by PLN, the utility company that has duties and responsibilities to supply electricity, for the development of electric power quality standards and developing the mechanism of power quality supervision, control and monitoring, for existing customers and new customers. Numbers of power quality limits are shown and discussed in this paper including the proper methods of power quality measurement and mitigation strategies. Implementation strategies for applying the power quality limitation rules in assessment procedures and article of power purchase agreement are described in detail..

NON LINEAR LOADS

It has been stated on the previous section that electrical load with the type of metal ore smelting plants usually use equipment arc furnace or induction furnace which categorized as one of non linear loads. Non-linear load is define as a load that draws a nonsinusoidal current wave when supplied by a sinusoidal voltage source which can cause power quality disturbances increased levels of harmonics, flicker and voltage fluctuations1, 2, 3. Single line diagram load model of the Arc Furnace is shown on Figure 1 below.

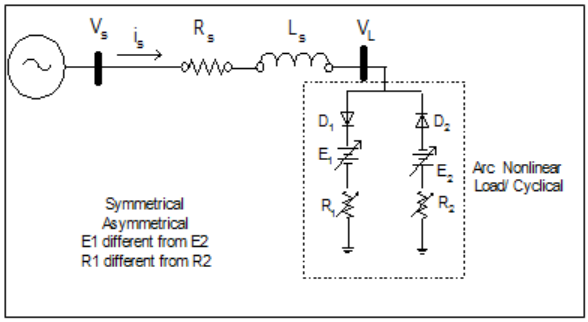

Figure 1 Type of Non Linear Load

The nature of non-linear loads is to generate harmonics in the current waveform. This distortion of the current waveform leads to distortion of the voltage waveform. Under these conditions, the voltage waveform is no longer proportional to the current. in addition, non-linear loads can cause voltage fluctuations and flicker. The non linear loads are : computer, computer-based controlled equipment, rectifier, induction furnace, arc furnace, programmable logic control, electric welding equipment, etc. In particular, the electelectric arc furnace, can also cause voltage fluctuations and flicker when connected to a weak electrical system.

Based on the above matters, utility electricity companies need to prepare themselves by providing adequate electrical power supply infrastructure, set the regulation of power quality limits and the ability of handling problems of power quality at the customer side and also on electrical power system. With it, customers can be maintained to not cause power quality problems.

POWER QUALITY STANDARD

The power quality standard is designed to set a maximum limit allowed of power quality distortion level in the customer connection point on the low voltage, medium voltage, and high voltage networks. The standard also includes measurement procedure, steps in evaluation and assessment, and mitigation of power quality problems on customer connection point. The purpose of this standard is as a general guideline in setting the terms and conditions to be met on the electrical power purchase agreement, within the limits of harmonic distortion, flicker and voltage fluctuations, and also as guideline to do measurements at the point of customer connection and to perform mitigation measures.

Power Quality Limits

Power quality limits that are stated on this standard particularly are harmonics distortion limits, limits of voltage fluctuations and flicker. Those power quality limits are considered closely related to the non-linear loads (such as mineral smelters) to be connected to the power system.

1. Harmonics

Harmonics is generated due to the non-linear loads connected to the power system. As stated on previous paragraph, non linear loads such as computer, computer-based controlled equipment, rectifier, induction furnace, arc furnace, programmable logic control, electric welding equipment, etc may cause harmonic currents in power distribution networks that generate harmonics voltage distortion on the electric power network. This harmonic distortion resulting in disruption of the operation of equipment such as: computers, transformers, motors, electronic control equipment connected to the same network. Therefore, the level of harmonic currents at the customer connection point has to be kept within a certain limit, so the level of harmonic voltage distortion in power system still meets the requirements. An example of harmonic distortion in the current and voltage waveform shown in Figure 2.

This power quality standards is developed based on the reference of IEEE Std 519-1992 IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power System[1]. document provides many of those definitions that are reproduced at the end of this chapter. Its offer a standardized terminology that facilitates discussion of system harmonic issues. The basic requirements of voltage distortion and current distortion are guides for many users, including utilities, electricity customers, etc. When followed they eliminate most of the power system concerns relating to application of solid state equipment.

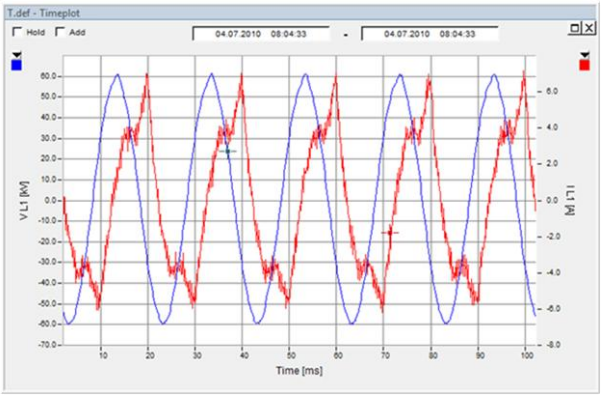

Figure 2 Measured voltage and current harmonics in the metal smelting plant

Utility companies have obligations to maintain the quality of the voltage of the power system within the harmonic voltage limit when the customer can meet the harmonic current distortion limits. Utility can only be fairly judged if customer is within its harmonic current limits[1].

Table 1 Harmonic Voltage Distortion Limits

Voltage Level (Vn)	Individual Voltage Distortion (%)	THD_{Vn} (%)
Vn ≤ 66 kV	3.0	5.0
66 kV < Vn ≤ 150 kV	1.5	2.5
Vn > 150 kV	1.0	1.5

Table 2 Harmonic Current Distortion Limits For Vn ≤ 66kV

Vn ≤ 66kV						
Ihs/IL	Harmonic Current Distortion Limit I_L (%)					
	Individual Harmonic Order I_h					TDD
	h < 11	11≤h <17	17≤h <23	23≤h <35	35≤h	
< 20*	4.0%	2.0%	1.5%	0.6%	0.3%	5.0%
20 – 50	7.0%	3.5%	2.5%	1.0%	0.5%	8.0%
50 – 100	10 %	4.5%	4.0%	1.5%	0.7%	12 %
100 – 1000	12%	5.5%	5.0%	2.0%	1.0%	15 %
>1000	15 %	7.0%	6.0%	2.5%	1.4%	20 %

Table 3Harmonic Current Distortion Limits For 66kV ≤ Vn ≤ 150kV

66 kV < Vn ≤ 150 kV						
Ihs/IL	Individual Harmonic Order I_h					TDD
	h < 11	11≤h <17	17≤h <23	23≤h <35	35≤h	
< 20*	2.0%	1.0%	0.75 %	0.3%	0.15 %	2.5%
20 – 50	3.5%	1.75 %	1.25 %	0.5%	0.25 %	4.0%
50 – 100	5.0%	2.25 %	2.0%	0.75 %	0.35 %	6.0%
100 – 1000	6.0%	2.75 %	2.5%	1.0%	0.5%	7.5%
>1000	7.5%	3.5%	3.0%	1.25 %	0.7%	10.0 %

Table 4Harmonic Current Distortion Limits For Vn >150 kV

Vn > 150 kV						
Ihs/IL	Individual Harmonic Order I_h					TDD
	< 11	11≤h <17	17≤h <23	23≤h <35	35≤h	
< 20*	2.0%	1.0%	0.75 %	0.3%	0.15 %	2.5%
20 – 50	3.5%	1.75 %	1.25 %	0.5%	0.25 %	4.0%

2. Flicker

Flicker is the impression of instability in the visual sensation of light caused by stimulation of its time-varying distribution spectrum caused by voltage fluctuations of electrical equipment such as electric arc furnace, starting of motor and switching of large electrical loads[2].

Table 5 Flicker compatibility and planning levels

	Compatibility Level	Planning Level	
	LV	MV	HV
P_{st}	1,0	0,9	0,8
P_{lt}	0,8	0,7	0,6

3. Voltage Fluctuations

Voltage drop due to the fluctuating industrial loads commonly called voltage flickering or flicker. Voltage drop above the generally expressed by the short circuit voltage depression (DTHS) with limits as listed in Table 6 below :

Table 6 Short circuit voltage depression limits

Level Tegangan	DTHS (%)
150kV	≤ 2.5
66 kV	≤ 2.75
20kV	≤ 3.0

The power quality standards should be defined as a corporate standard and has to be implemented.

Measurement

Measurement of power quality is an important activity since the measurement results will be compared with the applicable standards and determine next steps in monitoring the quality of electric power. In the electric power quality standards, there are several things that must be agreed as follows:

1. Determination of measuring points

Location of electric power quality measurements shall be done at the point of customer transactions

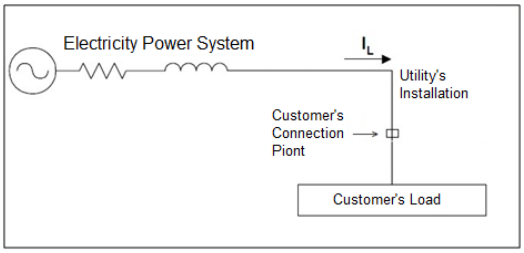

Figure 3 Measurements on customer transactions point

2. Duration of power quality measurement

In order to get the data of the installation during full load and normal cycle operating conditions, measurements should be carried out over a period of minimum 7 (seven) days.

3. Type of equipment that can be used in the measurement

Power quality measurements performed by using the energy meter transaction with characteristics in accordance with IEC 62053-22 and IEEE 1159-1995 Recommended practice for monitoring electric power quality.

Types of equipment that can be used to measure power quality are as follows :

a) Energy meter with power quality capabilities
b) Power quality analyzer
c) Power quality monitoring equipment

Mitigations of power quality problems

Mitigation of power quality problems are steps that can be taken in order to reduce the level of power quality distortions that would meet the required limits and do not interfere with operation of equipment at customer installations. Generally, mitigation of power quality problems can be done by fixing the power system configuration and also by installing compensator equipment that can filter out the distortion of power quality.

In the electric power quality standards, mitigation of harmonic currents in a power system the customer can be done with the following steps :

a) Grouping of customers that generate harmonics
b) Installation of passive filters
c) Installation of active filters
d) Selection of transformer windings relations
e) Relocation of Shunt Capacitor Banks
f) Transfering customer connection to higher short circuit level

Mitigation of flicker and voltage fluctuation effects may be done by:

a) Grouping of power transformer installation with voltage fluctuation source load separate from other customers
b) Installing compensators

ASSESSMENT AND CONTROL PROCEDURES

Electric power quality assessment conducted to determine the extent of power quality distortion occurs in a customer's installation. For existing customers, the assessment is carried out by measuring the level of power quality at the customer transactions point and the results are then compared with the applicable restrictions.

For prospective or new customers, power quality assessment is carried out using different methods. Because the installation of electrical power systems of potential customers has not been installed, then the assessment is done by simulating the load flow of power using computer simulation applications to get an estimation of the level of power quality distortions that may occur due to operation of the smelter customer installations. If simulation results shows level of distortion that may occur exceed allowable limits, then the prospective customer is required to install compensator equipment.

The flow diagram of power quality assessment is shown in Figure 2 below.

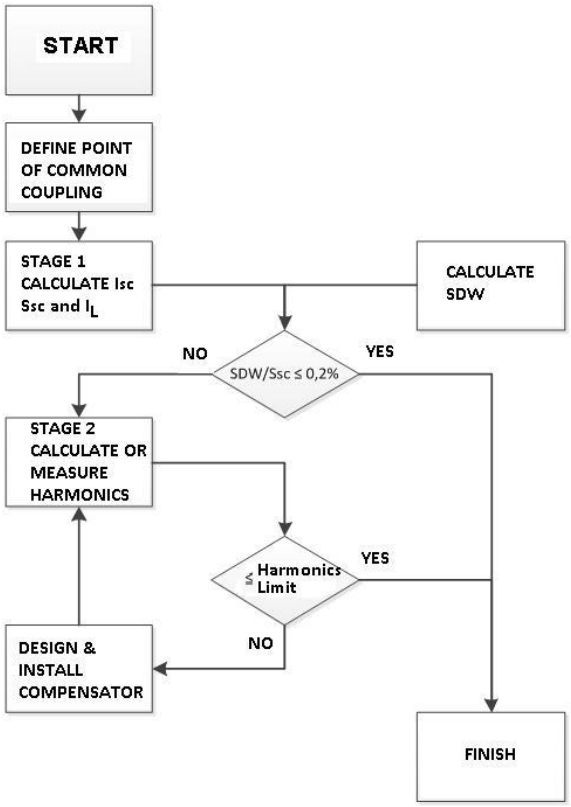

Figure 4 Power quality assessment procedure

PQ Assessment for existing customers

Referring to Figure 4 above, the power quality assessment for old electricity customers or existing customers begins with determining the point of measurement at the customer transactions point. Then, in the first stage, assesment is conducted by calculating and comparing power system short circuit capacity to weighted disturbing power (S_{DW}). S_{DW} is number of loads that cause harmonics in the customer's facility, and can be calculated using this formula:

$$S_{DW} = \sum_{i} (S_{Di} \times W_i)$$

If the comparison between the weighted disturbing power and short circuit capacity at the customer connection point less than 0,02% it means that means that the electrical load does not cause power quality disturbances and categorized as below the power quality limit.

$$S_{DW}/S_{SC} \leq 0.2\ \%$$

If the first requirement can not be met then assessment proceed to stage 2. In this stage power quality measurement will be conducted and the result shall be compared with the power quality limits. The electricity load will be eligible if the measurement result is below the required level, otherwise, electricity customers should install power quality compensator.

PQ Assessment for new customers

Assessment steps for new customers for the first stage, performed with the same steps as to the existing customer. assesment is conducted by calculating and comparing power system short circuit capacity to weighted disturbing power (S_{DW}). For new customers, the S_{DW} is calculated using their planned installation. Using the same formula as stated above, comparison between the weighted disturbing power and short circuit capacity at the customer connection point can be calculated and analyzed.

If the first requirement cannot be fullfilled then assessment proceed to the next stage. In the 2th stage, a simulation model of customers installation can be developed using general simulation software and the simulation result should be compared to the power quality limit. Similar to the method applied to existing customers, if the simulation result below the required level then it will pass. Otherwise, a power quality compensator shall be put into the simulation and and the simulation is repeated until the result shows the acceptable results.

POWER QUALITY IN POWER PURCHASE AGREEMENT

The important thing for the development of the power quality standards is the implementation of these rules to be applied by the utility to each electricity customer. In order to apply the standard and to have legally binding force, then the the power quality limits should be included in the letter of power purchase agreements (PPA). There are several important key factors thet should be mentioned as follows :

Definitions and detailed power quality descriptions

This section is designed to describe the definition of specific terms of power quality such as such as the definition of harmonics, voltage fluctuations and voltage flickering nor a definition of the induction furnace and electric arc furnaces, etc. With the explanation both parties are expected to have the same understanding of some specific power quality terms which are listed in the agreement. An examples of the article of power purchase agreement that mentioning about the explanation on the definition of power quality terms is shown on Figure 5.

Article 4

Special Technical Provisions for Induction Furnaces Customers

(1) Definition :

a. Harmonics are sinusoidal component of periodic current or voltage waveform and has an integer multiple frequencies (2, 3, 4, 5, etc.) of the fundamental waveform of current or voltage (50 Hz)
b. Total harmonic distortion Voltage is the ratio between the effective value of the voltage waveform of all the harmonics of the effective value of the voltage waveform fundamental frequency (50 Hz)
c. Individual Harmonic Voltage Distortion is the ratio between the effective value of each harmonic wave voltages of the effective value of the voltage waveform fundamental frequency (50 Hz)
d. The Individual Harmonic Current Distortion is the ratio between the effective value of each harmonic current waveform to the effective value of the voltage waveform fundamental frequency (50 Hz)
e. Total Demand Distortion (TDD) is the ratio between the effective value of all harmonics of the current wave effective value of the voltage waveform fundamental frequency (50 Hz)
f. Induction Furnace is an electric furnace electric furnace for use in smelting works, the creation and establishment of object-based metal / steel using alternating current electrical energy with frequency from 50 Hz to 10,000 Hz
g. Harmonic Filter is electrical equipment which function to filter the wave harmonic currents and deliver it to a certain place so it does not flow toward the power source (the First Party) and elsewhere

(2) The Second Party, in operating the induction furnace installations and equipment shall meet the following requirements:

Figure 5 Details of the definition of power quality

General Obligations

The agreement imposes obligations on each party to satisfy the conditions of the power purchase agreement. Generally, the duty of performance is the duty to fulfill each of the conditions of the agreement including the power quality limits. The approach of obligations of each party involves a divided responsibility between the customer and the utility :

1. The customer is responsible to maintain power quality current injection at the point of common coupling between the customer and the utility so the level of harmonics, flicker and voltage fluctuations are always within the allowable limits.
2. The utility is responsible for the voltage distortion at the point of common coupling. This means that the utility must make sure that system resonance conditions do not result in unacceptable voltage distortion levels, even if all customers are within the recommended guidelines for power quality[1].

Statements of power quality limits

Statements about the limitations of the required quality of electric power are the most important part which specificly corresponds to power quality matters. The power quality limits, which are written in the agreement, will be the main reference of power quality performance that must be complied by the customer.

An examples of the article of power purchase agreements that mentions about the power quality limits can be seen in Figure 6.

a. The Individual Harmonic Voltage Distortion and Total harmonic distortion Voltage (THD) on the point of transaction not exceed the provisions in Table 1 as shown below :

Tabel 1 Harmonic Voltage Distortion

Individual Harmonic Voltage Distortion (%)	Total harmonic distortion Voltage – THD (%)
3.0	5.0

b. The Individual Harmonic Current Distortion and Total Demand Distortion (TDD) on the point of transaction not exceed the provisions in Table 2 as shown below :

Tabel 2 Harmonic Current Distortion

h < 11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD (%)
4.0%	2.0%	1.5%	0.6%	0.3%	5.0%

Note :
1. Numbers in the table apply to the odd harmonics
2. Even harmonic components are limited to 25% of the limits in the tables

c. Voltage fluctuations caused by loading and measured at the point the transaction is not more than 5%
d. Average monthly Cos phi at least 0.85 lagging, and the number of live hours per month of cos phi is less than 0.5 lagging must not be more than 1/4 the total number of hours in the blazing

(3) The Second Party are required to install and operate a harmonic filter in order to comply with the provisions in paragraph (1) a and (1) b of this article.

Figure 6 Statement of Harmonic Limits

The imposition of sanctions for any violations

Last but not the least, in order to keep customers always maintaining the level of power quality in their installation, in the power purchase agreement has to state the matters concerning sanctions for any violations of technical provisions. These types of sanctions can be done in the form:

1. Temporary disconnection of electricity supply service

   Electricity supply to customers will be temporarily disconnected until the customer can resolve the problem.

2. The second party shall pay a penalty for the violations

   In the PPA included a large number of fines to be paid on an infringement

The agreement between the parties on the implementation of these sanctions will reinforce and will add value to the power purchase agreement, especially on the matters of power quality restrictions.

CONCLUSIONS

The development of power quality standards as defined in IEEE Std 519 as a corporate technical standard is a useful exercise and experience but often a challenging one. This power quality standard will be used as the main reference for the company to regulate and control their customers, both existing customers and prospective customers, so that their load will not cause power quality disturbances. Implementation of this power quality regulation certainly will take some effort but will produce a good achievement in near future.

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