PROVINCIAL ELECTRICITY AUTHORITY

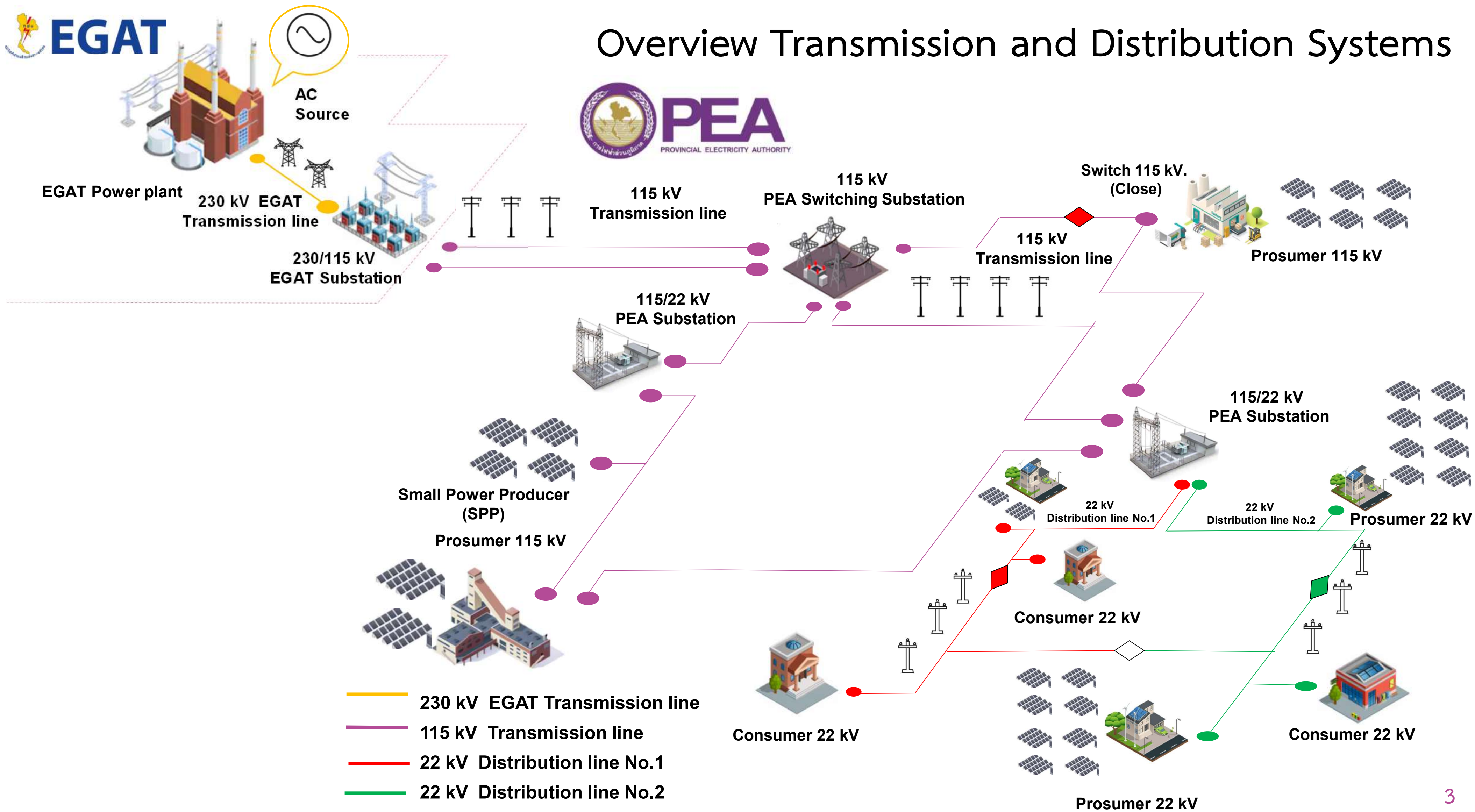
Analysis of Voltage Imbalance in Prosumer Medium Voltage Distribution Systems with Rooftop Photovoltaic Systems

Churit Pansakul[1], Pichaya Kaewchang[2], Prasopphol Changpan[3]

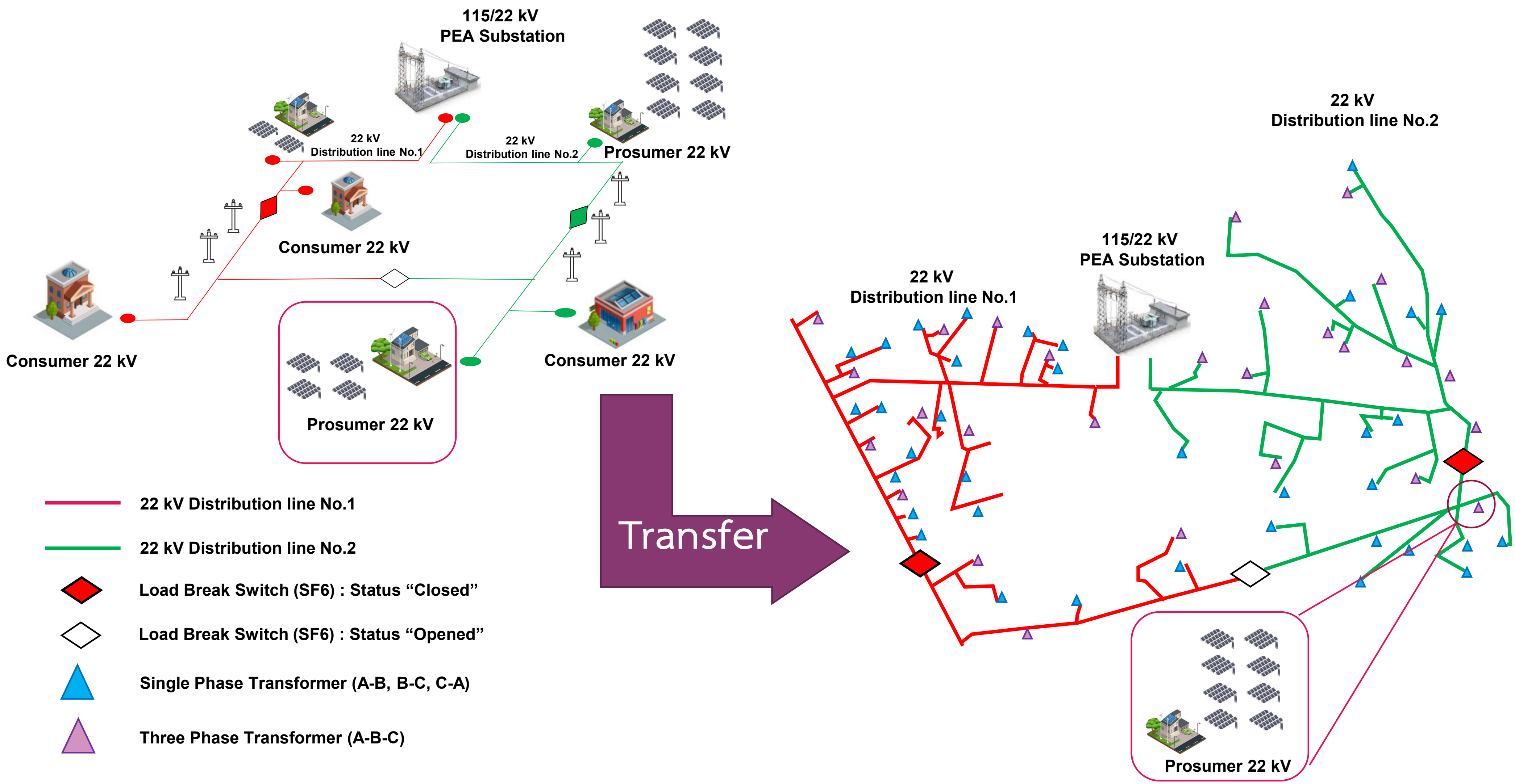
Agenda

- Overview Transmission and Distribution Systems
- Definition of Prosumer
- Provincial Electricity Authority’s Regulation on the Power Network System
- Interconnection Code B.E. 2559 (2016)
- Flow Chart Analysis
- Simulation 22 kV in Distribution System and Results

Overview Transmission and Distribution Systems

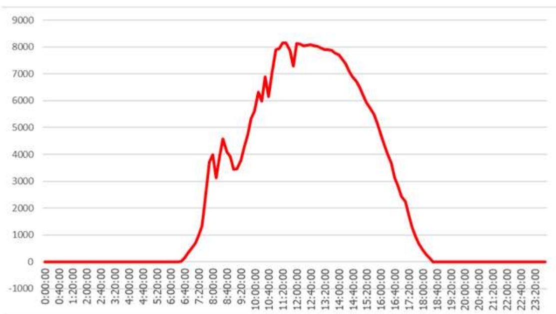


Overview Transmission and Distribution Systems



Definition of Prosumer

Prosumer is someone who both produces and consumes energy – a shift made possible, in part, due to the rise of new connected technologies and the steady increase of more renewable power like solar and wind onto our electric grid.



Power Generate Profile

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Load Profile

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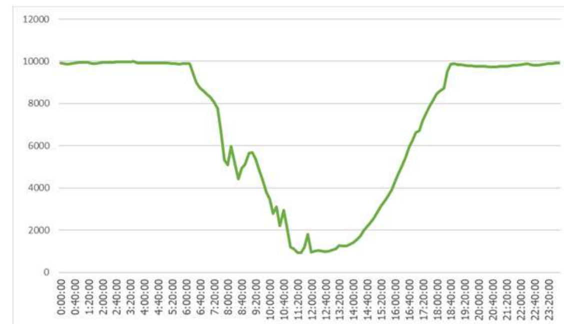
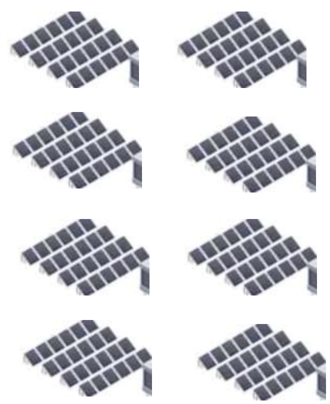
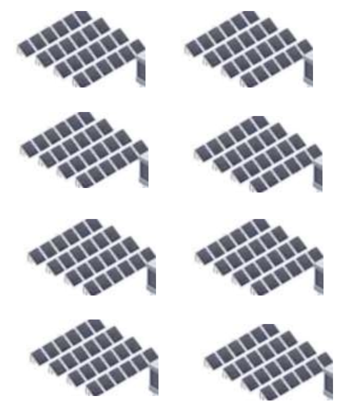
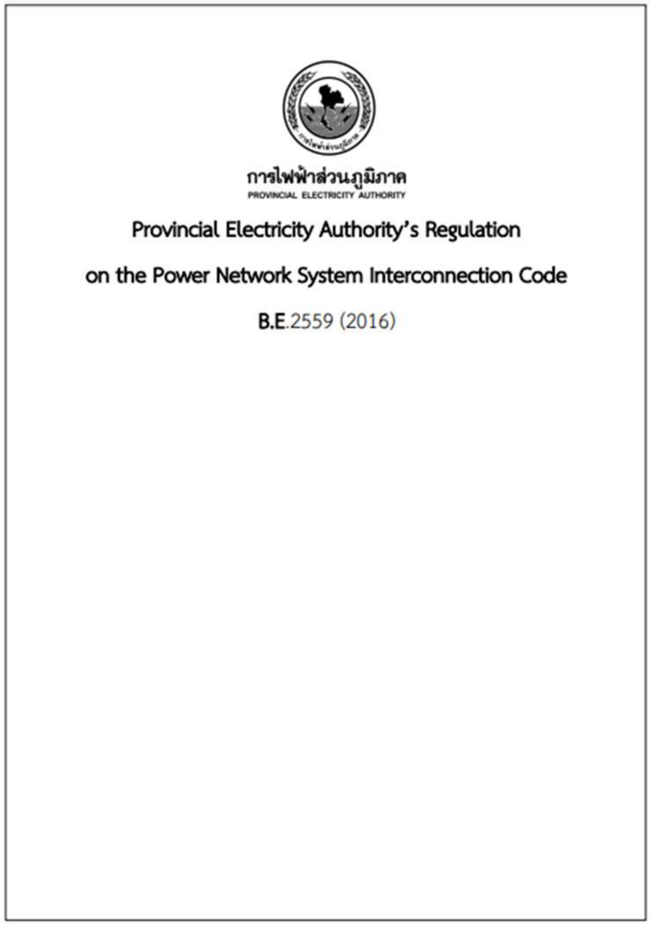


Prosumer Load Profile





Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code B.E. 2559 (2016)


การไฟฟ้าส่วนภูมิภาค
PROVINCIAL ELECTRICITY AUTHORITY
Provincial Electricity Authority's Regulation
on the Power Network System Interconnection Code
B.E.2559 (2016)

This Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code, B.E. 2559 (2016), aims to provide minimum criteria of the designing technique, technical specifications of electrical equipment, and the installation standards that a connection requester wishing to connect to PEA's power network system must comply with

- Frequency Regulator
- Voltage Regulator
- Voltage Fluctuation Regulator
    - Voltage Flicker
        - Short-term Flicker Severity (PST)
        - Long-term Flicker Severity (PLT)
    - Voltage Unbalance
- Harmonic Regulator

1. Frequency Regulator

The frequency of a power network system will be regulated by Electricity Generating Authority of Thailand (EGAT) to be within the standard of 50 ± 0.5 Hz per second.

	Unit	Min	Max
Frequency	Hz	49.50	50.50

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2. Voltage Regulator

A connection requester must design a voltage regulation system in line with PEA's standards of maximum and minimum voltage levels.

PEA's Standards of Maximum and Minimum Voltage Levels

Voltage Level	Normal State		Emergency State	
	Maximum	Minimum	Maximum	Minimum
115 kV	120.7	109.2	126.5	103.5
33 kV	34.7	31.3	36.3	29.7
22 kV	23.1	20.9	24.2	19.8
380 kV	418	342	418	342
220 kV	240	200	240	200

3. Voltage Fluctuation Regulator

A connection requester must design, install, and regulate his equipment in the manner that will not cause voltage fluctuation at the point of common coupling (PCC) that is excess of the levels acceptable to PEA, as specified in the Voltage Fluctuation Regulation for Business and Industrial Customers

- Voltage Flicker
  - Short-term Flicker Severity (PST)
  - Long-term Flicker Severity (PLT)
- Voltage Unbalance

Voltage Flicker

Voltage fluctuation and light flicker are technically two distinct terms, but have been erroneously referred to the same meaning. Aggravating the confusion is the use of the expression “voltage flicker”, which does not actually exist, even though it is often heard. In fact, IEEE has cautioned on the incorrect usage of these terms.

- Short-term Flicker Severity (PST)

- Long-term Flicker Severity (PLT)

Short-term Flicker Severity (PST)

This is based upon an observation period of 10 minutes, allowing evaluation of disturbances with a short duty cycle or those that generate continuous fluctuations. **PST** can be calculated using the equation shown:

$$PST = \sqrt{0.0314P_{0.1} + 0.0525P_{1S} + 0.0657P_{3S} + 0.28P_{10S} + 0.08P_{50S}}$$

where the percentages $P_{0.1}$, P_{1s}, P_{3s}, P_{10s}, P_{50s} are the flicker levels that are exceeded 0.1, 1.0, 3.0, 10.0, and 50.0 percent of the time. These values are taken from the cumulative distribution function. A P_{ST} of 1.0 unit on block 5 output represents irritable flicker.

Voltage Level at PCC (kV)	115 or under	115 or above
Short-term Flicker Severity (PST)	1	0.8

Long-term Flicker Severity (PLT)

On the other hand, the need for long-term assessment of flicker severity happens if the duty cycle is long or variable. These include electric arc furnaces or disturbances on the system that are caused by multiple loads operating simultaneously. PLT is derived from PST as shown below.

$$PLT = \sqrt[3]{\frac{\sum_{i=1}^{N} PST_i^3}{N}}$$

The number of PST readings (N) is determined by the duty cycle of the flicker-producing load, in order to capture one duty cycle of the fluctuating load. However, if the duty cycle is unknown, the recommended number of PST readings is 12 (two hours of measuring). The limit for PLT is 0.8 units.

Voltage Level at PCC (kV)	115 or under	115 or above
Short-term Flicker Severity (PST)	0.8	0.6

Voltage unbalance or imbalance

that is defined by IEEE as the ratio of the negative or zero sequence component to the positive sequence component. In simple terms, it is a voltage variation in a power system in which the voltage magnitudes or the phase angle differences between them are not equal. It follows that this power quality problem affects only polyphase systems

Voltage Level at PCC (kV)	115 or under (%)	115 or above (%)
Voltage Unbalance (%VU)	2	2

Unsymmetrical Component of Voltage

$$\%UV = \frac{I_2}{I_1} \times 100 \qquad (1)$$

$$V_0 = \frac{1}{3}(V_a + V_b + V_c) \qquad (2)$$

$$V_1 = \frac{1}{3}(V_a + aV_b + a^2V_c) \qquad (3)$$

$$V_2 = \frac{1}{3}(V_a + a^2V_b + aV_c) \qquad (4)$$

%UV คือ Percentage of Voltage Unbalance

V_0 : Zero Sequence Voltage

V_1 : Positive Sequence Voltage

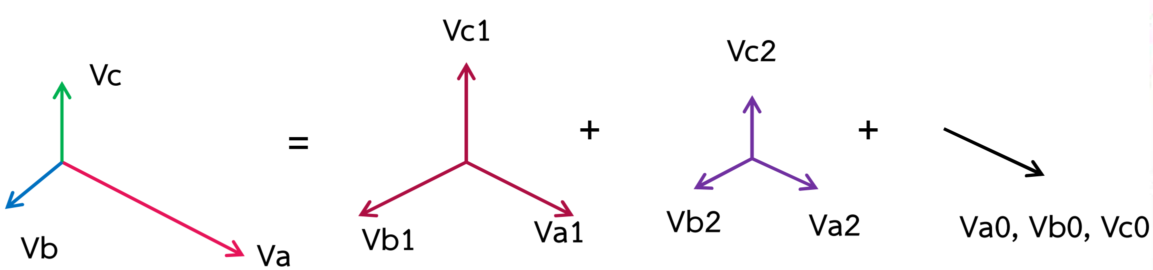
V_2 : Negative Sequence Voltage

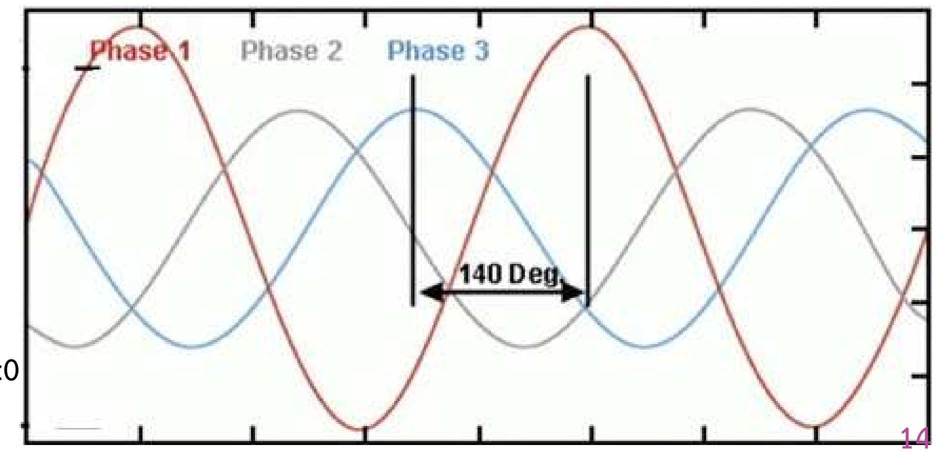
$V_a\angle\theta_a$: Magnitude and Angle of Voltage Phase A

$V_b\angle\theta_b$: Magnitude and Angle of Voltage Phase B

$V_c\angle\theta_c$: Magnitude and Angle of Voltage Phase C

Original System | Positive Sequence | Negative Sequence | Zero Sequence





4. Harmonic Regulator

A connection requester must design, install, and control his equipment in the manner that will not cause frequency and current distortion at the point of common coupling (PCC) that is excess of the levels acceptable to PEA, as specified in the Harmonic Regulation for business and Industrial Customers

4. Harmonic Regulator

$$\text{THD (Voltage)} = \frac{\sqrt{V_2^2 + V_3^2 + \dots\dots\dots}}{V_1}$$

$$\text{THD (Current)} = \frac{\sqrt{I_2^2 + I_3^2 + \dots\dots\dots}}{I_1}$$

Limit voltage harmonics for customer at PCC

Voltage Level at PCC (kV)	voltage harmonic distortion limits (%)	voltage harmonic distortion limits each level	
		odd	even
0.400	5	4	2
11, 12, 22 and 24	4	3	1.75
33	3	2	1
69	2.45	1.63	0.82
115 and above	1.5	1	0.5

Limit current harmonics for customer at PCC

Voltage Level at PCC (kV)	Current Harmonics limit and Sequence (A rms)																	
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0.4	48	34	22	56	11	40	9	8	7	19	6	16	5	5	5	6	4	6
11 and 12	13	8	6	10	4	8	3	3	3	7	2	6	2	2	2	2	1	1
22, 24 and 33	11	7	5	9	4	6	3	2	2	6	2	5	2	1	1	2	1	1
69	8.8	5.9	4.3	7.3	3.3	4.9	2.3	1.6	1.6	4.9	1.6	4.3	1.6	1	1	1.6	1	1
115 and above	5	4	3	4	2	3	1	1	1	3	1	3	1	1	1	1	1	1

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Flow Chart Analysis

Flow Chart Analysis under PEA Regulator Condition

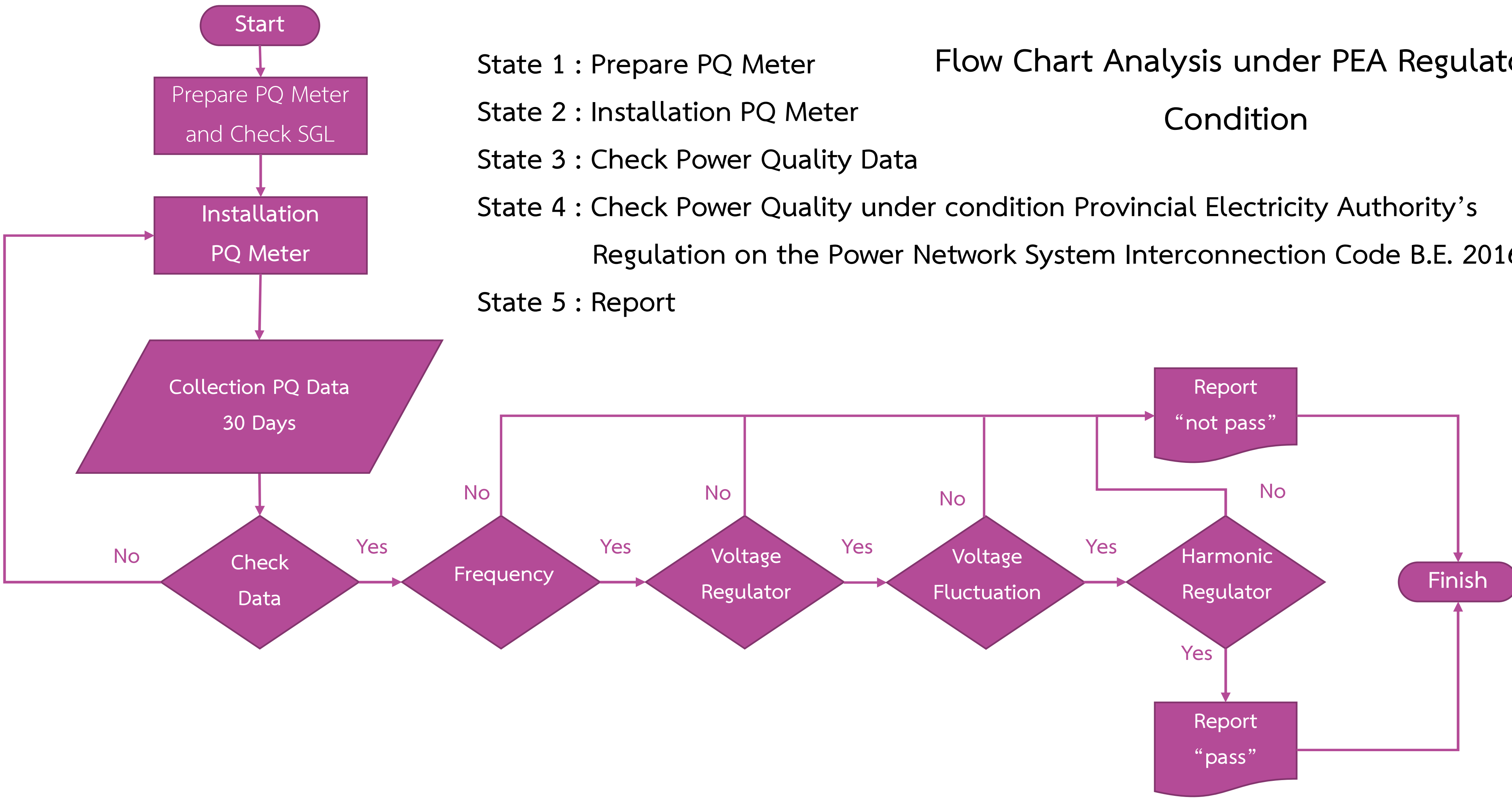
State 1 : Prepare PQ Meter

State 2 : Installation PQ Meter

State 3 : Check Power Quality Data

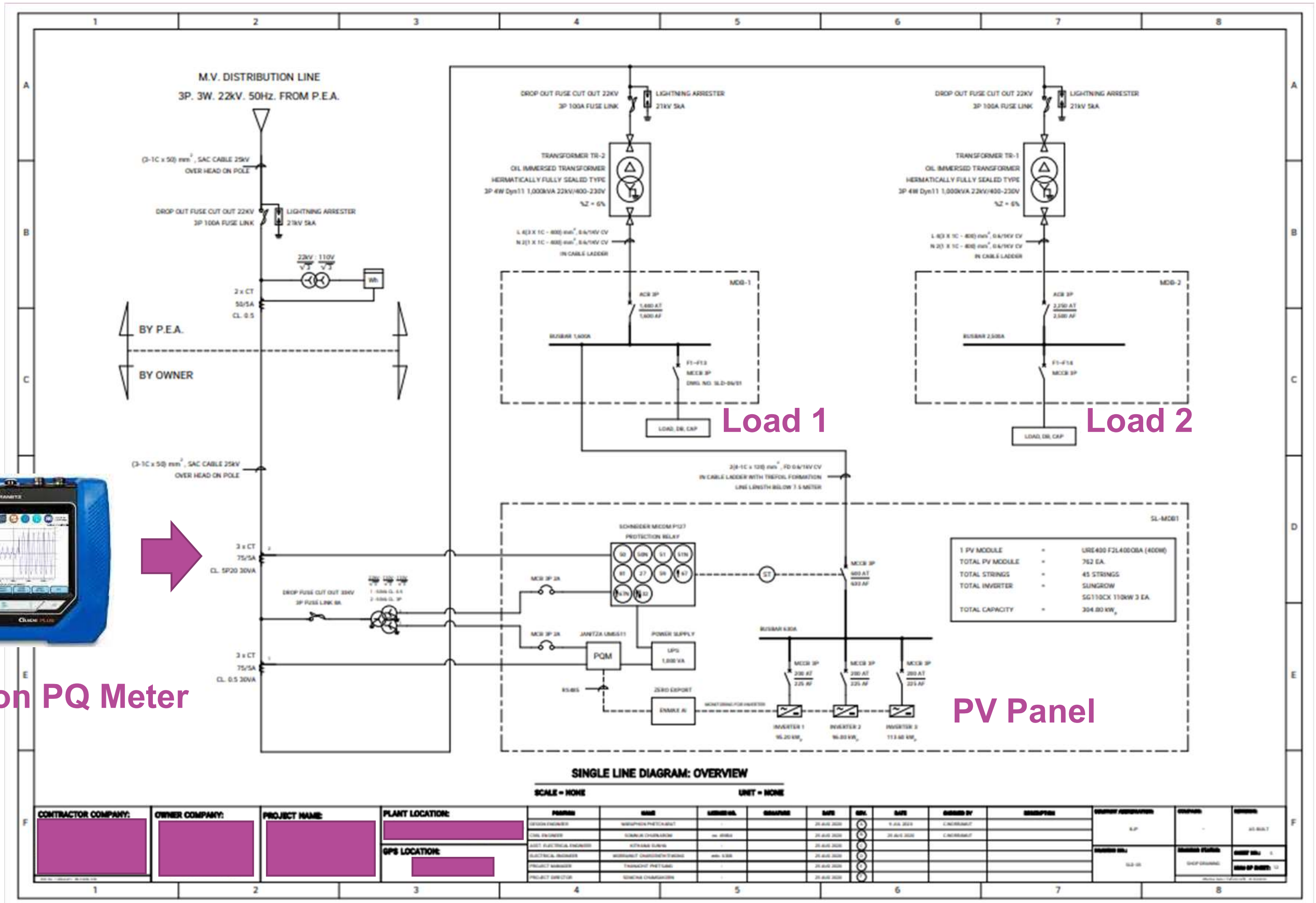
State 4 : Check Power Quality under condition Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code B.E. 2016

State 5 : Report

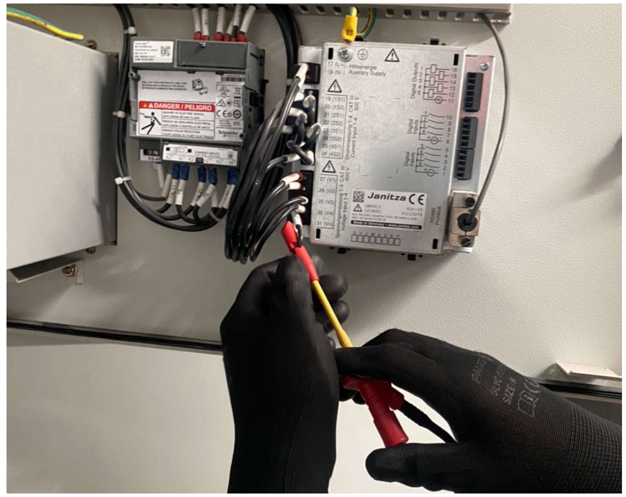


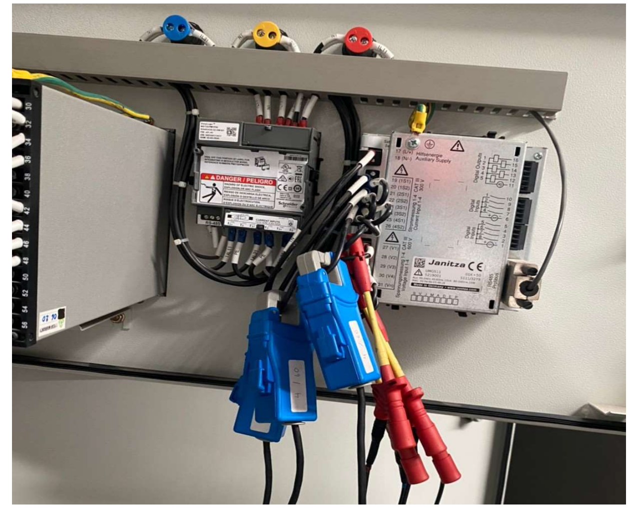
State 1 : Prepare PQ Meter and Single Line Diagram

Installation PQ Meter

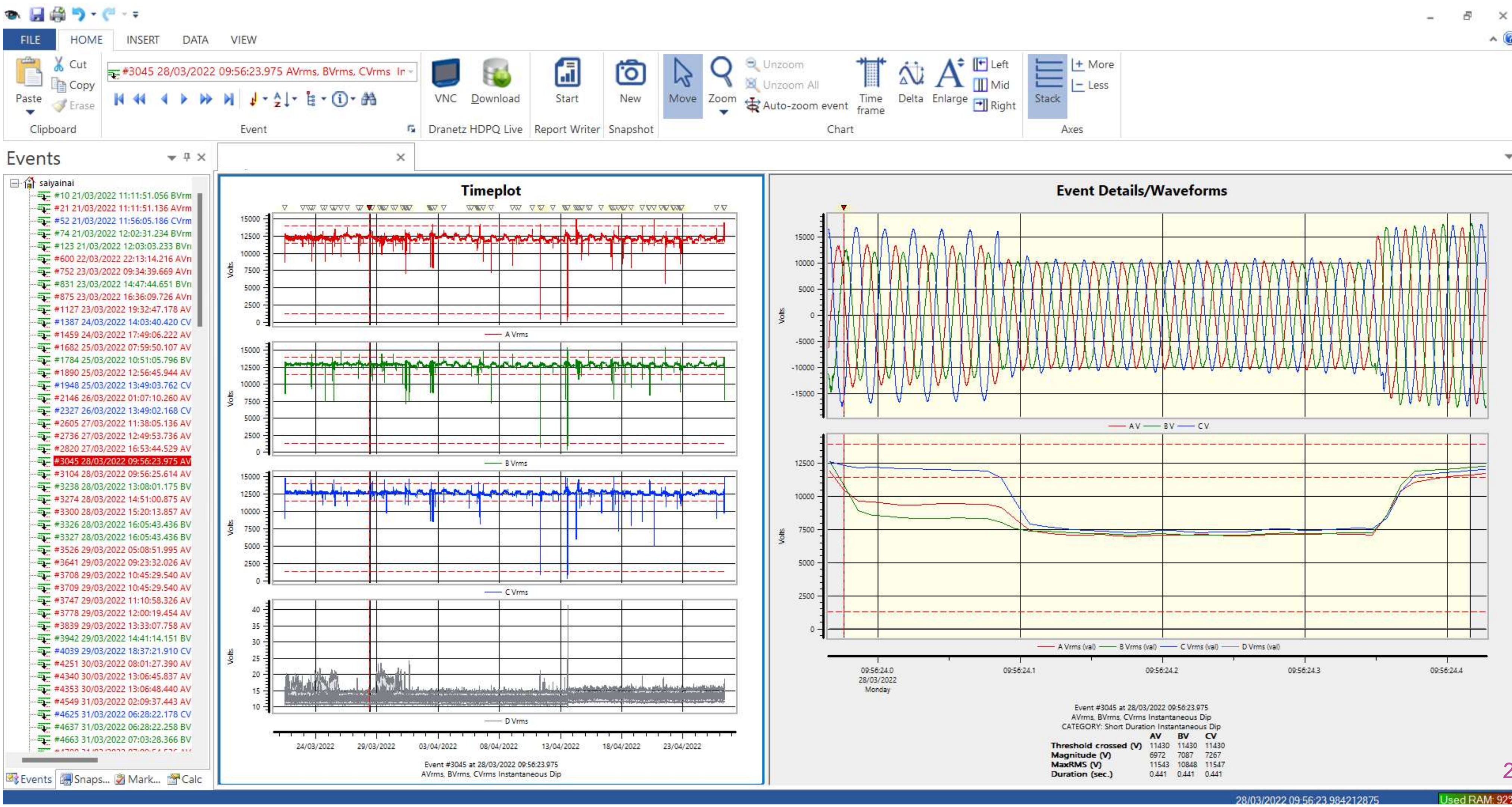


State 2 : Installation PQ Meter at PCC 22 kV





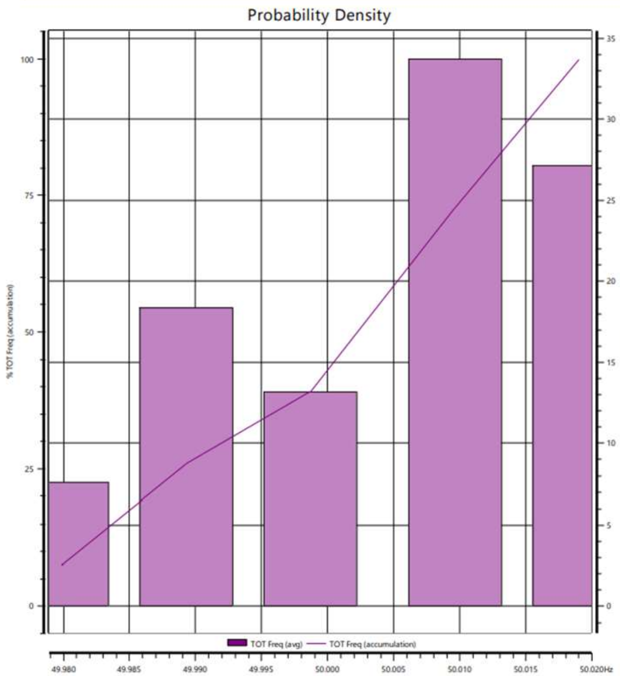
State 3 : Check Data of Power Quality

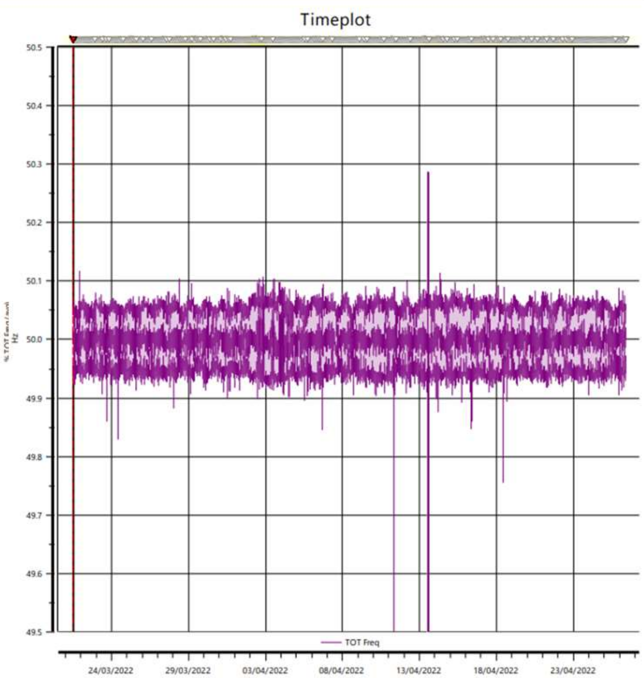


State 4: Check Power Quality under condition Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code B.E. 2016

Supply Voltage Frequency (PASSED)

Name PQ	Sampling	Min	Avg	Max	99%	Limitation	Standard
Frequency	2,127	41.55	49.99	50.29	50.03	± 0.5 Hz	PEA






Power Quality Control Regulation

1. Frequency Regulator

The frequency of a power network system will be regulated by Electricity Generating Authority of Thailand (EGAT) to be within the standard of 50 ± 0.5 Hz per second.

	Unit	Min	Max
Frequency	Hz	49.50	50.50

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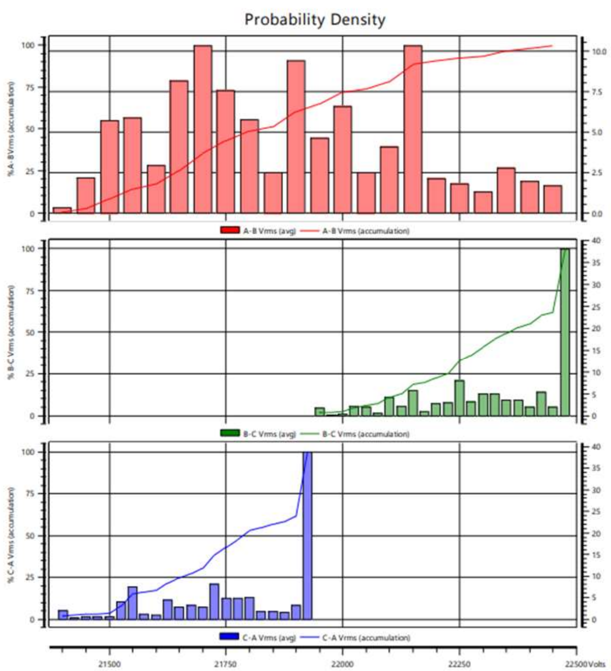
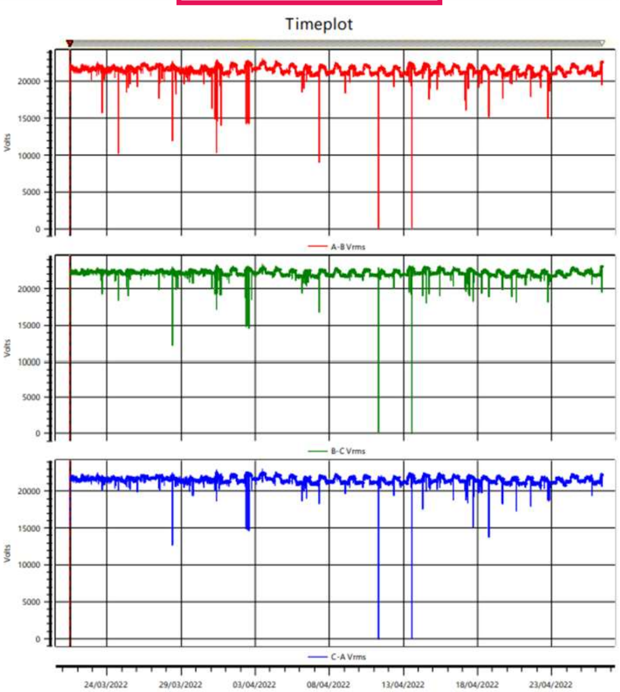
Supply Voltage Variations (PASSED)

Name PQ		Sampling	Min	Avg	Max	95%	Limitation	Standard
	ABvrms	2,127	-	21,949	22,754	22,442	**± 5 %**	EN 50160
Voltage	BCvrms	2,127	-	22,415	23,131	22,845	(20,900 -	OR
	CAvrms	2,127	-	21,847	22,647	22,277	23,100 V)	PEA





Power Quality Control Regulation

2. Voltage Regulator

A connection requester must design a voltage regulation system in line with PEA's standard of maximum and minimum voltage levels.

PEA's Standard of Maximum and Minimum Voltage Levels

Voltage Level	Normal State		Emergency State	
	Maximum	Minimum	Maximum	Minimum
115 kV	[illegible]	109.2	[illegible]	103.5
33 kV	34.7	[illegible]	36.3	29.7
22 kV	[illegible]	[illegible]	24.2	19.8
380 kV	418	342	418	342
220 kV	240	200	240	200

PASSED

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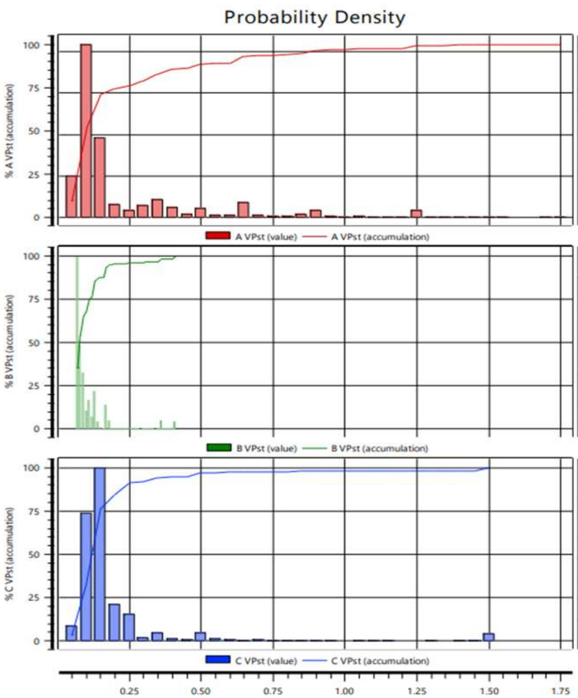
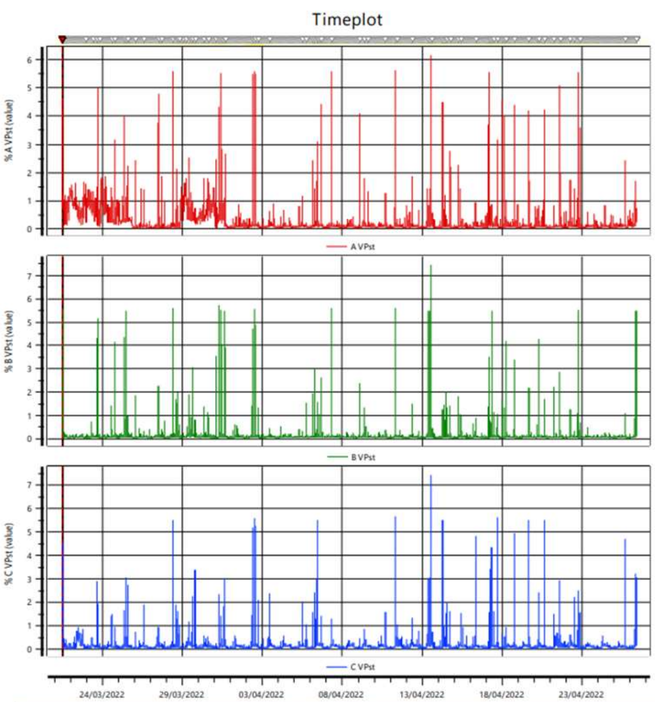
Short Term Flicker (PASSED)

Name PQ		Sampling	Min	Avg	Max	95%	Limitation	Standard
	AVPst	2,126	0.06	0.29	-	0.93		PRC - PQG – 02
Short Flick	BVPst	2,126	0.05	0.18	-	0.27	< 1 pu	/1998
	CVPst	2,126	0.07	0.25	-	0.54		





Power Quality Control Regulation

Short-term Flicker Severity (P[illegible]T)

This is based upon an [illegible]servation period [illegible] 1[illegible] minutes, allowing evaluation of disturbances with a [illegible]or[illegible] duty cycle or those that generate continuous fluctuations. **PST** can be calculated using the equa[illegible] shown:

$$PST = \sqrt{0.0[illegible]314P_{0.1} + [illegible] + 0.28P_{10S} + 0.08P_{50S}}$$

where the percentages $P_{0.1}$, [illegible], P_{3s}, P_{10s}, P_{50s} are th[illegible] flicker le[illegible] th[illegible] are exceeded 0.1, 1.0, 3.0, 10.0, and 50.0 percent of th[illegible] tim[illegible]. These values are taken from the [illegible]mul[illegible]e distribution function. A P_{ST} of 1.0 unit on block 5 output rep[illegible]sents [illegible] flicker.

Voltage Level at PCC (kV)	[illegible]	115 or above
Short-term Flicker Severity (PST)	1	0.8

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PASSED

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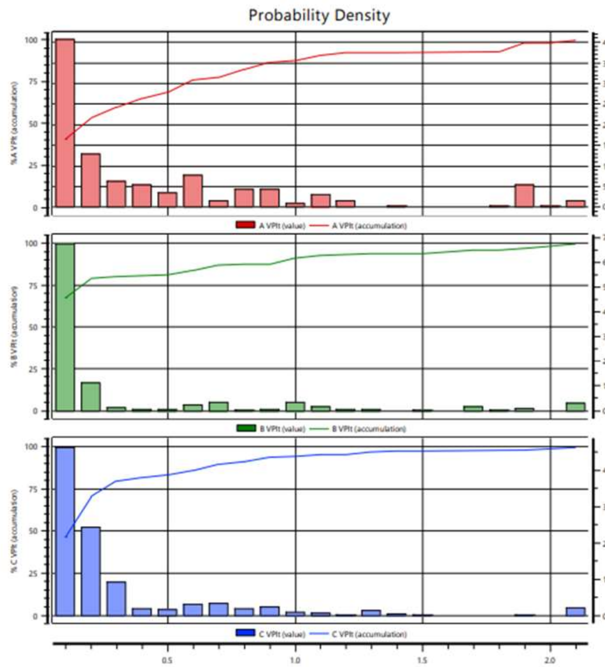
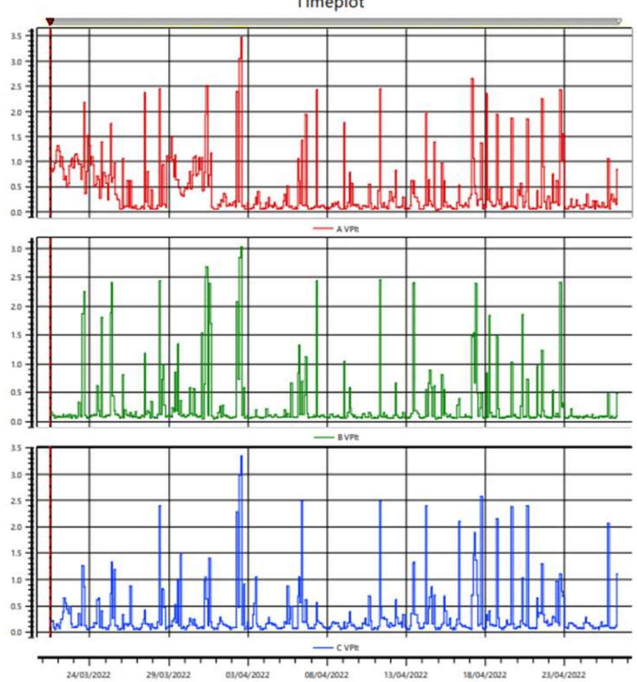
State 4: Check Power Quality under condition Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code B.E. 2016

Long Term Flicker (PASSED)

Name PQ		Sampling	Min	Avg	Max	95%	Limitation	Standard
	AVPlt	153	0.07	0.23	0.79	0.66		PRC - PQG – 02
Long Flick	BVPlt	153	0.06	0.13	0.73	0.44	< 0.8 pu	/1998
	CVPlt	153	0.08	0.21	0.70	0.55		





Power Quality Control Regulation

Long-term Flicker Severity (PLT)

PASSED

On the other hand, the need for long-term assessment of flicker severity happens if the duty cycle is long or variable. These include electric arc furnaces or disturbances on the system that are caused by multiple loads operating simultaneously. PLT is derived from PST as shown below.

$$PLT = \sqrt[3]{\frac{\sum_{i=1} PST^3}{N}}$$

The number of PST readings (N) is determined by the duty cycle of the flicker-producing load, in order to capture one duty cycle of the fluctuating load. However, if the duty cycle is unknown, the recommended number of PST readings is 12 (two hours of measuring). The limit for PLT is 0.8 units.

Voltage Level at PCC (kV)	115 and under	115 or above
Short-term Flicker Severity (PST)	0.8	0.6

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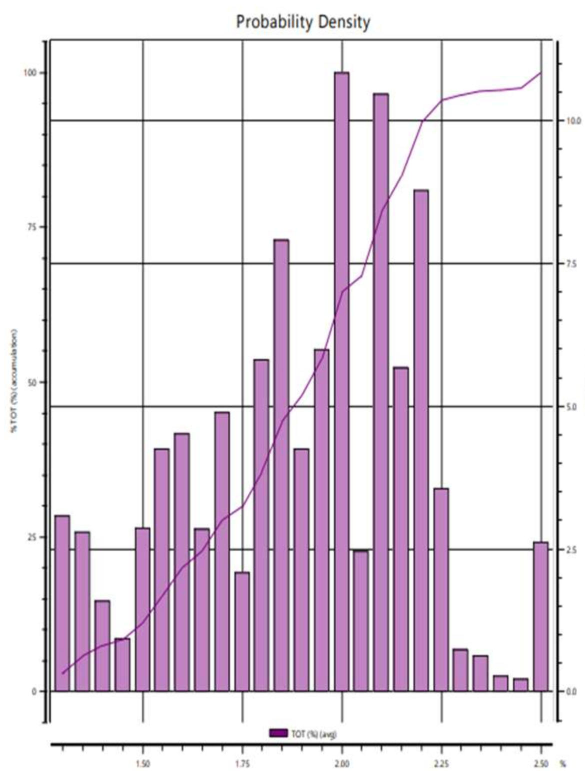
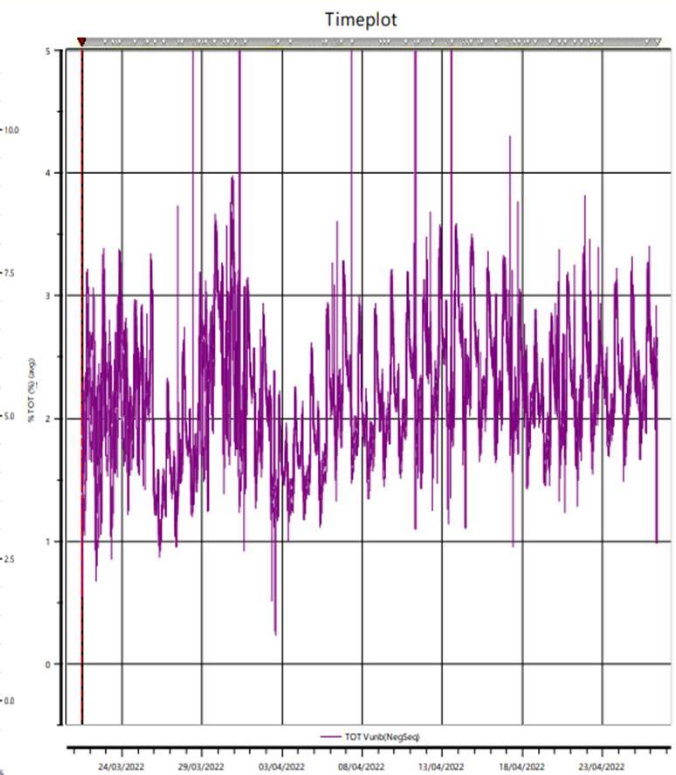
State 4: Check Power Quality under condition Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code B.E. 2016

Voltage Unbalance (ABNORMAL)

Name PQ		Sampling	Min	Avg	Max	95%	Limitation	Standard
Unbalance	Vunb	2,127	0.97	2.03	136.08	2.33	**<2%**	EN 50160





Power Quality Control Regulation

Voltage unbalance or imbalance

that is defined by ... the ra... he negative or zero sequence component to the po... sequence comp...t. In simple terms, it is a voltage variation in a... ver system ... the ...ltage magnitudes or the phase angle differe... between them are not equal. It follows that this power quality probl... affect only ...

DO NOT PASS

Voltage Level at PCC (kV)	115 or under (%)	115 or above (%)
Voltage Unbalance (%VU)		2

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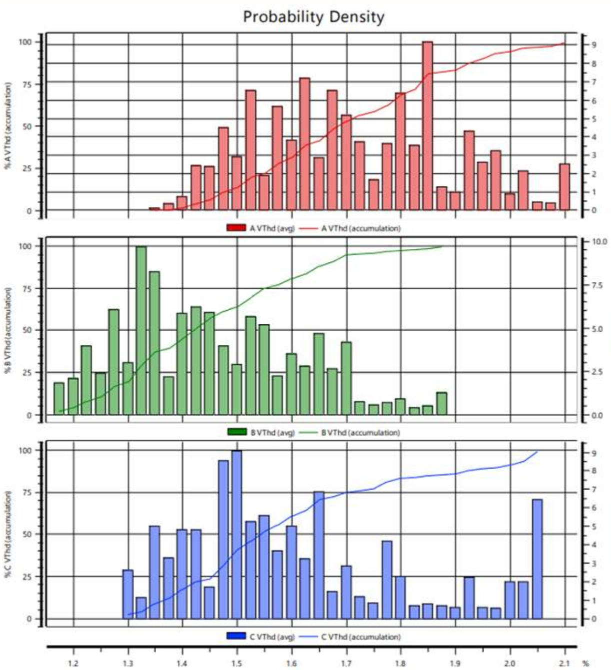
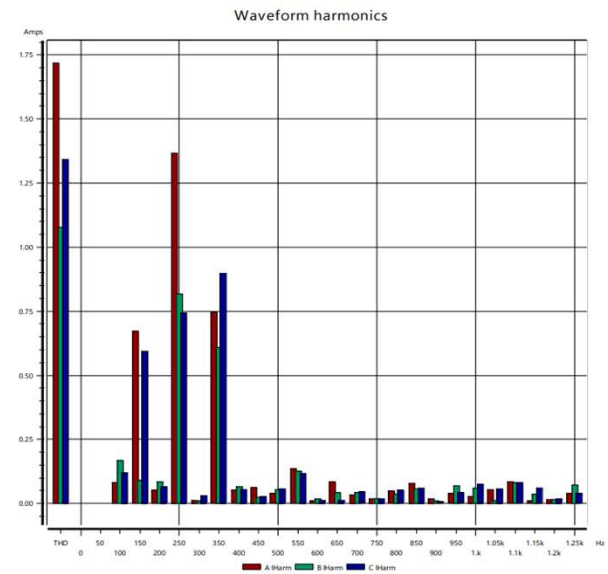
State 4: Check Power Quality under condition Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code B.E. 2016

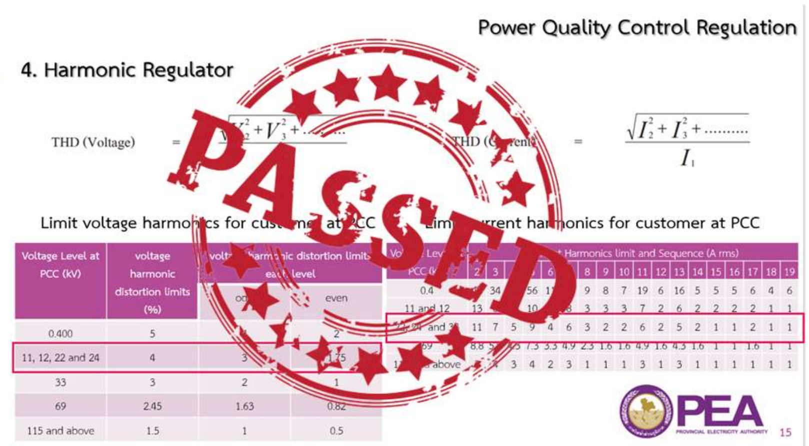
Voltage Harmonics (PASSED)

Name PQ		Sampling	Min	Avg	Max	95%	Limitation	Standard
	AVThd	2,129	1.17	-	-	2.12		PRC - PQG - 01
Harmonic	BVThd	2,129	1.06	-	-	1.88	< 4 %	/1998
	CVThd	2,129	1.17	-	-	2.14		





ลำดับที่	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ข้อกำหนด 22 kV	11	7	5	9	4	6	3	2	2	6	2	5	2	1	1	2	1	1
ผลตรวจวัด 22 kV	2.52	0.72	1.76	3.24	0.17	1.67	0.42	0.27	0.24	0.76	0.06	0.52	0.12	0.08	0.09	0.29	0.03	0.28
ผลการประเมิน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน	ผ่าน



Power Quality Control Regulation

4. Harmonic Regulator

THD (Voltage) = $\sqrt{V_2^2+V_3^2+\dots}$ [illegible]

THD (Current) = $\frac{\sqrt{I_2^2+I_3^2+\dots\dots\dots}}{I_1}$

Limit voltage harmonics for customer at PCC

Voltage Level at PCC (kV)	voltage harmonic distortion limits (%)	voltage harmonic distortion limits each level	
		odd	even
0.400	5	[illegible]	2
11, 12, 22 and 24	4	3	1.75
33	3	2	1
69	2.45	1.63	0.82
115 and above	1.5	1	0.5

Limit current harmonics for customer at PCC

Voltage Level at PCC (kV)	Current Harmonics limit and Sequence (A rms)																	
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0.4	[illegible]	34	[illegible]	56	[illegible]	[illegible]	9	8	7	19	6	16	5	5	5	6	4	6
11 and 12	13	[illegible]	[illegible]	10	[illegible]	[illegible]	3	3	3	7	2	6	2	2	2	2	1	1
22, 24 and 33	11	7	5	9	4	6	3	2	2	6	2	5	2	1	1	2	1	1
69	8.8	[illegible]	[illegible]	7.3	3.3	4.9	2.3	1.6	1.6	4.9	1.6	4.3	1.6	1	1	1.6	1	1
115 and above	[illegible]	[illegible]	3	4	2	3	1	1	1	3	1	3	1	1	1	1	1	1

PASSED

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State 5: Report

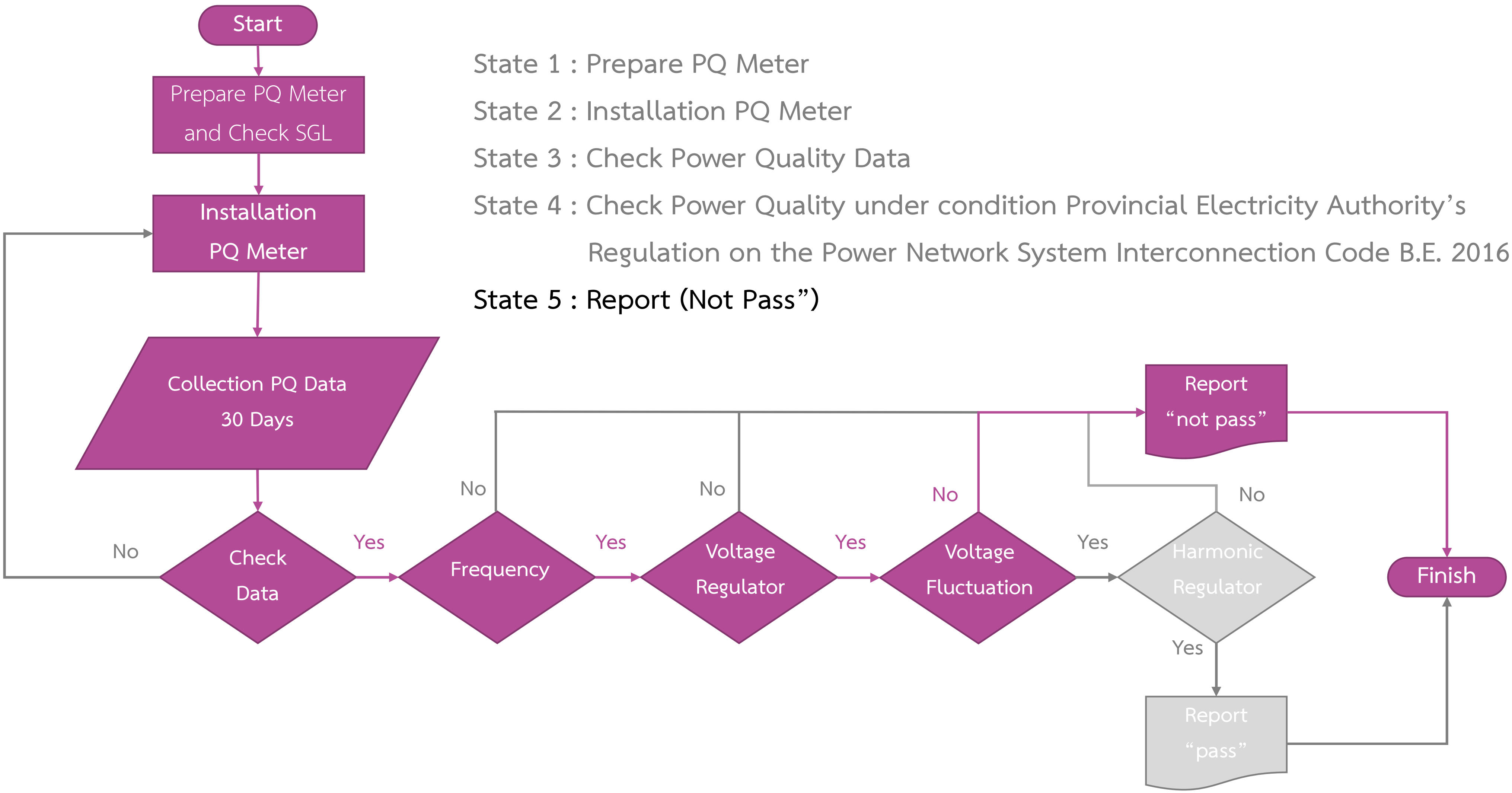
State 1 : Prepare PQ Meter

State 2 : Installation PQ Meter

State 3 : Check Power Quality Data

State 4 : Check Power Quality under condition Provincial Electricity Authority's Regulation on the Power Network System Interconnection Code B.E. 2016

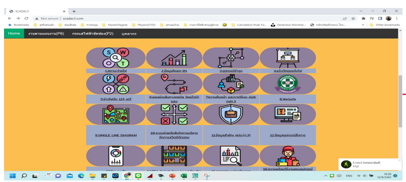
State 5 : Report (Not Pass")



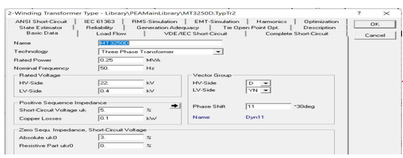
Simulation 22 kV in Distribution System and Results

Model .dz

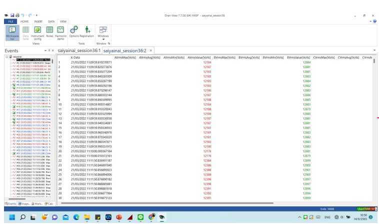
Distribution System 22 kV



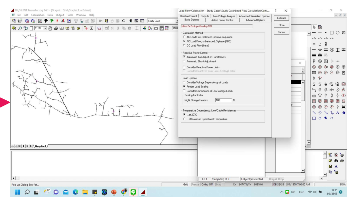
Load profile Feeder

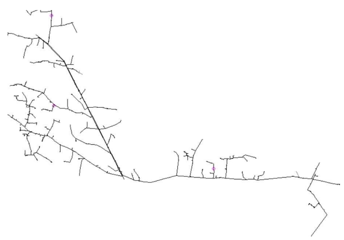


Parameter in Model

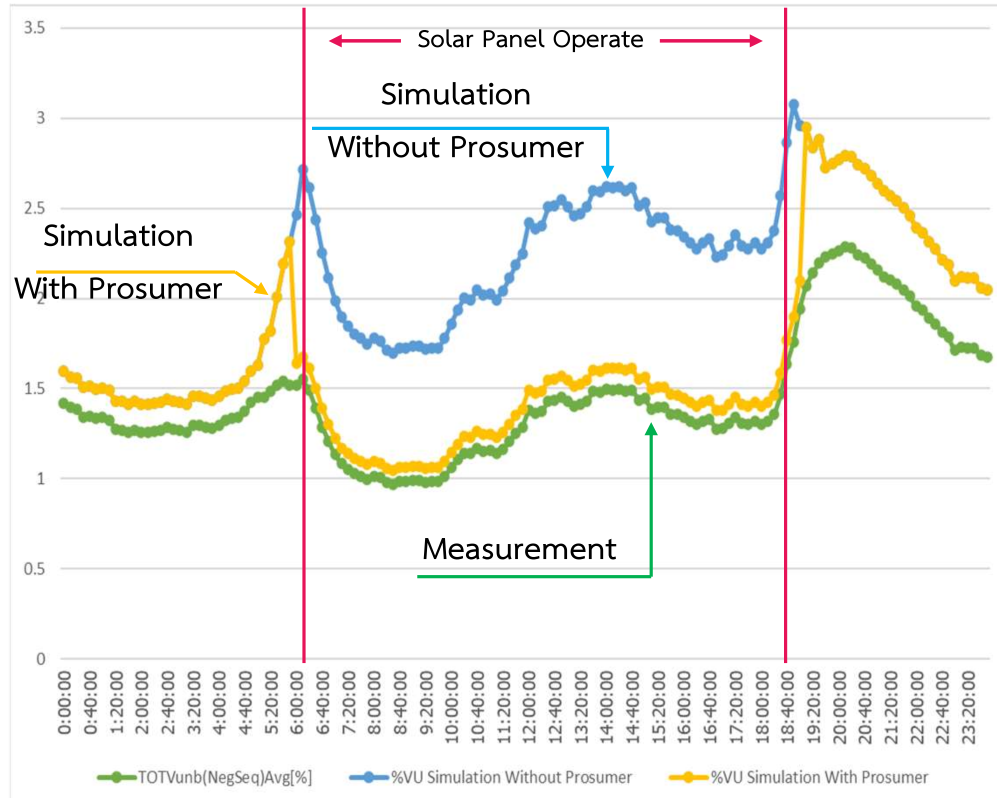


Data of Measurement



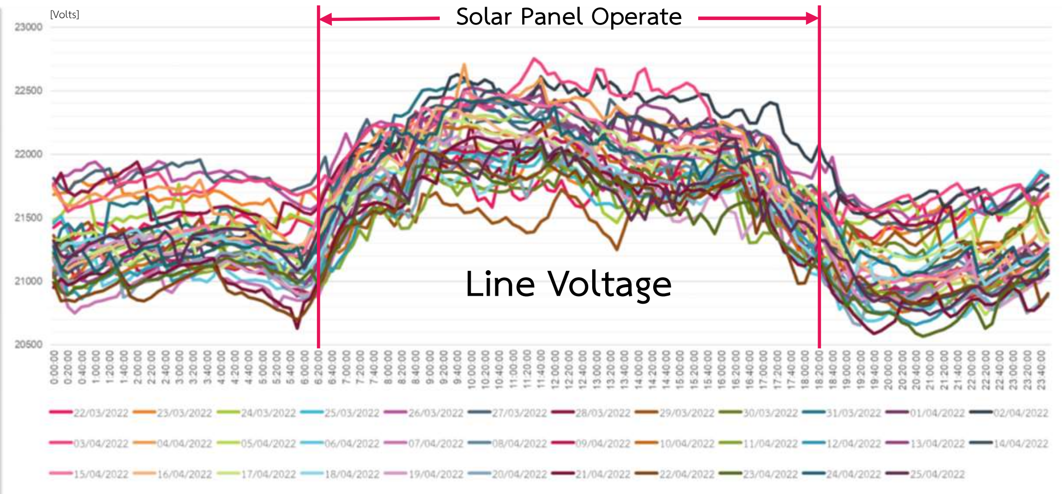


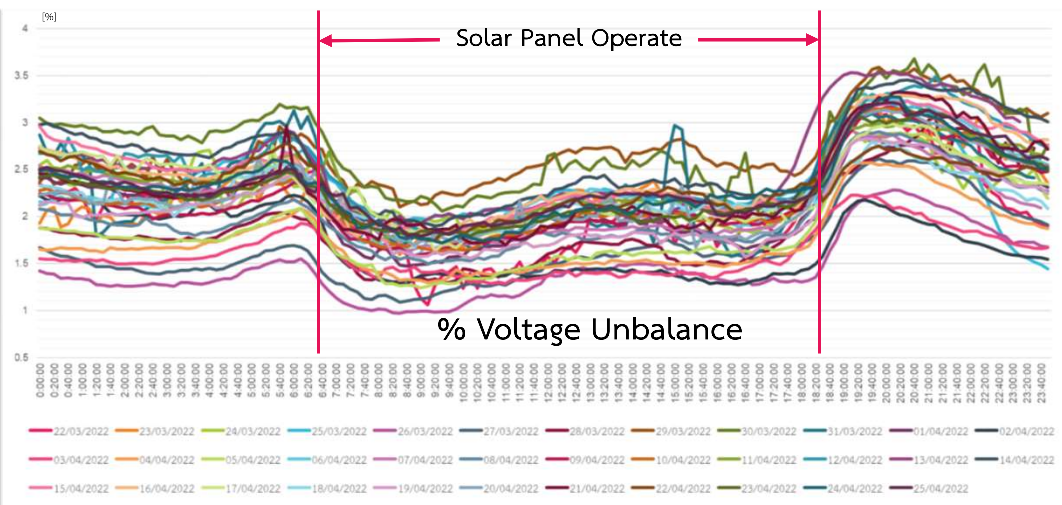
%Voltage Unbalance at PCC

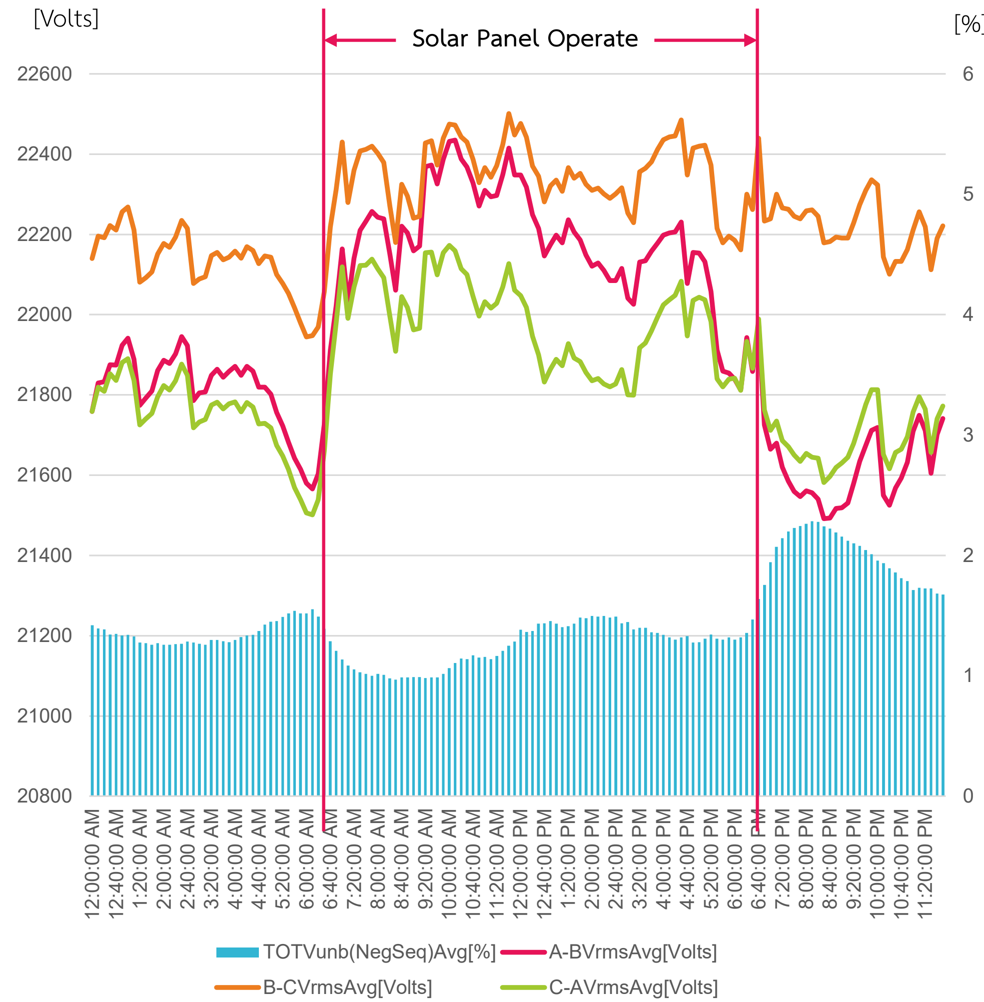


Result of Simulation

Simulation 22 kV in Distribution System and Results



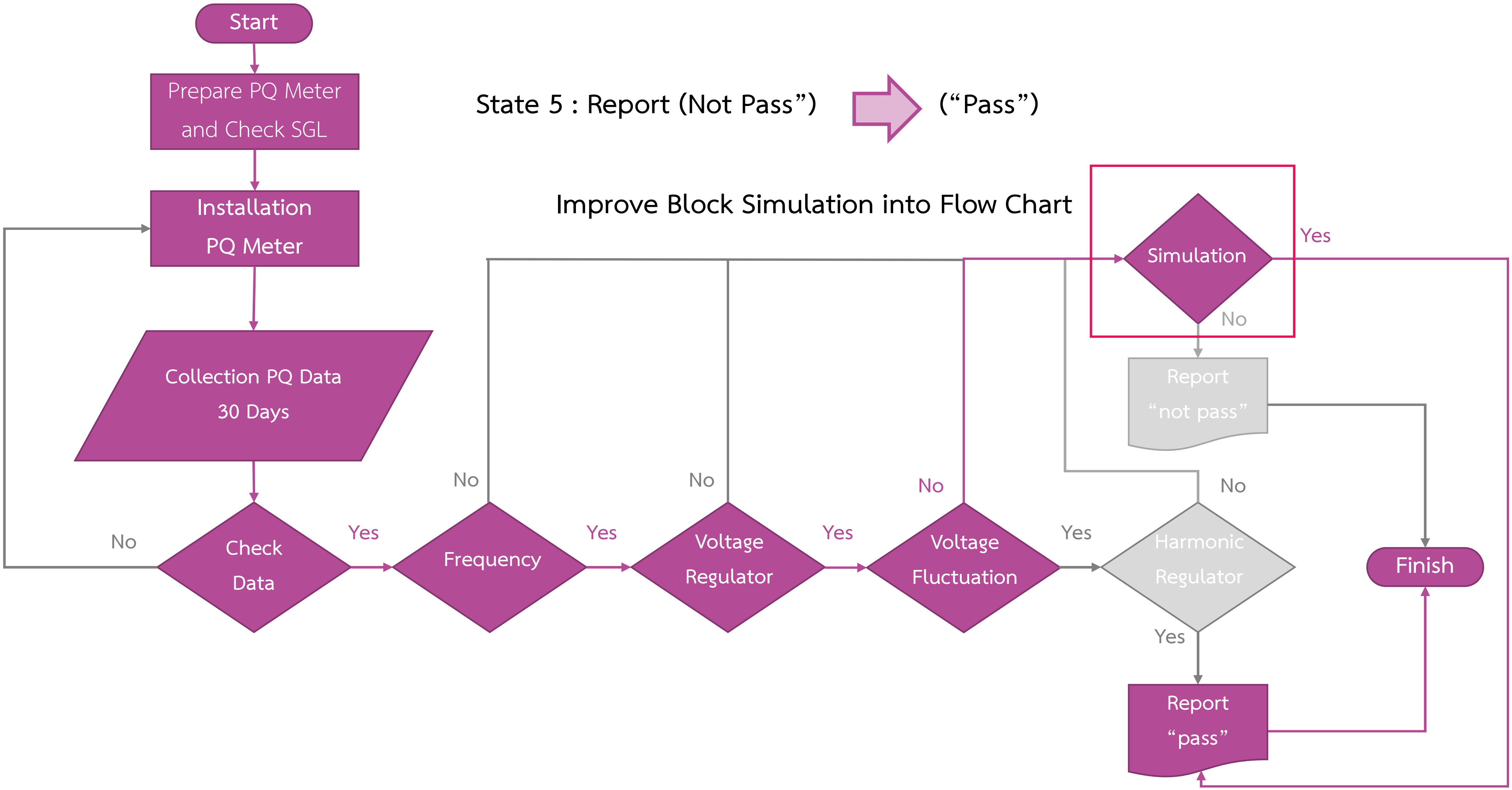




Simulation 22 kV in Distribution System and Results

State 5 : Report (Not Pass") ("Pass")

Improve Block Simulation into Flow Chart



Thank you

for your attention

Biography

Name	Churit Pansakul	Pichaya Kaewchang	Prasopphol Changpan
Position	Assistant Chief of Section Power Quality Analysis	Engineer of Power Quality Analysis Section C3	Engineer of Service and Business Section C3
Company, country	Provincial Electricity Authority (PEA), Thailand	Provincial Electricity Authority (PEA), Thailand	Provincial Electricity Authority (PEA), Thailand
short description	BEng degrees in Electrical Engineering from King Mongkut's University of Technology Thonburi in 2009 and MEng degrees in Electrical Engineering from Kasetsart University in 2015. He is currently employed as a Provincial Electricity Authority (PEA), interests include distributed energy storage and the potential impacts of electric vehicles on the grid.	BEng degrees in Electrical Energy Engineering from King Mongkut's Institute of Technology Ladkrabang in 2015. He is currently employed as a Provincial Electricity Authority (PEA), interests include distributed energy storage and the potential impacts of electric vehicles on the grid.	BEng degrees in Electrical Engineering from Kasetsart University in 2020. He is currently employed as a Provincial Electricity Authority (PEA), interests include distributed energy storage and the potential impacts of electric vehicles on the grid.