Analysis Of Power Quality Effect On The Life Time Transformer

Jepi Yuli Hindarianto

Department of Mechanical Engineering, Swiss German University, Tangerang 15143, Indonesia

Abstract. In the industry that runs today, of course, electricity cannot be separated from the electricity used for all production processes. In Indonesia, currently PT. PLN (Persero) (PLN) is the only one of electrical energy provider for the medium and larger scale of industry. The electricity power for industry is usually supplied by 20 kV distribution grid. Meanwhile, industrial utilities, equipment and machinery mostly require lower voltage. Therefore, it is necessary to step down the voltage of the PLN distribution grid from 20 kV to 2 kV, 1 kV, 400 Volt or lower by using step down transformer. Step down transformer has very important role in any industrial facility. Failure and under performance in the maintenance and operation of step down transformer will cause significant effect to the continuation of industrial facility. There are several things that can affect the lifetime of the transformer, one of them is the power quality of the supplied electricity from the grid. The power quality in the form of Total Harmonic Distortion Voltage (THDV), Total Harmonic Distortion Current (THDI), voltage sag, flicker, current, and power must be maintained in required limit or standard range so that it keeps the step down transformer in the best performance and also longer lifetime. In order to know the performance and lifetime of the transformer, there are two important tests that need to carry out periodically which are Dissolved Gas Analysis (DGA) and Break Down Voltage (BDV) test. These tests examine the dissolved gas content and dielectric strength in the transformer oil. The work in this thesis is to carry out a study of power quality effect on a transformer lifetime. The supplied power quality of the PLN grid in the outgoing of step down transformer was measured by using HIOKI PW319 power analyser. Experiment and analysis in this thesis concluded that there is a strong correlation between the supplied power quality of PLN grid and the performance and lifetime of the examined transformers. Poor power quality causes the running lifetime and the performance of the examined transformers decreases.
Keywords: Transformer, Power Quality, THDV, THDI, Power Analyzer

1. Introduction

In an industrial process, Electricity is one of the important factors used to support the Production process. Equipment and machinery used in industries require enormous electrical energy. Similarly, PT. GeTe uses large electricity to run its production machinery. The use of this large electricity must be supported by the quality of electricity supply. Power quality not only affects the customer side but can also affect PLN which acts as the main resource. PLN as the main electricity source flows a voltage of 20KV, so that for the production process a tool is needed to reduce the voltage, namely the step down transformer.

The use of the voltage-dropping transformer is not only used by PLN but also the middle and upper scale customers also use voltage-lowering transformer. PT. GeTe is a medium-scale electricity utility PLN that gets 20 kV power supply input. So to run the industrial process working voltage needs to be lowered first with a voltage-lowering transformer. There are over 100 voltage reducing transformers available in this company, so that proper maintenance is required for the transformer to work with the maximum and also the transformer has a longer working life.

In this case, transformer owned by PT. GeTe needs to be tested to determine the performance of the transformer installed. By using transformer oil test (Dissolved Gas Analysis and Break Down Voltage) it will be known transformer performance or can be called with the transformer lifetime. Lifetime transformer is closely related to the quality of electrical power included in the transformer.

Transformer contained in PT. GeTe is known to experience some performance degradation after testing of transformer oil. This is what underlies the author to do research related to the existing transformer performance so that it can be done to prevent damage to the transformer. By doing this research will know the relationship of transformer performance or lifetime with the quality of electric power. Then from these results can be recommended how to make the transformer performance is maintained and can even work longer.

The author considers this very important given the role of the transformer is so vital in the production process and minimize the losses experienced if the transformer suffered sudden damage.

2. Scope

The limitations of the problem in this research are as follows:

1. The analysis used is statistical analysis or comparison data.
2. Taking the transformer test data in the Mixing plant
3. Measuring tool using Hioki Power analyser PW3198
4. Analysis focused on power quality research on transformer.
5. Temperature of the transformer not measure.

3. Methodology

Methodology used by writer to know the degradation of transformer performance by collecting data result of Dissolved Gas Analysis (DGA) test, Break Down Voltage (BDV) on mixer transformer 1 and transformer 2.Then measured at each transformer output by using measuring instrument HIOKI PW3198. After the data collected then performed the comparison of oil test results and power quality of each transformer

3.1. Dissolved Gas Analysis (DGA)

DGA (Dissolved Gas Analysis) can literally be interpreted as an analysis of transformer conditions based on the amount of solute gas in transformer oil. DGA in the industrial world is also known as a blood test or blood test on the transformer. Human blood is a compound that is easy to dissolve other substances that are in the vicinity. Through testing the substances dissolved in the blood, it will obtain related information about human health. Similarly, the transformer, the test of solutes (usually gas) on transformer oil (transformer oil is analogous to human blood) will provide information related to the overall health and quality of the transformer.

Certain gases generated in an oil-immersed transformer should be addressed as the first indication of a malfunction that may eventually lead to failure if not connected.

Some indications of the source of the gases and the kind of insulation involved may be gained by determining the composition of the generated gases and interpreted according to IEEE standard C57.104-2008. (IEEE Standard C57.104-2008)

Table 1. Dissolved Gas Concentration Standard

STATUS	Disolved Key Gas Concentration Limits [(µL/L (ppm)2]							
	Hydrogen (H2)	Methane (CH4)	Acetylene (C2H2)	Ethylene (C2H4)	Ethane (C2H6)	Corbon Monoxide (CO)	Carbon dioxide (CO2)	TDCG
Condition 1	100	120	1	50	65	350	2500	720
Condition 2	101 - 700	121 - 400	2 - 9	51 - 100	66 - 100	351 - 570	2500 - 4000	721 - 1920
Condition 3	701 - 1800	401 - 1000	10 - 35	101 - 200	101 - 150	571 - 1400	4001 - 10000	1921 - 4630
Condition 4	> 1800	> 1000	> 35	> 200	> 150	> 1400	> 10000	> 4630

Whereas
Condition 1 (Very Good):
Total Dissolved Combustible Gas (TDCG) below this level indicates the transformer is operating satisfactorily
Condition 2 (Good):
Total Dissolved Combustible Gas (TDCG) within this range indicates greater than normal combustible gas level.
Condition 3 (Bad):
Total Dissolved Combustible Gas (TDCG) within this range indicates a high level of decomposition
Condition 4 (Very Bad):
Total Dissolved Combustible Gas (TDCG) within this range indicates excessive decomposition

3.2. Break Down Voltage (BDV)

Test Break Down Voltage (BDV) is a Breakdown Voltage Test. It is necessary to check the dielectric strength of the Transformer oil. The dielectric strength is the maximum capacity of the transformer oil to withstand the insulating oil voltage. This test shows the strength of the Transformer oil dielectric.
The oil contained in the transformer has two functions, the first as isolation, and the second as cooling the transformer core and windings. So the use of transformer oil in the transformer depends on the voltage rating. Therefore, the oil test is performed according to the voltage rating.
The Electrical strength of the oil given the breakdown voltage, measured using an electrode system in accordance with IEC 60156 and IEC 60422. The electrode are spherical with 12.5 mm 13 mm radius and electrode gap are 2.5mm. The measurement is carried out at rated frequency 40-60 HZ. The rate of increase of the voltage being 2 kV/s. Start from zero up to the value producing break down.
The electric strength of the oil shall be carried out six times on the same cell filling. The Electrical strength is the arithmetic mean of the six results which have been obtained.
The dielectric strength of old oil in service oil should be at least like table below.

Table 2 Dielectric Strength Standard

Transformer Category		Condition		
		Good	Fair	Poor
170 - 400	KV	> 60	50 - 60	< 50
72.5 - 170	KV	> 50	40 - 50	< 40
< 72.5	KV	> 40	30 - 40	< 30

Oil which does not whit stand this voltage may contain bubble, dust or moisture.

3.3. Hioki PW3198

The Hioki 9624-50 PQA-HiView Pro is a software application for analysing binary format measurement data from the Hioki 3196, m197 and 3198 Power Analysers on a computer.
The PQA-HiView Pro can load and read only binary data recorded with the Hioki 3196, 3197 and 3198 Power Analysers.

Figure 1 HIOKI PW3198

Figure 2 *Schematic Measurement output transformer*.

3.4. Power Quality

Power Quality as a term often defined as the ability of the power grid to supply the flow of electricity acts as a provider of available power flow, has noise-free with pure wave sinusoidal form, and always in voltage and frequency tolerance. However, deviations from these ideal conditions often occur in most networks, usually the amount of burden imposing disturbances increases rapidly. Problems with Power Quality is a problem for a number of business sectors with high costs and increasing number of disruptions causing modern production equipment to become more sensitive to interference. Ironically, often the equipment itself is the cause of the coming disorder. Measures Causing Losses and Disturbances The acts that cause harm and disruption are simplified terms for related technical phenomena that are problems in the scope of the electrical world.

Power quality has several problems, such as :

3.4.1 Voltage Sag

Voltage Sag event is a voltage drop. This event could be caused by network error or entry of equipment requiring large initial flows to the network.

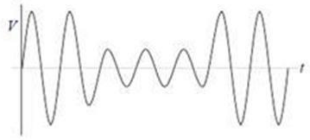

Figure 3 Voltage sag

Voltage sag can result in equipment failure, computer errors, computer memory loss. The phenomenon of Voltage Sag is known as a flicker phenomenon. Flicker is a distortion phenomenon in the amplitude of the voltage wave repeatedly.

3.4.2 Power Surge

Power Surge is an imposition of a sudden increase in power supply to a load. This event is perceived as an increase in stress at the load. This event can happen if the electric equipment that uses a large power suddenly loose/removed from the network. This incident is felt by the other load as an increase in voltage (at normal frequency) this voltage rise can reach 110% or more of the normal voltage.

Power Surge can cause flicker, equipment off, errors on computer, and memory loss in computer.

3.4.3 Transient

Transient is a variable change (voltage, current) that takes place during the transition from one stable condition to another. The causes of transient occurrence include:

a. Load switching (connection and disconnection)
b. Capacitance switching
c. Transformer inrush current
d. Recovery voltage

Transients are power quality disorders involving high currents and destructive tensions or even both. It can reach thousands of volts and amps even in low voltage systems. However, such phenomena exist only in a very short duration and less than 50 nanoseconds up to 50 milliseconds. Transients include abnormal frequencies, which can reach a value of 5 MHz.

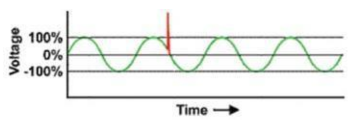

Figure 4 Transients

In addition, transients are also known as waves. The surge is a voltage wave, current or power while in an electrical circuit (IEEE 100). Another IEEE definition indicates that it is part of a variable change that is lost during the transition from one operating condition to another. Such descriptions are too vague, which can be used to describe almost all the unusual events occurring in the electrical system.

In addition, most electrical engineers will refer to the muffled oscillator transient phenomenon in the RLC circuit when hearing the term.

3.4.4 Transient

Voltage unbalance can be defined as the ratio of negative or zero order component to positive sequence component (IEEE). Or it can be said as a voltage variation in the power system where the magnitude of the voltage or phase difference between them is not the same. Therefore this power quality problem only affects the poly phase system.

The voltage between the phases is mostly unbalanced. However, when the voltage imbalance becomes excessive, it can cause problems for poly phase motors and other loads. In addition, adjustable speed drives (ASD) can be more sensitive than standard motors. Causes Voltage unbalance due to unequal load on distribution lines or in production machines. In other words, negative or zero sequence voltages in the power system are usually generated from unbalanced loads that cause negative sequence current or zero to flow.

Voltage Unbalance means that the voltage available in the three phases is not the same, this can happen in any distribution system.

Researcher will use ANSI / NEMA definition / calculation, because it is simpler and can be readily calculated from the measured data. In practical, there will be no difference if we use IEC definition by more than 0.05%. We calculate the voltage imbalance based on ANSI / NEMA definition, as follows:

An example, for each phase voltage V A = 230 Volt, V B = 232 Volt, V C = 225 Volt. V AVERAGE = (V A + V B + V C) / 3 = 229 Volt. Maximum deviation from V AVERAGE is due to V C; V C – V AVERAGE = 4 Volt. Therefore, the voltage imbalance = (4 / 229) × 100% = 1.75%. Desirable level of voltage imbalance is less than 1% at all voltage levels. The ANSI C84.1-1995 requires the voltage imbalance to be < 3%, while the more recent IEC 61000-3-13 requires the voltage imbalance to be < 2%. Based on the experiment on NEMA Std. Pub. MG 1-1998, motors will get additional heating which varies as cube of voltage imbalance (3% of unbalance equals to 25% additional heating of the motors).

3.4.5 Harmonic

Harmonics can be regarded as a sinusoidal voltage or current which has a frequency and is an integer multiple of the fundamental frequency at which the power system is designed to operate. This means that for a 60-Hz system, the harmonic frequency is 120 Hz (2nd harmonic), 180 Hz (3rd harmonic) and so on. Harmonics and the base or current voltage can produce non-sinusoidal forms, thus, distortion waves are a matter of power quality. The non-sinusoidal waveform corresponds to the number of different sine and phase-phase waves, and has a frequency that is a multiple of the system frequency.

The harmonic distortion values can be shown by the harmonic spectrum with the magnitude and phase angle of each harmonic component. In general use Total Harmonic Distortion (THD), as a measure of the effective value of harmonic distortion. Protection from high level harmonics including isolation or source modification, multiplication phase, pulse width modulation (PWM) and passive or active harmonic filter application.

Harmonics is a disturbance that occurs in the electric power distribution system due to the current and voltage wave distortion. The distortion of current and voltage waves is caused by the formation of waves with a frequency multiplied by a frequency of the fundamental frequency. In fact, the existence of this harmonic causes a loss in the distribution transformer, harmonics are a symptom of the formation of waves with different frequencies which are all integers with their basic frequencies. This is called the harmonic frequency that arises in the original waveform while the base frequency multiplier is called the harmonic sequence number. For example, the basic frequency of an electrical system is 50Hz, so the second harmonic is a wave with a frequency of 100Hz, the third harmonic is a wave with a frequency of 150Hz and so on. If the frequency at 50 Hz is said to be the fundamental frequency or basic frequency (f), then if the wave is distorted if it experiences multiple frequency from its basic frequency, for example the second harmonic (2f) at 100 Hz, third (3f) at 150 Hz and the harmonics n has an nf frequency. These waves will ride on the fundamental frequency wave and a defective wave will form which is the sum of pure waves with the 3rd harmonic wave.

In Figure 2-4, the third harmonic distorted fundamental waveform is shown. As the standard harmonics reference used is the IEEE 519. 1992 standard, "IEEE Recommended Practices and Requirements for Harmonic Control in Electric in Electrical Power Systems". Based on the IEEE 519. 1992 standard there are criteria used to evaluate harmonic distortions, namely the limits for current harmonics and voltage harmonics limits as shown in table 3 and table 4.

Table 3 Standard Current harmonics (THDI)

System Voltage	*Isc/ILOAD*	*THDI (%)*
Vrms ≤ 69 kV	< 20	5.0
	20-50	8.0
	50-100	12.0
	100-1000	15.0
	> 1000	20.0
69 kV < Vrms ≤ 161 kV	< 20	2.5
	20-50	4.0
	50-100	6.0
	100-1000	7.5
	> 1000	10.0
Vrms > 161 kV	< 50	2.5
	≥ 50	4.0

Table 4 Standard Voltage harmonics (THDV)

System Voltage	*IHDv (%)*	*THDv (%)*
Vrms ≤ 69 kV	3.0	5.0
69 kV < Vrms ≤ 161 kV	1.5	2.5
Vrms > 161 kV	1.0	1.5

The transformer is designed to deliver the required power to the load with a minimum loss on its fundamental frequency. Harmonic currents and voltages will significantly cause more heat. There are two effects of more heat on the transformer when the load current contains the following harmonic components:

a) Current harmonics cause increased copper losses

b) Voltage harmonics cause increased iron losses, such as eddy currents and hysteresis losses. Eddy current occurs when the core of a ferromagnetic (iron) material is electrically conductive. The eddy current concentration is higher at the ends of the transformer winding because the effect of the magnetic field density leaks on the coil which causes the phenomenon of the eddy current to occur. Increasing eddy current losses because harmonics affect the working temperature of the transformer which is seen in large real power losses (watts) due to the eddy current.

4. Test result

In Table 3 there is a difference from the results of testing the quality of oil. In the transformer 1 results are very clear that there are some items on the transformer that the value of measurement outside the standard set. While in the transformer 2, all the measurements enter the standard set. This indicates that transformer 1 is in declining performance condition or the transformer is in poor condition.

In table 4 is the result of measurement Dissolved Gas Analysis test where transformer 1 in bad condition compared with measurement result in transformer 2. If this condition is not immediately handled will cause damage transformer. TDCG (Total Dissolved Combustible Gas) which is the amount of combustible gas dissolved in transformer1 represents a very large value of the set value limit.

While the measurement at the transformer output as shown in Table 5, clearly visible the quality of electric power that flows. In transformer 1 the quality of electric power flowing is worse than the one flowing in transformer 2.

By looking at the comparison of power quality measurements on the two transformers (see table 5) then compared with the results of the oil test as in the comparison table in the 3 and 4 table tables we can conclude that the quality of power affects the condition or performance of the transformer. Load characteristics also greatly affect the quality of electric power thus affecting the condition of the transformer.

Table 5 Comparing Result Oil Quality Transformer 1 and 2

Item	Standard	Unit	Limit	Result Transformer 1		Result Transformer 2	
				Value	Note	Value	Note
Water Contance	IEC 814	mg/kg	< 40	48.0	Outside Limits	9.0	Inside Limits
Breakdown Voltage	IEC 156	kV/2.5mm	> 40	31.0	Outside Limits	80.0	Inside Limits
Colour	ASTM D 1500	ASTM scale	-	Amber/L2.5	-+	Clear/0.0	-+
Interfacial Tension	ISO 6295	mN/m	> 28	24.3	Outside Limits	38.2	Inside Limits
Neutralisation Value	IEC 60296	mgKOH/g	< 0.1	0.080	Inside Limits	0.020	Inside Limits
Oil Quality index Number	OQIN/WP 222	.	> 160	304.0	Good	1910	Good

Table 6 Comparing Result DGA Test Transformer 1 and 2

Gas		Transformer 1		Transformer 2	
		Part per Million (ppm)	Condition	Part per Million (ppm)	Condition
Water	H20	48		9.06	
Hydrogen	H2	4615	Condition 4	<10	Condition 1
Methane	CH4	3285	Condition 4	4	Condition 1
Acetylene	C2H2	420	Condition 4	<1	Condition 1
Ethylene	C2H4	10783	Condition 4	40	Condition 1
Ethane	C2H6	3177	Condition 4	2	Condition 1
Carbon monoxide	Co	409	Condition 2	74	Condition 1
Carbon dioxide	CO2	3883	Condition 2	1993	Condition 1
Total Dissolved Combustible Gas (TDCG)		22699	Condition 4	120	Condition 1

Table 7 Comparing measurement output transformer 1 and 2

ITEM PQ	Transformer 1		Transformer 2	
	Result	Condition	Result	Condition
U unbalanced	1.97%	Fair	0.34%	Good
I unbalanced	9.84%	Fair	15.70%	Fair
Current	429.5 A	-	60.8 A	-
THDV	6.17%	Poor	2.75%	Good
THDI	80.88%	Poor	4.39%	Good
Frequency avg	49.994 Hz	Good	50.001 Hz	Good

5. Conclusion

Experiment and analysis in this thesis concluded that:

1. Poor supplied power quality from PLN grid as indicated in Table 5 is the main cause of the decreasing of the performance and lifetime of the examined transformers.
2. Lifetime transformers are influenced by the supplied power quality. So it is important to maintain the supplied power quality at the standard range and minimize its effect to the transformer.
3. Further analysis indicates that poor transformer insulation and higher load fluctuation load coil or stray capacitance may cause harmonic harvesting in the grid.
4. Load characteristics such as load fluctuation affects, indirectly the supplied power quality.
5. By comparing the results of the transformer 1 and transformer 2 measurements with the oil measurement results of each transformer can be seen that the power quality greatly affect the performance of the transformer.
6. From the measurement results, it can also be concluded that the transformer is also influenced by the production load.

6. Recommendations

After looking at the results of the study then the authors recommend several things as follows:

1. Taking into account the load characteristics before installing or selecting the transformer is required to maintain the long-lasting performance of the transformer.
2. Installation of filters can be done to reduce harmonic voltage
3. Use of transformer type for fluctuating load
4. Quickly Schedule Purification oil transformer to make new performance transformer.

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