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Power Quality Analysis of Electrical Installation at Commercial Center

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Abstract: For many years, power quality analysis has constantly been carried out at the power stations or sub-stations using the data collected at the data Centre of the power plant. However, this practice has proven to be erroneous and tedious to determine the exactly power quality problem especially when it comes to commercial facilities. Therefore, a revised approach of analysis for the power quality problems at the sites where they occur has been used in this research. This is because of the sensitivity of modern electronic equipment used in commercial facilities and also the need for accuracy of the data measurements carried out at the sites henceforth, with accurate data measurement, we can easily identify the power quality issues. Through-out this research, load unbalance of 28% was found. The solution to load unbalance was to balance the loads to 3,3% among the three phases and power losses caused by this unbalance current were calculated. Although the neutral conductor remained unchanged, harmonics especially triplen-harmonics was found to be more 10% recommended by IEC standards, therefore active harmonic filter of 200A was installed at the main panel board to reduce the losses caused by harmonics at the facility.

Keywords: *Power Quality, Unbalance loads, current unbalaced, triplen – harmonics,*

1. Pendahuluan

The theme of power quality is deep and wide by nature. It covers all aspects of power system engineering, from transmission and distribution level analyses to end-user problems. Therefore, electric power quality has become the concern for both utilities and end users. Electric utility managers and designers then build and operate systems by taking into account the interaction between customer facilities and power system. Customers since then started learning to respect the rights of their neighbors and control the quality of their nonlinear loads. However, the efficiency of this method is still low. Studies show that the best and the most efficient solution to power quality problems is to control them at their source. This chapter introduces the subject of electrical power quality. After a brief definition of power quality and its causes. A detailed classification of the subject is presented especially in the range of load unbalance, current unbalance, voltage unbalance, and harmonics. This is mainly because the subject of power quality in electrical power system is broad and wide which cannot be done on the time frame under this thesis. The formulations and measures used for power quality are explained and the impacts of poor power quality on power system and end-use devices such as appliances are mentioned. The Power quality according to IEC(International Electrotechnical Commission), it is defined as, “set of parameters defining the properties of the power supply as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (magnitude, frequency, waveform).similarly, bestowing to IEEE dictionary, power quality is defined as “the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment[1]”. Other definitions such as Utility defines it as the reliability, according to Load aspect, it is defined as the power supplied for satisfactory performance of all equipment i.e., all sensitive equipment [2]. Ideally, the best electrical supply would be a constant magnitude and frequency sinusoidal voltage waveform. This article aims to evaluate the actually situations of the load

2. Methodologi

The approach used in this project elaborate using of real current and voltage data in the analysis of power quality problems experienced at the mall. The current and voltage data was measured using circutor (Energy Management Software) meter installed at 1.44, DPB behind the main entrance. The raw data was measured from the electrical systems at the commercial center.

2.1 Workflow

The research flow chart presented here is of power quality analysis research carried out at Mog Mall. Therefore, to simplify the process of stages involved in this thesis. Research flow chart is used as follows :

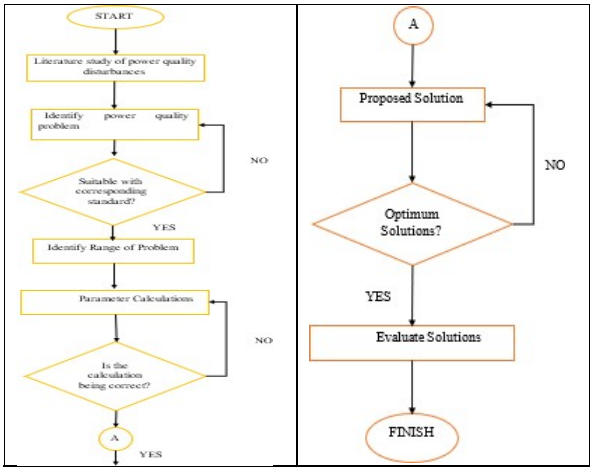

FIGURE 2.1. FLOWCHART

2.2 Load Unbalanced

In three-phase systems a voltage unbalance or current unbalance occurs when the magnitudes of line or phase voltages or currents are different, or the phase angle are different from the balanced conditions, or any combined situation of the two previously mentioned. The unbalance in three-phase electric systems is framed inside the problems of Power Quality. Load unbalance in power systems is mainly caused by single phase loads, American National Standards Institute (ANSI) C84

2.3 Harmonics

In recent years, with the increasing use of power electronics,

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the quality of electricity supply, together with energy efficiency, has become a key issue, and companies responsible for energy production are more and more aware of the benefits of paying attention to harmonic, although until today, there is still no code for harmonic mitigation instead there only standards available[12]. The main representation of power quality is the harmonic distortion, which represents the deviation between the ideal sinusoidal waveform the network voltage or the load current Harmonics are usually grouped by two different criteria: the type of signal (voltage or current), and the order of the harmonic (even, odd, triplen, or non-triplen odd); in a three-phase system, they can be further classified according to their phase sequence (positive, negative, zero).,

TABLE 2.1: LOW VOLTAGE SYSTEM CLASSIFICATION AND DISTORTION LIMITS (CONSUMERS' HARMONIC VOLTAGE LIMITS BASED ON LINE-LINE VOLTAGE)

	Special applications	General System	Dedicated system
Notch Depth	10%	20%	50%
THD(Voltage)	3%	5%	10%
Notch Area (A_N)□(2/)	16400	2800	36500

TABLE 2: VOLTAGE DISTORTION LIMITS (UTILITIES VOLTAGE DISTORTION LIMITS) IEEE STD 519 – 2014

PCC	Harmonics	Distribution THD (%)
V < 1,0kV	5,0	8
1kV < V ≤ 69 kV	3	5
69 < V ≤ 161 kV	1,5	2,5
V > 161 kV	1	1,5

TABLE 2.2: CURRENT DISTORTION LIMITS (220V – 69KV) MAXIMUM HARMONIC CURRENT DISTORTION IN PERCENT OF I_L

Individual harmonic order (odd harmonics)						
I_sc/I_L	<11	11≤h<17	17≤h<23	23≤h<35	23≤h<35	TDD
<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	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

3. Result and Discussion

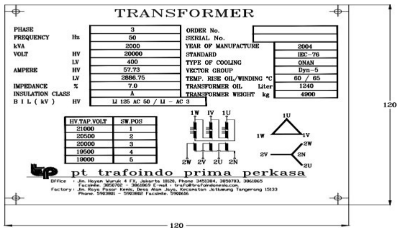

FIGURE 3.1. TRANSFORMER SPESIFICATION

TABLE 3.1 COMPARISON LOAD MEASUREMENT RESULTS BEFORE AND AFTER LOADBALANCING

	Load Measurement Results Before Load Balancing											
	Time of Measurement					Date: 12/06/2022 – Date: 17/06/2022						
	Load-Measurement (Ampere)					Phase-Phase Voltage (Volts)			Phase-Neutral voltage (Volts)			(Ω)
	R	S	T	N	G	R-S	R-T	S-T	R-N	S-N	T-N	Rg
1	95	57	48	50	22	398	401	401	230	230	231	4
	Load Measurement Results After Load Balancing											
	Time-Measurement (Ampere)					Phase-Phase Voltage (Volts)			Phase-Neutral voltage (Volts)			(Ω)
	R	S	T	N	G	R-S	R-T	S-T	R-N	S-N	T-N	Rg
1	68	65	67	25	10	399	399	400	229	229	230	4

From the table above, a current flow scheme is made as shown in the following figure:

Schematic of Current Flow on the Secondary Side of the Transformer Before Load Balancing.

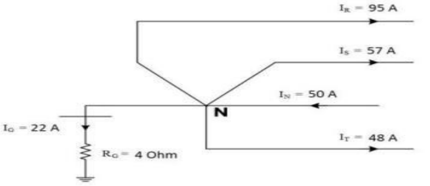

FIGURE 3.1. CURRENT FLOW BEFORE LOAD BALANCING

Schematic of Current Flow on the Secondary Side of the Transformer After Load Balancing

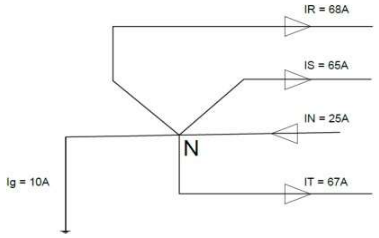

FIGURE 3.2. CURRENT FLOW AFTER LOAD BALANCING

3.1 Transformer Load Analysis

From data known, S (apparent power) of transformer is equal 2000 kVA, Line to line voltage rating is 400 V, I_{FL} = S/(1,73x400) = 288,86 A. I $_{\text{(Average before load balancing)}}$= ($I_R$+$I_S$+$I_T$)/3 = (95+57+48)/3 = 66,67

Therefore, the percentage of transformer loading is: Before load balancing:

$I_{\text{(Average before load balancing)}}/I_{FL}$×100% = 66,67/288,86×100% = 23%

Transformer Load Unbalance Analysis At:

3.1.1 .Before Load Balancing work:

I_R = a.I = a= I_R/I = 95/66,67 = 1,42A I_S = a.I = a= I_S/I = 57/66,67 = 0,85A I_T = a.I = a= I_T/I = 48/66,67 = 0,72A

In a balanced state, the magnitude of the coefficients a, b, and c is 1. Therefore, the average load imbalance in (%) is:

= {⟨a-1 │ b-1 │ c-1⟩/3}×100% = {⟨1,42-1 │ 0,85-1 │ 0,72-1⟩/3}×100%

= (0,42+0,15+0,28)/3×100% = 28,33%

3.1.2 After Load balancing work:

I_R = a.I = a= I_R/I = 68/66,67 = 1,02A I_S = a.I = a= I_S/I = 65/66,67 = 0,97A I_T = a.I = a= I_T/I = 67/66,67 = 1,00A

In a balanced state, the magnitude of the coefficients a, b, and c is

1. Therefore, the average load imbalance in (%) is:
= {⟨a-1 │b-1 │c-1⟩/3}×100% = {⟨1,02-1 │ 0,97-1 │ 1,005-1⟩/3}×100%
= (0,02+0,03+0,05)/3×100% = 3,33%
From the calculation above, it can be seen that after balancing the load, the percentage decreased from 28,33% to 3,33%

3.2. Analysis of Loss Due to Presence of Neutral Current in the Neutral Current of the Transformer

The load from the measurement table, losses due to the presence of neutral currents in the neutral conductor of the transformer, the magnitude can be calculated, namely:

$P_N = I_n^2 \times R_n = 50^2 \times 0{,}6842 = 1710{,}5W \approx 1{,}71kW$

Where: Active Power of Transformer: Known: cosφ = 0,85

$P = S \times \cos\varphi$ $P = 100 \times 0{,}85 = 85kW$

Thus, the percentage of the losses due to neutral currents in the neutral conductor of the transformer

$\%P_N = P_N/P \times 100\% = 1{,}71/85 \times 100\% = 2{,}01\%.$

Magnitude can be calculated as seen below:

$P_N = I_N^2 \times R_N = 25^2 \times 0{,}6842 = 427{,}625W \approx 0{,}476kW$

Where: Active Power of Transformer: Known: cosφ = 0,85 P=S×cosφ

$P = 100 \times 0{,}85 = 85kw$

Thus, the percentage of the losses due to neutral currents in the neutral conductor of the transformer

$\%P_N = P_N/P \times 100\% = 0{,}476/85 \times 100\% = 0{,}56\%$

From the calculation above it can be seen that after balancing the load, the value of losses due to the presence of neutral currents in the neutral conductor of the transformer decreases, namely:
%P_(n before load balance) - %P_(n after load balance) = 2,01-0,56=1,45%

3.3 Analysis of Losses Due to Neutral Currents Flow to Ground

From the measurement table, losses due to the presence of neutral currents in the neutral conductor of the transformer,

3.3.1. Before load balancing

From the measurement table, Losses due to the neutral current flowing into the ground can be calculated, namely:

$P_G = I_G^2 \times R_G = 22^2 \times 4 = 1936W \approx 1{,}936kW$

Where: Active Power of Transformer: Known: cosφ = 0,85 P=S×cosφ

$P = 100 \times 0{,}85 = 85kW$

Thus, the percentage of the losses due to neutral currents in the neutral conductor of the transformer

$\% P_G = P_G / P \times 100\% = 1{,}936/85 \times 100\% = 2{,}28\%$

3.3.2. After Load Balancing

From the measurement table, Losses due to the neutral current flowing into the ground can be calculated, namely:

$P_G = I_G^2 \times R_G = 10^2 \times 4 = 400W \approx 0{,}4kW$

Where: Active Power of Transformer: Known: cosφ = 0,85 P=S×cosφ

$P = 100 \times 0{,}85 = 85kW$

Thus, the percentage of the losses due to neutral currents in the neutral conductor of the transformer

$\% P_G = P_G/P \times 100\% = 0{,}4/85 \times 100\% = 0{,}47\%$

From the calculation above it can be seen that after balancing the load, the value of losses due to the neutral current flowing to the ground decreases, namely:
%P_(G before load balance) - %P_(G after load balance) = 2,28-0,47=1,81%

3.4. Triplen Harmonics

From the graph below, the triplen harmonic of 3,9, and 15 is shown, and from the calculations we can see that calculation of neutral current (a) due to triplen harmonics. The total current due to triplen harmonic in each phase can be determined by adding up all individual triplen currents using equation (30) as shown below:

3.4.1. Before load balancing

I_(3%) = I_3/I_1 ×100 = 13,72 = I_3/686,78×100 = 94.2A I_(9%) = I_3/I_1 ×100 = 26,76 = I_3/686,78×100 = 183,8A I_(15%) = I_3/I_1 ×100 = 4,04 = I_3/686,78×100 = 27.7A
IRh = I3 + I9 + I15 = 94,2+ 183,8 + 27,7 = 305,7A
I_(3%) = I_3/I_1 ×100 = 16,31 = I_3/671,3×100 = 109,5A I_(9%) = I_3/I_1 ×100 = 18,35 = I_3/671,3×100 = 123,2A I_(15%) = I_3/I_1 ×100 = 4,04 = I_3/671,3×100 = 27.1A

I_(9%) = I_3/I_1 ×100 = 19,51 = I_3/661,7×100 = 129,1A
I_(15%) = I_3/I_1 ×100 = 5,82 = I_3/661,7×100 = 38,5A
ITh = I3 + I9 + I15 = 51,5 + 129,1 + 38,5 = 219,1A

Where,

Phase R: 305,7A	CosPhi: 0,97	Angle: 14,07
Phase S: 259,8A	CosPhi: 0,95	Angle: 18.19
Phase T: 219,1A	CosPhi: 0,97	Angle: 14,07

The magnitude of the neutral current due to triplen harmonics can be calculated using equation. But before adding vectors, it is necessary to change from polar form to cartesian form using the equation below
(I_R)̅ = x+y
= |I┤ ├ R┤|×(〖cosθ〗 _R)+j(|IR|)×(〖sinθ〗 _R)
=|305,7|×(cos14,07)+j(|305,7|)×(sin14,07) 296,5+j74,3
(I_S)̅ = x+y
= |I┤ ├ S┤|× 〖cos〗 _s (θ_s-120°)+j(|IS|)× 〖sinθ〗 _S (θ_s-120°)
=|259,8|×cos(18,19-120°)+j(|259,8|)×sin(18,19-120°)
-53,2 - j254,3
(I_T)̅ = x+y
= |I┤ ├ T┤|× 〖cos〗 _T (θ_T+120°)+j(|IS|)× 〖sinθ〗 _T (θ_T+120°)
=|219,1|×cos(14,07+120°)+j(|219,1|)×sin(14,07+120°)
-154.1 – j155,7
IN = (296,5+j74,3)+(-53,2-j254,3)+(-154,1-j155,7) 89,2 – j335,7
347,35< -75,12°A
and In = 347,35A< – 75,12

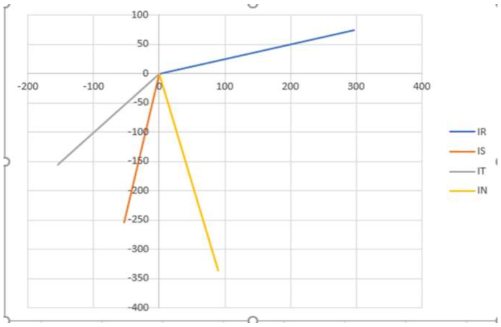

FIGURE 3.3. PHASOR DIAGRAM BEFORE LOAD BALANCING

3.4.2. After load balancing

The magnitude of the neutral current due to triplen harmonics can be calculated using equation. Where,

Phase R: 258 A CosPhi: 0,97 Angle: 14,07
Phase S: 257A CosPhi: 0,95 Angle: 18.19
Phase T: 263 A CosPhi: 0,97 Angle: 14,07

But before adding vectors, it is necessary to change from polar form to cartesian form using the equation below
(I_R) ̅= x+y
= |I┤ ├ R┤ |×(〖cosθ〗 _R)+j(|IR|)×(〖sinθ〗 _R)
=|258|×(cos14,07)+j(|258|)×(sin14,07) 250,3+j62,7
(I_S) ̅= x+y
= |I┤ ├ S┤ |× 〖cos〗 _s (θ_s-120°)+j(|IS|)× 〖sinθ〗 _S (θ_s-120°)
=|257|×cos(18,19-120°)+j(|257|)×sin(18,19-120°)
-52,6 – j251,6
(I_T) ̅= x+y
= |I┤ ├ T┤ |× 〖cos〗 _T (θ_T+120°)+j(|IS|)× 〖sinθ〗 _T (θ_T+120°)
=|263|×cos(14,07+120°)+j(|263|)×sin(14,07+120°)
-182.9 – j186,9
In = (250,3+j62,7)+(-52,6-j251,6)+(-182,9-j186,9) 14,8 – j375,8 =358,1< -87,7°A

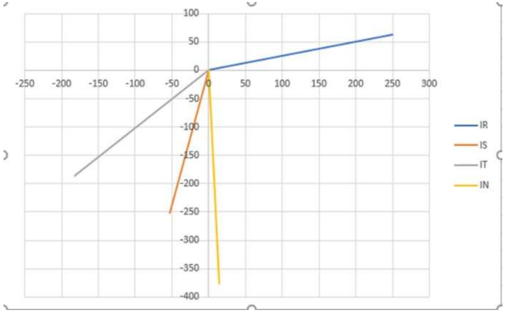

FIGURE 3.4. PHASOR DIAGRAM AFTER LOAD BALANCING

3.5 Active Harmonic Filter Sizing

Just as on the table of load balancing, the main loads are divided amongst the three-phases, i.e., the elevators, air conditionings, lightings, inductive loads, asynchronous motors and arc furnace and other minor loads at the commercial center.

3.6. Active Harmonics Filter Sizing

The Graph below shows Harmonic Current Distortion in the form of THDi. This is hovering between 10 and 35%. Ideally, it should be less than 10% and preferably less than 8% THDi.

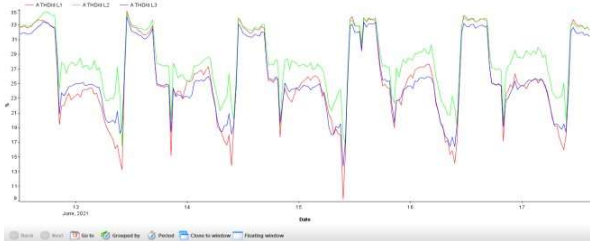

FIGURE 3.5. HARMONICS CURRENT DISTORTION OF THDI

The highest value of average total harmonic distortion (THDi%) across three phases was calculated from raw data. This value is 35,77%THDi and was recorded at time shown.

At the same time, average line current (Amps) across three phases was 707.53A
From data above, Highest Average THDi = 35.77%
At the same time, Average I RMS across three phases was 707.53A.
Taking Y to be = fundamental frequency current I_RMS = √((12+0.3577)) ×Y=707.53
I_RMS = √((12+0.3577)) ×Y=707.53
1.03987y = 707.53

Y = 707.53/1.03987 = 680.402A
Let harmonic current 1 be X
I_RMS = √(680.402+X) = 707.53A
〖680.402〗 ^2+X^2 = 500,598.7009 X = √(500,698.7009 – 462,946.882) X = 194.3A
Thus the harmonic current 1 is 194.3A Let harmonic current 2 be Z
If %THDi = 8% (An appropriate value to satisfy electrical supply utilities)
I_RMS = √((680.402+(0.08×680.402)2)) I_RMS = √(462,946.882+2190.89) I_RMS = 682A
√((680.402+Z) = 682A
〖680.402〗 ^2+Z^2 = 465124 Z = √(465124 – 462,946.882) Z = 46.66A
Active Harmonic filter size = harmonic current 1 (x)harmonic current 2 (z)
〖Active〗 _(Harmonic Filter) = 194.3A-46.66A
〖Active〗 _(Harmonic Filter) = 147.64A
Thus – To reduce % THDi at Incomer from 35.77% to 8% or less, requires 147.64A of harmonic filtering (194.3A-46.66A). Active Harmonic Filter come in sizes of 60A, 120A,200A and 300A. To reduce THDi to a level of 8% would require a 200A filter.

4. Conclusion

In summarize, this thesis has presented, discussed and analysed power quality problems at a shopping centre, especially at 1.44 DPB entrance of the shopping centre. From the literature reviewed in this thesis, the most common type of power disturbances identified were current harmonic distortion (causing the heating of the transformer), voltage harmonic distortion, frequency instability, voltage unbalance, current unbalance, load unbalance. In addition, from the literature, it was found that most of the power quality problems originate from the end user's equipment especially the nonlinear loads. In this project, power data was measured from the electrical system at mall and saved in the form of spreadsheets. From these spreadsheets, calculations were done and with the help of power vision plus, graphs were plotted in order to identify the power quality issues experienced at the mall. After identification of the power quality issues, the effect of these issues on parameters such as voltage angle and phase, current angle and phase, temperature of the equipment was determined by calculation. These results were then compared to the theoretical principles contained in the literature review section. The results indicate that at the mall, the power quality problems experienced are current unbalance, load unbalance, and current harmonic distortion. Using both the IEC and NEMA methods, the percentage voltage unbalance was found to be lower than the maximum set value of 2 %. As a result, this voltage unbalance would not affect three- phase equipment in the system. However, the current unbalance was found to be little high but still under recommended standard, and was considered safe for the equipment although, it can result in heating and thus degradation in windings of motor and transformers and a reduction of their efficiency. Although the 1% voltage unbalance is still under the recommended voltage unbalance by American National Standards Institute (ANSI). The current unbalance (7%) generated by this 1% voltage unbalance can still cause 6% - 10% unbalance in currents leading to torque pulsation, increased vibration and mechanical stress, increased losses, and motor overheating, and transformer overheating. But was still considered safe by the standards.

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