A.2 Assessment on Power Distribution

Assessment on power distribution is conducted to assess power quality of TK-3 Cogen Power Distribution. Profile of Power Quality is measured using Power Quality

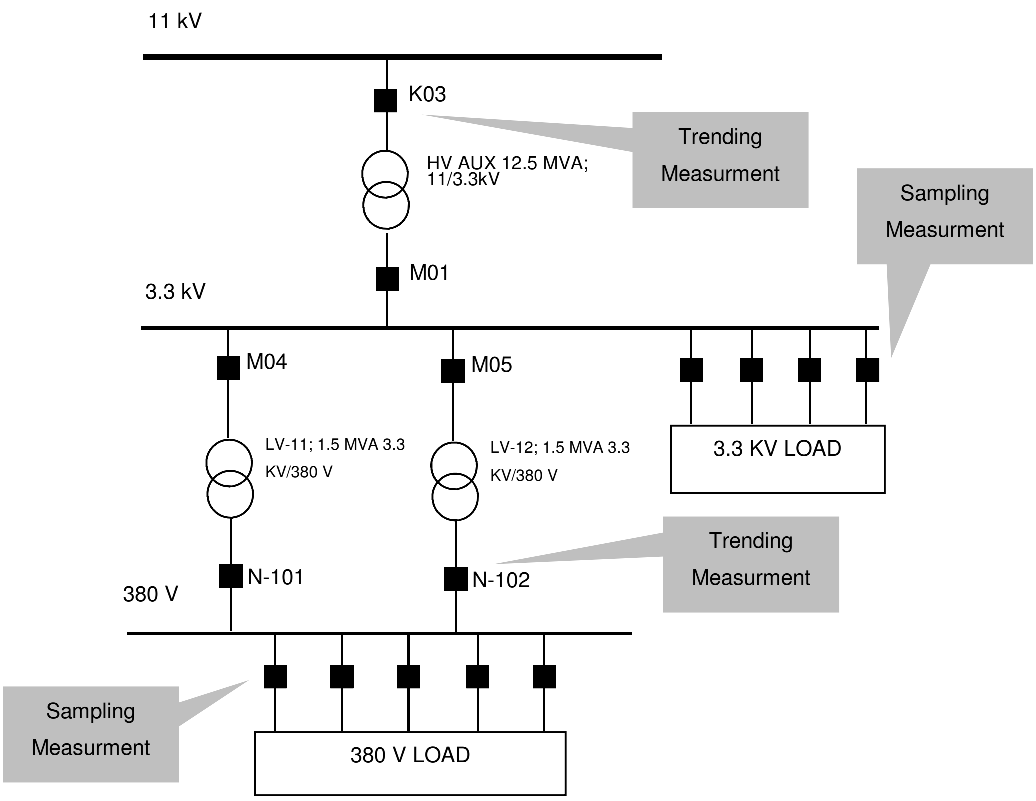


Figure 4. Single Line Diagram of Co-Gen TK 3 Auxiliary and measurement point

Power quality data retrieval is done by two methods of data collection, which is trending method and sampling method.

Trending Method

Trending method is used to determine the characteristics and load consumption that is absorbed by the system in a given time duration. According to energy audit in Co-Gen TK 3, trending data collection was conducted to know energy consumption absorbed by Co-Gen TK 3 Auxiliary.

Sampling Method

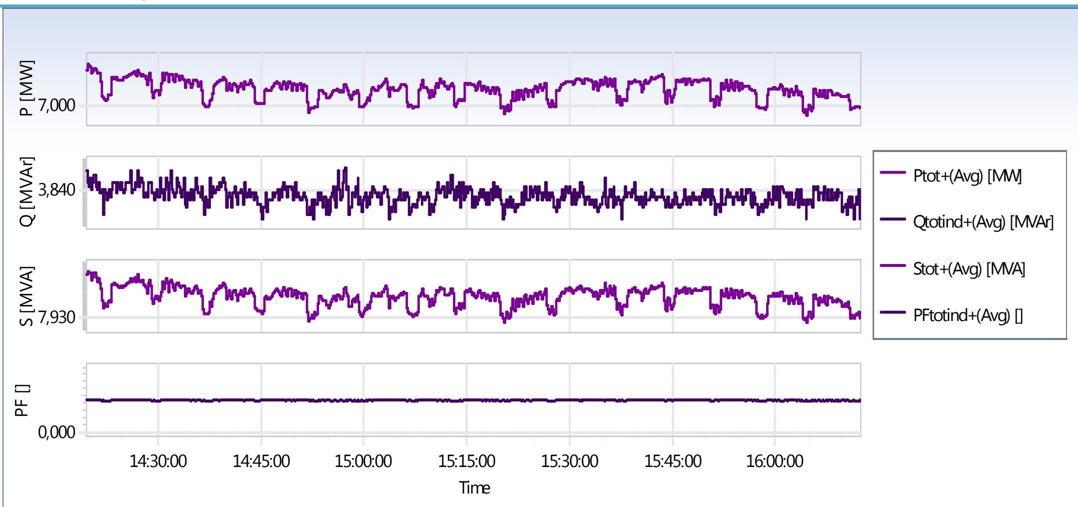
Sampling method is used to determine the characteristics and load consumption that is absorbed by the equipment at a certain period. Because the sampling data retrieval process is a quick measurement, it is possible that the measured power value during the audit carried out and other times the data obtained are not same due to the characteristics of the equipment has fluctuative load characteristics. Sampling measurements performed on the load – side of voltage 380 V and 3.3 kV.

MCC Room		Switchgear Room	
1	Incoming MCC N102	1	Panel M05 TR#3 1500kVA
2	Panel TR-4 220V	2	Panel M07 BFWP #A 1750kW
3	Panel TR-4 380V	3	Panel M09 FDF 800kW
4	Panel AC CCR	4	Panel M10 PAF #C 150kW
5	Panel AC ICS	5	Panel M11 PAF #B150kW
6	Panel CAF A	6	Panel M12 PAF #A 150kW
7	Panel Condensat Pump A	7	Panel M13 IDF
8	Panl Condensat pump C	8	Panel M15 CAF #B
9	Panel Conveyor	9	Panel M16 CAF #C
10	Panel CWP Boiler	10	Panel M17 CAF #D
11	Panel Deisel Oil Pump	11	Panel M19 CWP #B
12	Panel L.O.P Pulverizer	12	Panel M20 CWP #C
13	Panel Pulverizer A	13	Panel M21 DFWP #A
14	Panel Pulverizer B		
15	Panel Pulvarizer C		
16	Panel Compressor ZT200		
17	Panel Compresor No.1		
18	Panel Compressor No.3		
19	Panel Main Oil Pump A		
20	Panel M. Air		

A.2.1 Assessment on Power

Trending measurement of Co-Gen TK 3 was conducted onIncoming Cubiclel K03. Switchgear K03 supply electricity to Co-Gen TK 3 auxiliary

Data collection of Switchgear K03 is conducted on 10th Nov 2014, with a duration of about 2 hours (14.19 – 16.12)



	14:19:39	14:19:49	14:19:59	14:20:09	14:20:19	14:20:29	14:20:39	14:20:49	14:20:59	14:21:09	14:21:19	14:21:29	14:21:39	14:21:49
Ptot+(Avg) [MW]	7,320	7,368	7,356	7,344	7,284	7,308	7,332	7,332	7,320	7,284	7,296	7,284	7,212	7,080
Qtotind+(Avg) [MVAr]	3,900	3,864	3,852	3,876	3,840	3,864	3,888	3,888	3,852	3,840	3,864	3,828	3,828	3,840
Stot+(Avg) [MVA]	8,292	8,316	8,304	8,304	8,244	8,268	8,304	8,304	8,268	8,232	8,256	8,220	8,172	8,064
PFtotind+(Avg) []	0,880	0,880	0,880	0,880	0,880	0,880	0,880	0,880	0,880	0,880	0,880	0,880	0,880	0,870

Figure … Trend Data Power of Switchgear K03

Analysis:

From the trend data recorded of Switchgear K03, the third graphics of power (P, Q, and S) have the same shape, up and down following the load demand of Co-Gen TK 3 Auxiliary.

Power measurement as follows:

Switchgear K03				
	Active Power - P (MW)	Apparent Power – S (MVA)	Reactive Power – Q (MVAR)	Cos phi
Min	6,9	7,8	3,7	0,87
Max	7,3	8,3	3,9	0,9

Table … Power Measurement of Switchgear K03

Based on the figure above, the electricity consumption profile obtained the highest daily load of 7,3 MW with an average of 7.1 MW. Highest daily power of 8.3 MVA with an average of 8.1 MVA. And the highest daily cos phi of 0.9 with an average of 0.8.

A.2.2 Assessment on Power Factor

The power factor defined by IEEE and IEC is the ratio between the applied active (true) power and the apparent power. Active (true) power is measured in watts (W) and is the power drawn by the electrical resistance of a system doing useful work. Apparent power is measured in volt-ampere (VA) and is the voltage on an AC system multiplied by all the current that flows in it. Reactive power is measured in volt-amperes reactive (VAR).

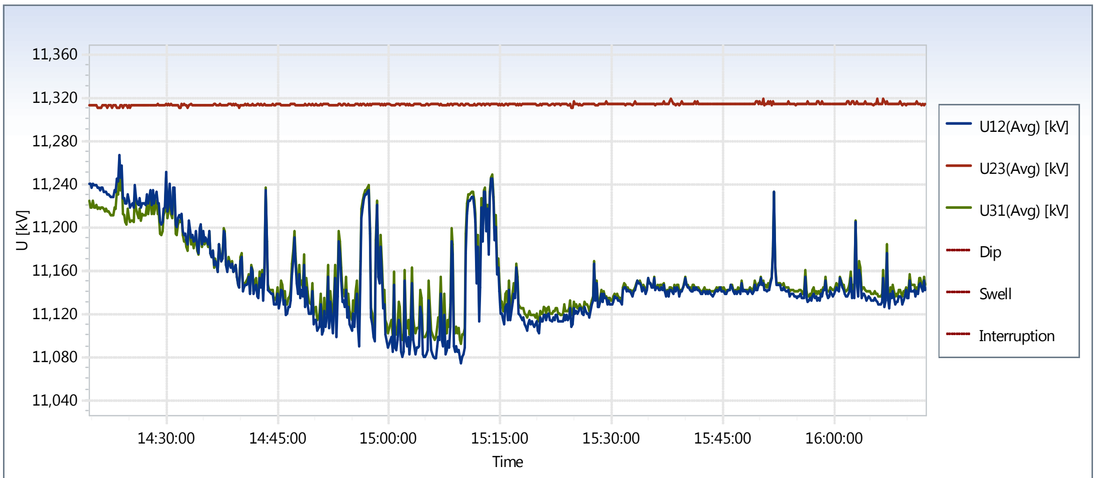
Reactive power is required for the magnetization of a motor but doesn't perform any action. The reactive power required by inductive loads increases the amounts of apparent power in distribution system. Increasing of the reactive and apparent power will cause the power factor to decrease.

From table of Power Measurement of Switchgear K03, it is shown that power distribution has good power factor, range from 0.8 to 0.9 with average is 0.8. This power factor value is in accordance with standard set out by PLN, 0.85

A.2.3 Assessment on Voltage

Voltage unbalance between phases on a 3-phase motor can cause current values to reach six to ten times the value of the voltage unbalance. Because current causes heat and overheating is one of the leading causes of motor failure, distribution systems should be monitored for unbalance.

Voltage profile of Switchgear K03 is shown in the figure below:



	15:09:19	15:09:29	15:09:39	15:09:49	15:09:59	15:10:09	15:10:19	15:10:29	15:10:39	15:10:49	15:10:59	15:11:09	15:11:19	15:11:29	15:11:39
U12(Avg) [kV]	11,084	11,086	11,078	11,074	11,080	11,082	11,088	11,176	11,212	11,224	11,224	11,228	11,228	11,218	11,204
U23(Avg) [kV]	11,314	11,312	11,312	11,314	11,314	11,312	11,312	11,314	11,314	11,314	11,312	11,312	11,312	11,314	11,312
U31(Avg) [kV]	11,102	11,106	11,096	11,092	11,100	11,100	11,106	11,194	11,222	11,230	11,230	11,232	11,232	11,224	11,212

Figure … Trend Data Voltage of Switchgear K03

Analysis:

The figure above shows profile of voltage.

$$\%\ \text{Unbalance Voltage} = \frac{V\max - V\ average}{V\ average}\ x\ 100\%$$

The profile of the minimum and maximum voltage per phase is provided in the following table:

Phase	Voltage	
	Min	Max
R-S	11,074	11,266
S-T	11,310	11,318
T-R	11,100	11,272

Table … Minimum and Maximum Voltage on Switchgear K03

Based on table above, unbalance voltage calculation is shown in table below:

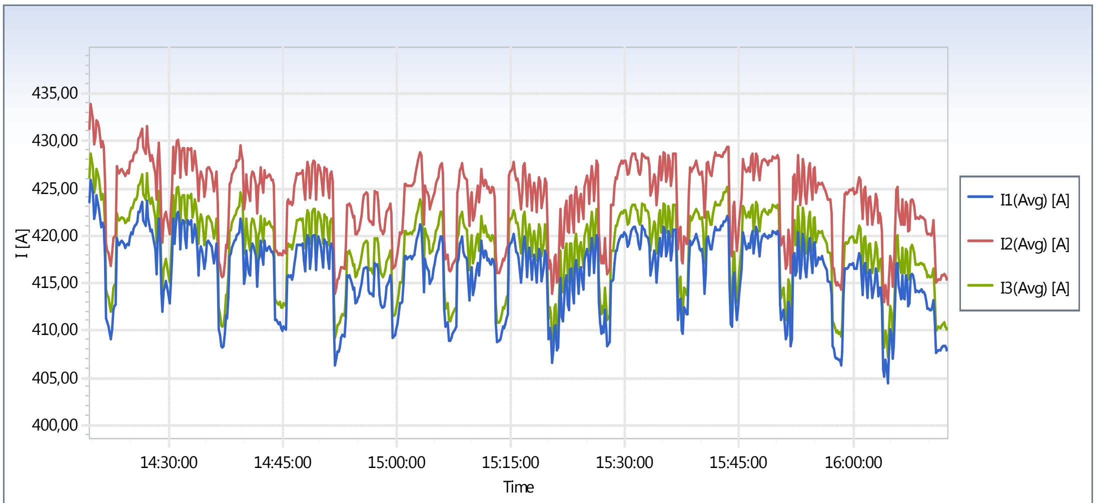
Item	Switchgear K03
Unbalance voltage minimum	0.1
Unbalance voltage maximum	1.07

Table … Minimum and Maximum Unbalance Voltage

From the table above, it is shown minimum and maximum unbalance voltage. Refers to the standard NFPA-70B (unbalance voltage < 5%), unbalance voltage mentioned above is still in the normal standard.

A.2.4 Assessment on Current

Current measurement is conducted to know current profile during certain period and unbalanced current. The unbalanced current will cause torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating, which can reduce the life of motor's winding.



	14:19:39	14:19:49	14:19:59	14:20:09	14:20:19	14:20:29	14:20:39	14:20:49	14:20:59	14:21:09	14:21:19	14:21:29	14:21:39	14:21:49	14:21:59
I1(Avg) [A]	423,48	425,88	425,28	424,44	421,80	422,40	424,20	423,48	422,76	420,84	421,32	420,84	417,60	411,24	410,76
I2(Avg) [A]	431,28	433,80	433,08	432,24	429,60	430,32	432,12	431,88	431,40	429,36	429,84	429,36	425,64	419,04	418,44
I3(Avg) [A]	426,12	428,64	428,04	427,08	424,56	425,16	426,96	426,60	426,00	423,84	424,32	423,84	420,84	414,24	413,76

Figure … Trend Data Current of Switchgear K03

Analysis:

The figure above shows profile of Current.

The profile of the minimum and maximum current per phase is provided in the following table:

Phase	PM Incoming Cubicle	
	Min	Max
R-S	404.4	425.8
S-T	412.6	433.8
T-R	407.1	428.6

Table … Minimum and Maximum Voltage on Switchgear K03

Based on table above, unbalance current calculation is shown in table below:

Item	Switchgear K03
Unbalance current minimum	0.95
Unbalance current maximum	3.6

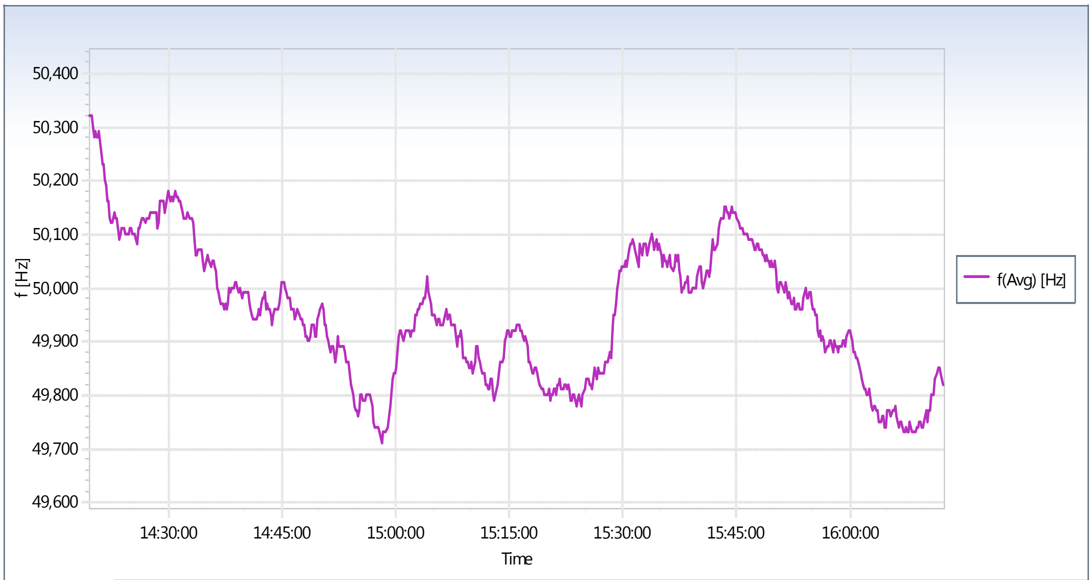
Table … Minimum and Maximum Unbalance current

From the table above, it is shown minimum and maximum unbalance current. Refers to the standard NFPA-70B (unbalance voltage < 5%), unbalance voltage mentioned above is still in the normal standard.

A.2.5 Assessment on Frequency

The power line frequency is the frequency of oscillations of alternating current (AC) in an electric power grid transmitted from a power plant to the end user. In large parts of the world this is 50 Hz.

Frequency data trending is shown in the figure below



	14:19:39	14:19:49	14:19:59	14:20:09	14:20:19	14:20:29	14:20:39	14:20:49	14:20:59	14:21:09	14:21:19	14:21:29	14:21:39	14:21:49	14:21:59
f(Avg) [Hz]	50,320	50,320	50,320	50,300	50,280	50,290	50,280	50,280	50,290	50,250	50,230	50,230	50,200	50,190	50,160

Figure…Recorded trend data frequency

During data collection, the measured frequency fluctuates with the range 49.71 – 50.32 Hz, or 50 Hz $\pm$ 0.32, with maximum deviation:

$$\% \text{ Deviation max} = \frac{0.32}{50} \, x \; 100\%$$

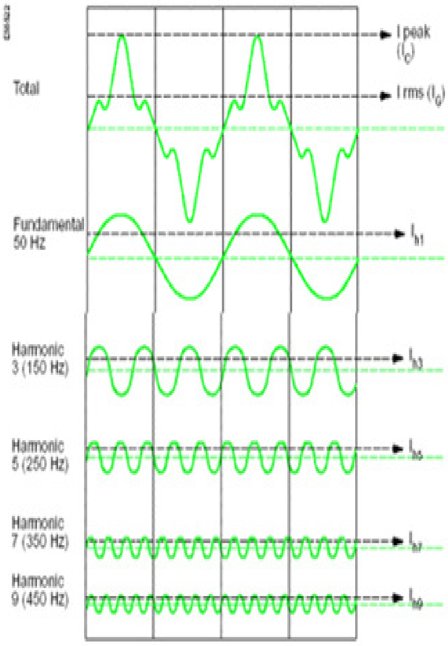
$$\% \text{ Deviation max} = 0.64 \, \%$$

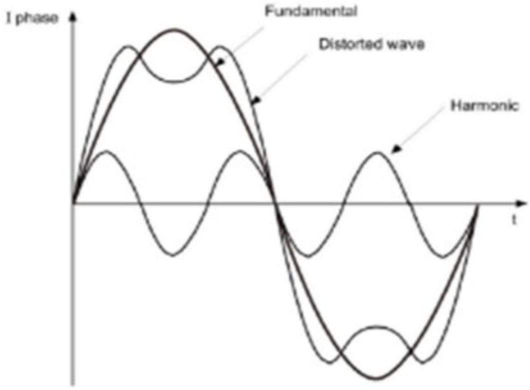
Some manufactures limit the maximum value allowable deviation is < 2%, so the measured frequency is still in the normal range operation.

A.2.6 Harmonic Distortion

According to the IEEE standard 519-1992, harmonic is a sinusoidal componenet of a periodic wave having fundamental frequency of 50 Hz/60 Hz of the power systems. The harmonic components appear in the voltage or current may increase the flow of the current.

The electrical voltage and current input of the electrical equipment particularly installed in the industrial processes is non-linear and no longer a pure sinusoidal wave, but contains several multiples of the fundamental frequency, which is called harmonics.

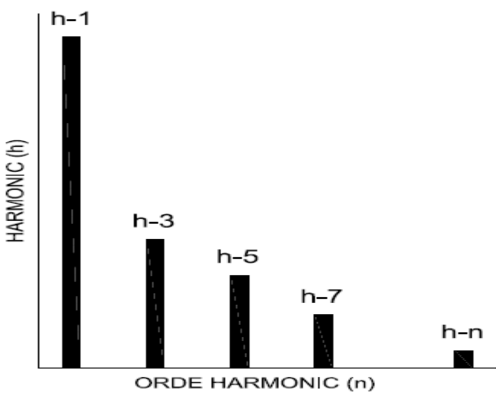




High frequency wave riding on the wave of the fundamental frequency, thus forming defects wave is the sum of the basic wave with harmonic wave.

Individual harmonic distortion (IHD)

Individual harmonic component is defined as the percentage of harmonics for order h with respect to the fundamental.



h1 is the basic current (*fundamental*), is the current wave of 50Hz.
h-3, h-5, h-7,...h-n is value of (RMS) harmonic with a frequency n times the fundamental frequency (150hz, 250hz, 350,...n*50).

Total harmonic distortion (THD)

The Total Harmonic Distortion (THD) is an indicator of the distortion of a signal and the total of the order of frequency harmonics to -2 to the – nth order (max).

$$THD : \sqrt{\left({h_2}^2 + {h_3}^2 + {h_4}^2 + \cdots + {h_\sim}^2\right)}$$

$$THD : \sqrt{\sum_{n=2}^{\sim} h^2}$$

For current and voltage harmonic, the equation is:
Current (RMS) with harmonic:

$$I_{rms}: \sqrt{I_1^2 + (THD_I)^2}$$

Voltage (RMS) with the harmonic:

$$V_{rms} : \sqrt{V_1^2 + (THD_V)^2}$$

The existence of the current/voltage harmonics has a significant impact on electrical equipment, especially transformers, motors, cable channels, etc. As consequence, there is an increase in energy losses and overheat which leads to inefficient energy use. Moreover, it also reduces the capacity of the equipment capability due to rerating of respective equipment.

Therefore some harmonic tests are required to examine whether the Total Harmonic Distortion (i.e harmonic index) of the system exceeds the limits according to the IEEE 519-1992 standard or not, this also shows the energy loss of the system. A system without harmonics shall have zero THD value, and the higher value of THD_V shows more energy losses.

Standard harmonics currents according to IEEE 519-1992

Current Distortion Limits 120 -69kV						
Isc/IL	< 11	11 ≤ n < 17	17 ≤ n < 23	23 ≤ n < 35	35 ≤ n	THD
*<20	4	2	1,5	0,6	0,3	5
20 - 50	7	3,5	2,5	1	0,5	8
50-100	10	4,5	4	1,5	0,7	12
100-1000	12	5,5	5	2	1	15
>1000	15	7	6	2,5	1,4	20

Table … Standard current harmonics according to IEEE 519-1992

Power distribution with voltage range of 120 V – 69 kV, IEEE 519-1992 determine limit of current harmonics based on comparison between value of Isc / IL.

Isc : short circuit current at the point of common coupling

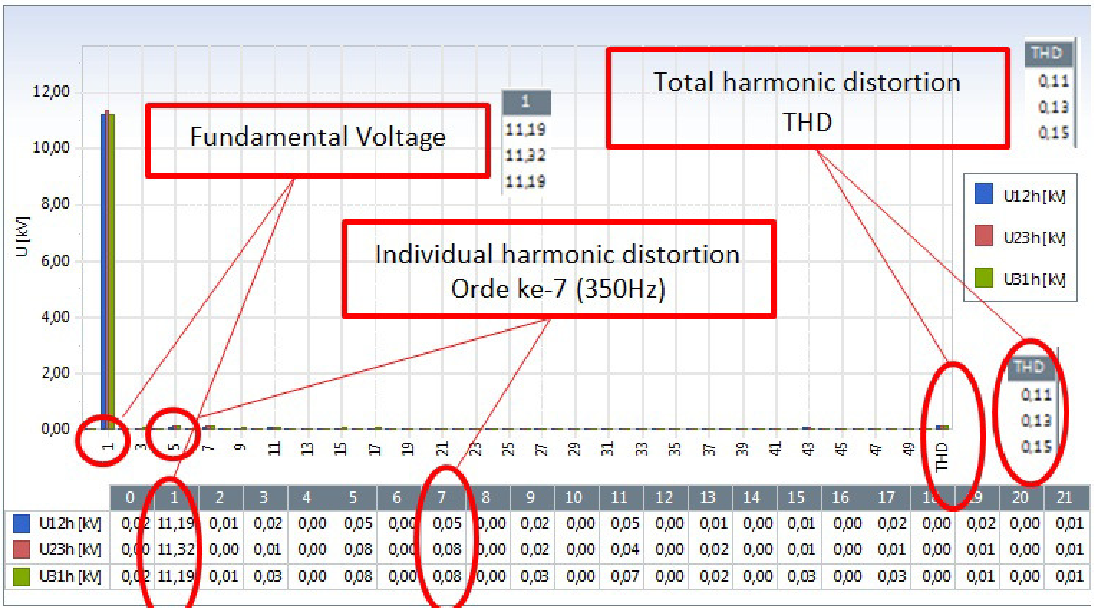
IL : demand load current

Voltage Distortion Limits		
Bus Voltage	**Individual Voltage Distortion (%)**	**Total Voltage Distortion THD (%)**
69 kV and Below	3	5
69,001 kV through 161 kV	1,5	2,5
161,001 and above	1	1,5

Table … Standard voltage harmonics according to IEEE 519-1992

A.2.6.1 Harmonic Voltage

Spectrum harmonic voltage on Switchgear K03 :



Figure….Recorded spectrum harmonic voltage

From the spectrum harmonic data above, it is known that the highest harmonic is in the 7th harmonics.

Fundamental Voltage V_1= 11.19 kV

Total harmonic distortion THD = 0.11% x 11.19 kV

Total harmonic distortion THD = 0.012 V

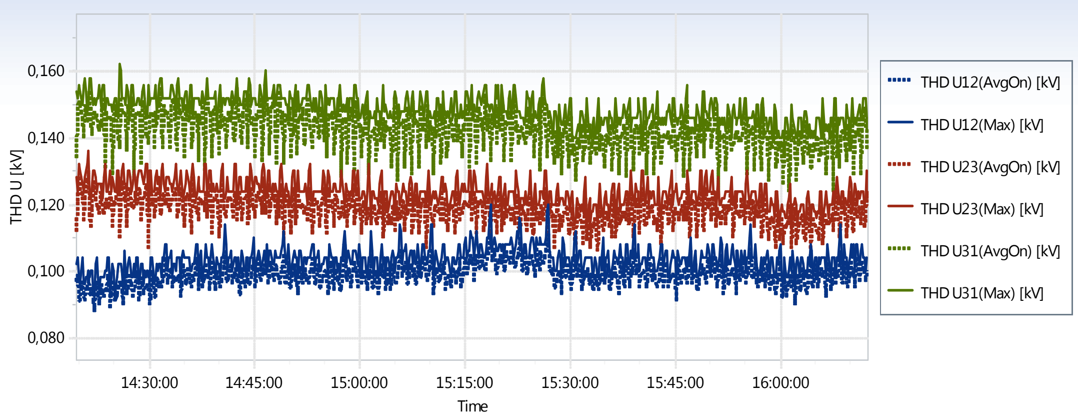
Voltage (RMS) dengan harmonisa:

$$V_{rms} : \sqrt{V_1^2 + (THD_V)^2}$$

$$V_{rms} : \sqrt{11{,}190^2 + 0.012^2}$$

$$V_{rms} : 11.19\ kV$$

THD harmonics effect on the value of V_{rms} is not significant, so it can be concluded that THD Voltage not effect on the power distribution Co-Gen TK 3.



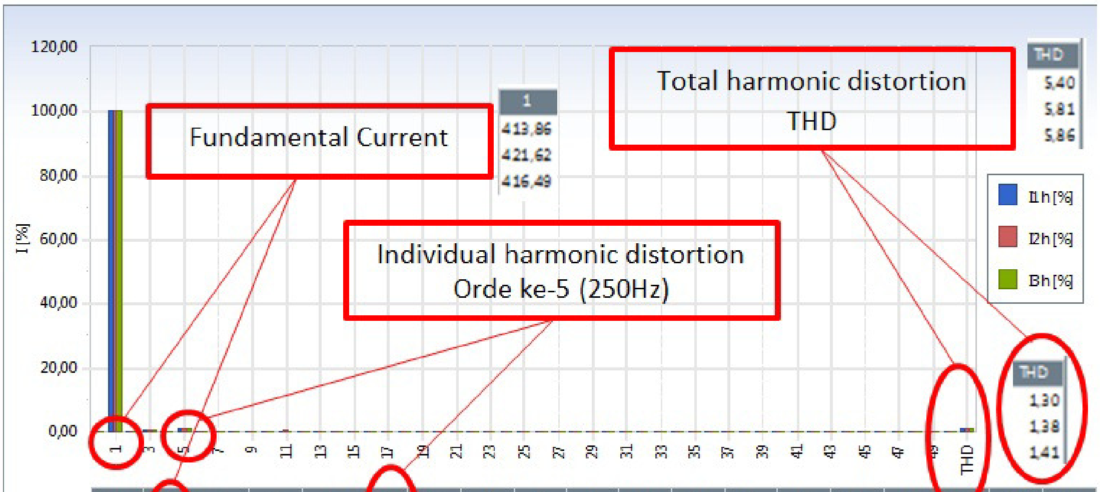
	15:48:39	15:48:49	15:48:59	15:49:09	15:49:19	15:49:29	15:49:39	15:49:49	15:49:59	15:50:09	15:50:19	15:50:29	15:50:39	15:50:49
THD U12(AvgOn) [kV]	0,099	0,102	0,099	0,101	0,098	0,096	0,104	0,103	0,100	0,098	0,104	0,104	0,100	0,098
THD U12(Max) [kV]	0,102	0,106	0,104	0,104	0,104	0,104	0,108	0,106	0,104	0,100	0,108	0,108	0,104	0,104
THD U23(AvgOn) [kV]	0,126	0,125	0,114	0,112	0,124	0,125	0,119	0,120	0,122	0,115	0,124	0,122	0,119	0,113
THD U23(Max) [kV]	0,130	0,130	0,118	0,124	0,128	0,130	0,124	0,124	0,124	0,128	0,130	0,124	0,124	0,118

Figure….Recorded trend data THD voltage

From data spectrum, it is known that Individual Harmonics Distortion and Total Harmonic Distortion on Incoming Switchgear K03 is below the maximum limit value allowed by IEEE 519-1992. From data trending THD above, range value of THD is 0,09 – 0.13. According to IEEE 519-1992, measured THD voltage on SPE Incoming Cubicle value is still within the standard (THD voltage < 5%).

A.2.6.1 Harmonic Current

Spectrum harmonic current on Incoming Switchgear K03 :



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
I1h [%]	0,02	100,00	0,02	0,24	0,03	1,24	0,02	0,16	0,01	0,01	0,01	0,18	0,02	0,13	0,01	0,02	0,01	0,03	0,02
I2h [%]	0,05	100,00	0,05	0,28	0,02	1,30	0,02	0,16	0,02	0,03	0,01	0,22	0,01	0,12	0,01	0,02	0,01	0,04	0,02
I3h [%]	0,02	100,00	0,04	0,29	0,01	1,34	0,01	0,09	0,01	0,04	0,01	0,20	0,01	0,14	0,01	0,04	0,01	0,03	0,01

Figure….Recorded spectrum harmonic current

From the spectrum harmonic data above, it is known that the highest harmonic is in the 5th harmonics.

Fundamental Current I_1= 413.86 A

Total harmonic distortion THD = 1.3% x 413.86

Total harmonic distortion THD = 5.38 A

Current (RMS) with harmonics:

$$I_{rms} : \sqrt{I_1^2 + (THD_I)^2}$$

$$I_{rms} : \sqrt{413.86^2 + 5^2}$$

$$I_{rms} : 413.89 \text{ A}$$

THD current effect on the value of I_{rms} is not significant, so it can be concluded that THD current not effect on the power distribution of Co-Gen TK 3.

A.2.7 Thermography – Electric Equipment

Thermography is an objective image-giving measuring method with which the surface temperature can be determined contactless. Weak points of electrical installations can be detected in a very short time. The measuring tool used for thermography receives emission which is not visible for the human eye and converts this in visibly thermal images.

The purpose of thermography are:

- Rise of availability and reliability of installations.
- Early detection of weak points respectively damages
- Reduction of risks of fire and accident
- Avoiding of consequential loss

THERMOGRAPH INSPECTION

Location : Switchgear Room 3.3 KV

No	Panel	Conductor Terminal	Cable	Component
1	PANEL M 01-1 3.3 KV INCOMING SOURCE	31.6℃	30℃	27.6℃
2	PANEL M 02 3,3 KV STAND BY GCB	30.5℃	30.9℃	26.6℃
3	PANEL M 04 #TR 3 1500 KVA TR	30.6℃	27.1℃	27.8℃
4	PANEL M 05 #TR 3 1500 KVA TR	26.5℃	24.8℃	33.7℃
5	PANEL M 06 800 KVAR CAP BANK	30.3℃	26℃	25.9℃
6	PANEL AUX 3.3 KV GPT	30.9℃	26.6℃	30.5℃
7	PANEL M 07-1 REACTOR SHORT	29.8℃	33.3℃	29℃
8	PANEL M 08 MH02 1750 KW	27.4℃	27℃	26.1℃
10	PANEL M 10 MH 04 150 KW	28.7℃	30℃	28.6℃
11	PANEL M 11 MH 07 150 KW	28.3℃	28.4℃	35℃
12	PANEL M 12 MH 08 150 KW	30℃	29.1℃	34.4℃
13	PANEL M 13 MH 09 830 KW	24.7℃	24.2℃	26.8℃
14	PANEL M 14 MH 10 190 KW	24.7℃	23.9℃	26.9℃
15	PANEL M 15 MH 11 190 KW	25℃	27.3℃	24.9℃
16	PANEL M 16 MH 12 190 KW	24.4℃	23.7℃	31.5℃
17	PANEL M 17 MH 13 190 KW	24.1℃	23.3℃	23.9℃

19	PANEL M 19 MH 15 1120 KW	28.8℃	24.4℃	29.4℃
20	PANEL M 20 MH 16 1120 KW	28.8℃	29.7℃	25.2℃
21	PANEL M 21 MH 17 190 Kw	26.4 ℃	30.0 ℃	28.8 ℃
22	PANEL M 22 MH 18 190 Kw	31.6 ℃	30.0 ℃	28.8 ℃
23	PANEL M 23 MH 19 190kW	30.9 ℃	26.6 ℃	31.7 ℃

Table … Thermography result of Switchgear 3.3 KV

Analysis:

According to IEC 60890, cubicles must be capable of operating at room temperature 40℃. Based on ABB Manual Book for Switchgear, maximum temperature cubicle components of cubicle are:

- Conductor Terminal : max. 105° C
- Components, metering/measuring instrument : max. 50℃ (metal) and 60℃ (plastic)
- Enclosure : max. 65℃ (metal) and 75℃ (plastic)

Referring to the above operating temperature limits, operating temperature of components and measuring instrument does not exceed the maximum limit.