Analyzing the health index (HI) of substations supplying power to industrial estates using logistic regression for power quality improvement

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PowerQuality Thailand LTD.

AGENDA

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Key Word : Power Quality, Health Index, SAIFI, SAIDI, SARFI, Logistic Regression

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Power Quality, Health Index, SAIFI, SAIDI, SARFI, Logistic Regression

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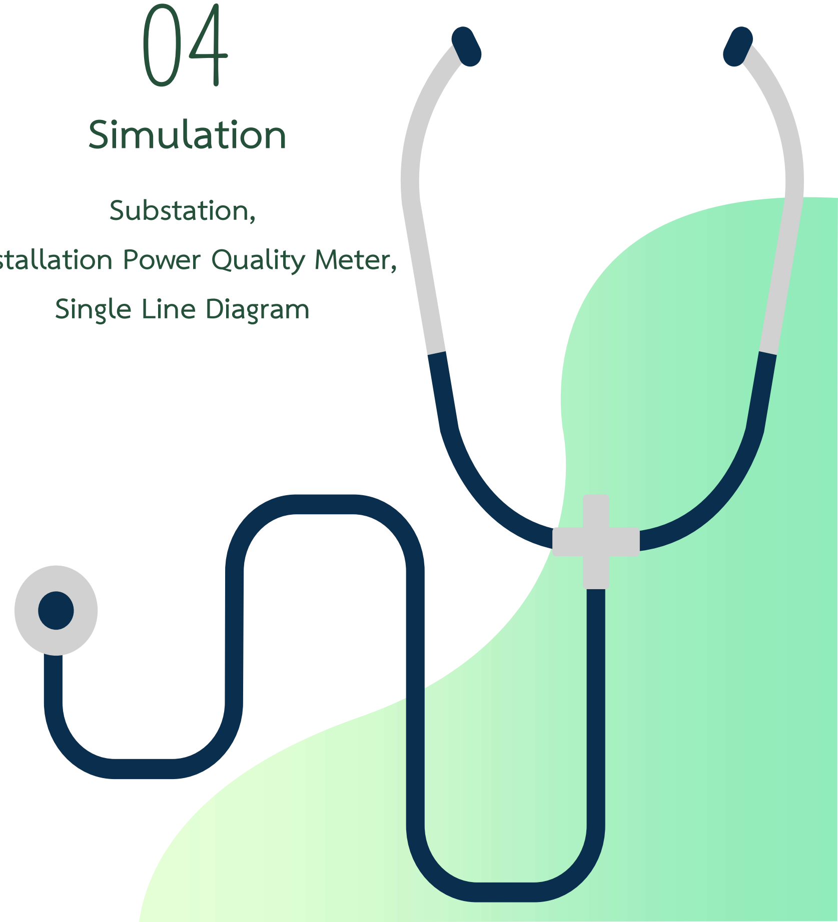
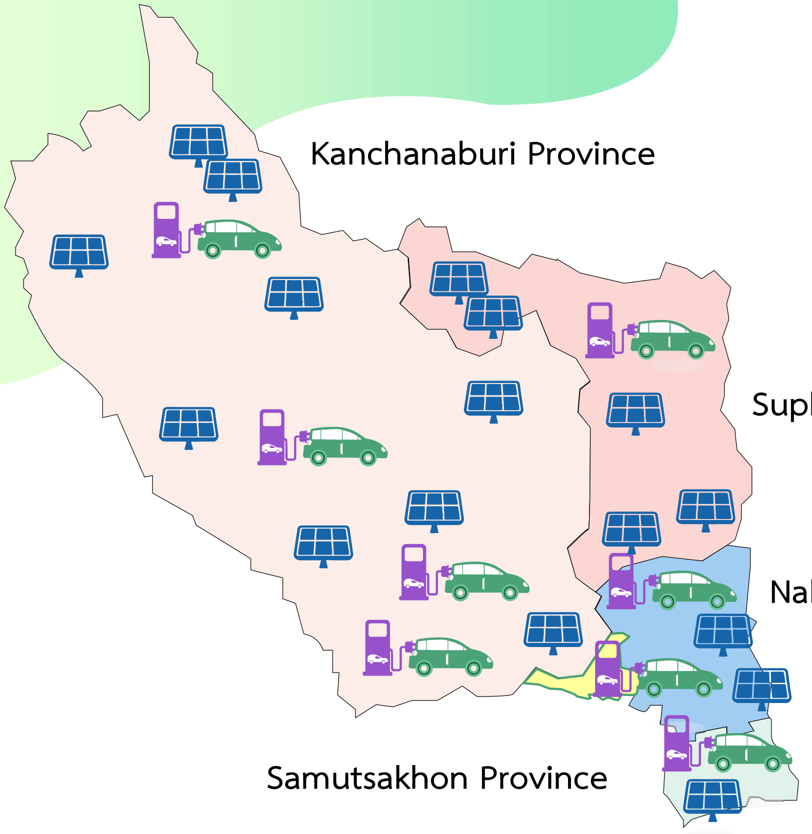
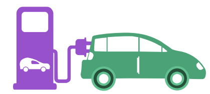


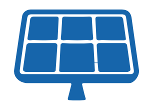
01

Introduction

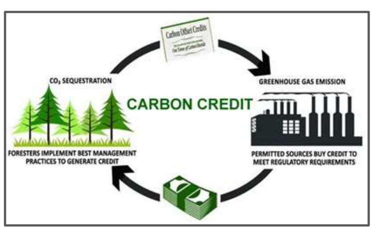
Introduction

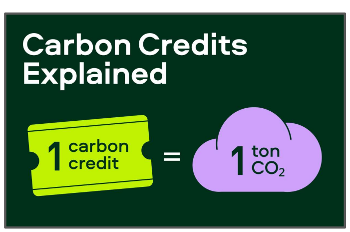


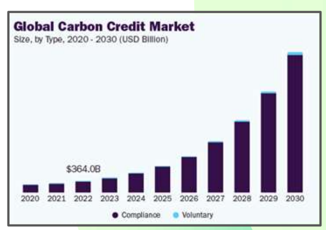

EV Charger Station and Plugin

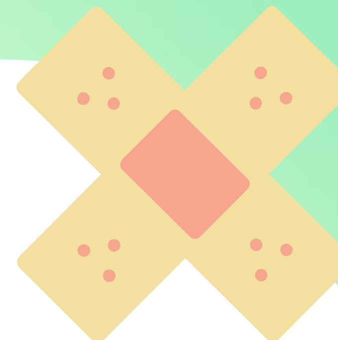

Solar Rooftop and Farm

Now power station and the 22 KV distribution system of the Provincial Electricity Authority (PEA) that supplies power to industrial estates Construction has been completed and has been supplying power for a long time. In addition, there is improvement and construction of a 22 KV distribution system to support the growing industry. In addition, the government policy encourages companies or entrepreneurs to install Solar Rooftops in order to reduce electricity costs. and reduce or store greenhouse gas emissions (Carbon Credit). For these reasons, companies or entrepreneurs within industrial estates install more solar rooftops and assemble machinery and electrical equipment. It has a non-linear load characteristic (Non-Linear Load), affecting the power quality of the 22 KV distribution system and the power station. to which the 22 KV distribution system is connected.







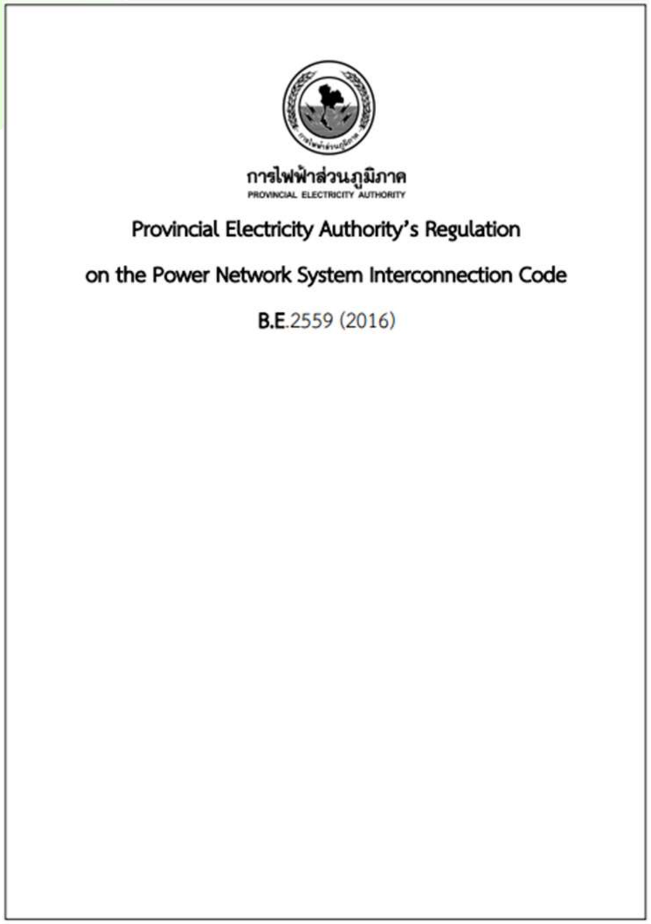


02

Theory

Power Quality, Health Index, SAIFI, SAIDI, SARFI, Logistic Regression

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

PEA
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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

PEA
PROVINCIAL ELECTRICITY AUTHORITY

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

PEA

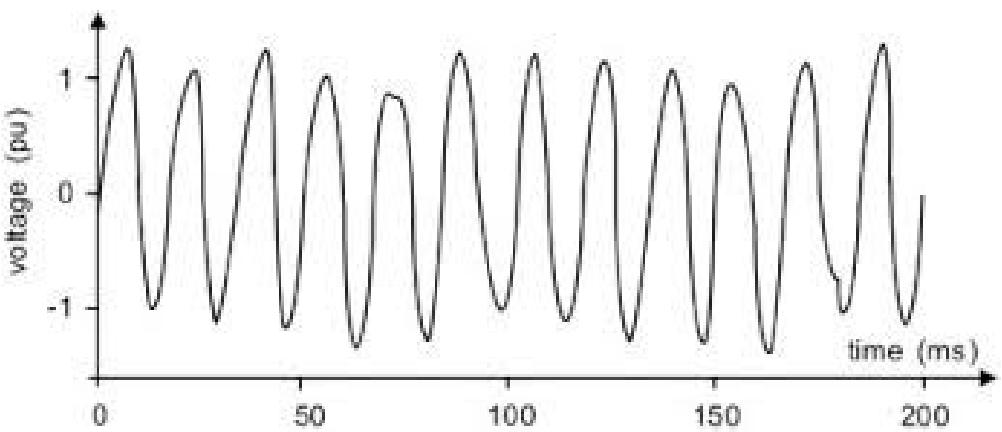
PROVINCIAL ELECTRICITY AUTHORITY

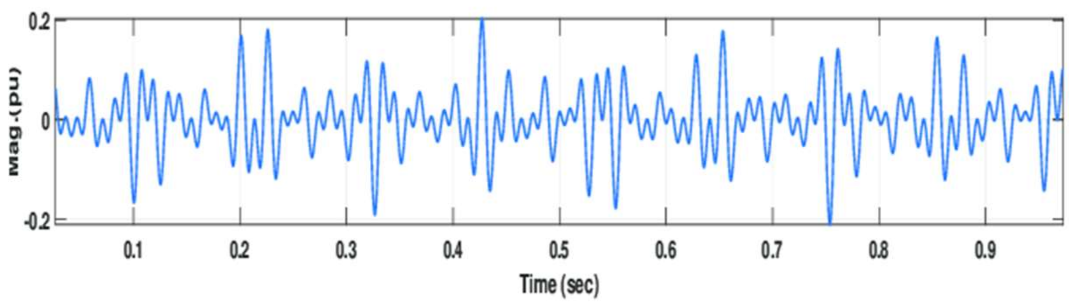
4. Voltage Flicker

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)





PROVINCIAL ELECTRICITY AUTHORITY

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

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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

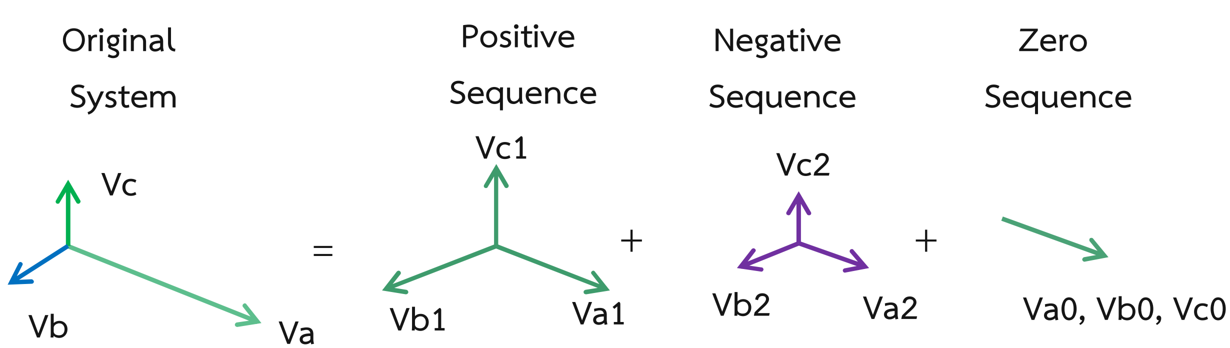
V_1 : Positive Sequence Voltage

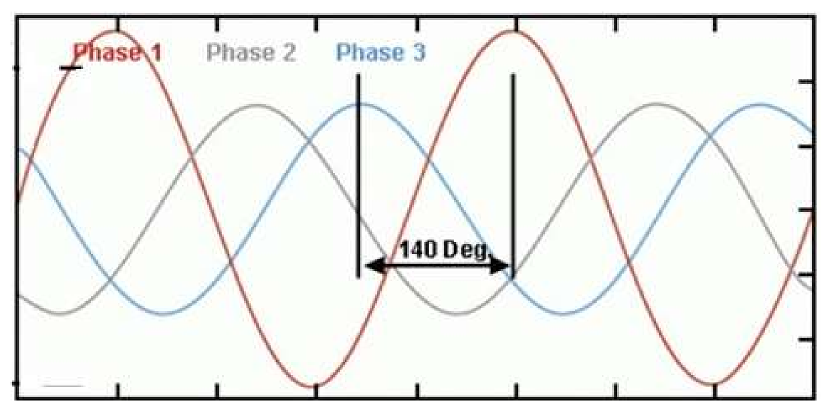
V_2 : Negative Sequence Voltage

$V_a\angle\theta_a$: 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





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

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

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

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

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

System Average RMS Frequency Index

System average RMS Variation Frequency Index Voltage: SARFI (Root-Mean-Square, RMS) It is a tool for evaluating power quality for a given circuit. The index may be applied to systems of different sizes from distribution systems. It is considered as the number of measured events and voltage level variations during the evaluation period of the voltage value.

N_e Number of events affected by voltage level variation during the evaluation period. By considering the condition of momentary voltage drop (Voltage Sag, Dip)

D Number of measurement days for a single measurement point, a single consumer, a single circuit, a single power station. and power station groups

$$SARFI = \frac{N_e}{D} \times 30\ Days$$

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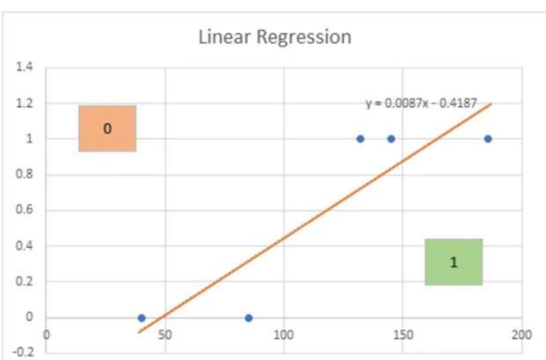
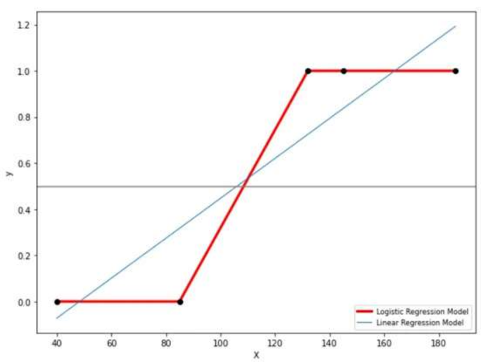
Logistic regression analysis

Logistic regression analysis It is an analytical technique. Qualitative statistics Used for finding relationships between independent variables. (greater than or equal to 1) with the dependent variable and predict the chance of the event of interest occurring When divided according to the measurement level of the variable Can be divided into 2 types: Binary logistic regression and Multinomial logistic regression. Such logistic regression analysis They differ in terms of the dependent variable. By analyzing Binary logistic regression, it can be used with a dependent variable that has only 2 values: 0 and 1.



เส้นการทำนายผลการพักจากการอ่านหนังสือ



Linear Regression vs Logistic Regression — source code

คนที่	เวลาในการอ่านหนังสือ:นาที (X)	ต้องการพักหรือไม่? (Y)	ผลการความน่าจะเป็นที่จะพักการอ่านหนังสือทำนายด้วย LR (Y_hat)	ผลการความน่าจะเป็นที่จะพักการอ่านหนังสือทำนายด้วย Logistic Regression (Y_hat)
1	40	0	-0.0707	0.0000
2	145	1	0.8428	0.9998
3	186	1	1.1995	1.0000
4	85	0	0.3208	0.0048
5	132	1	0.7297	0.9954

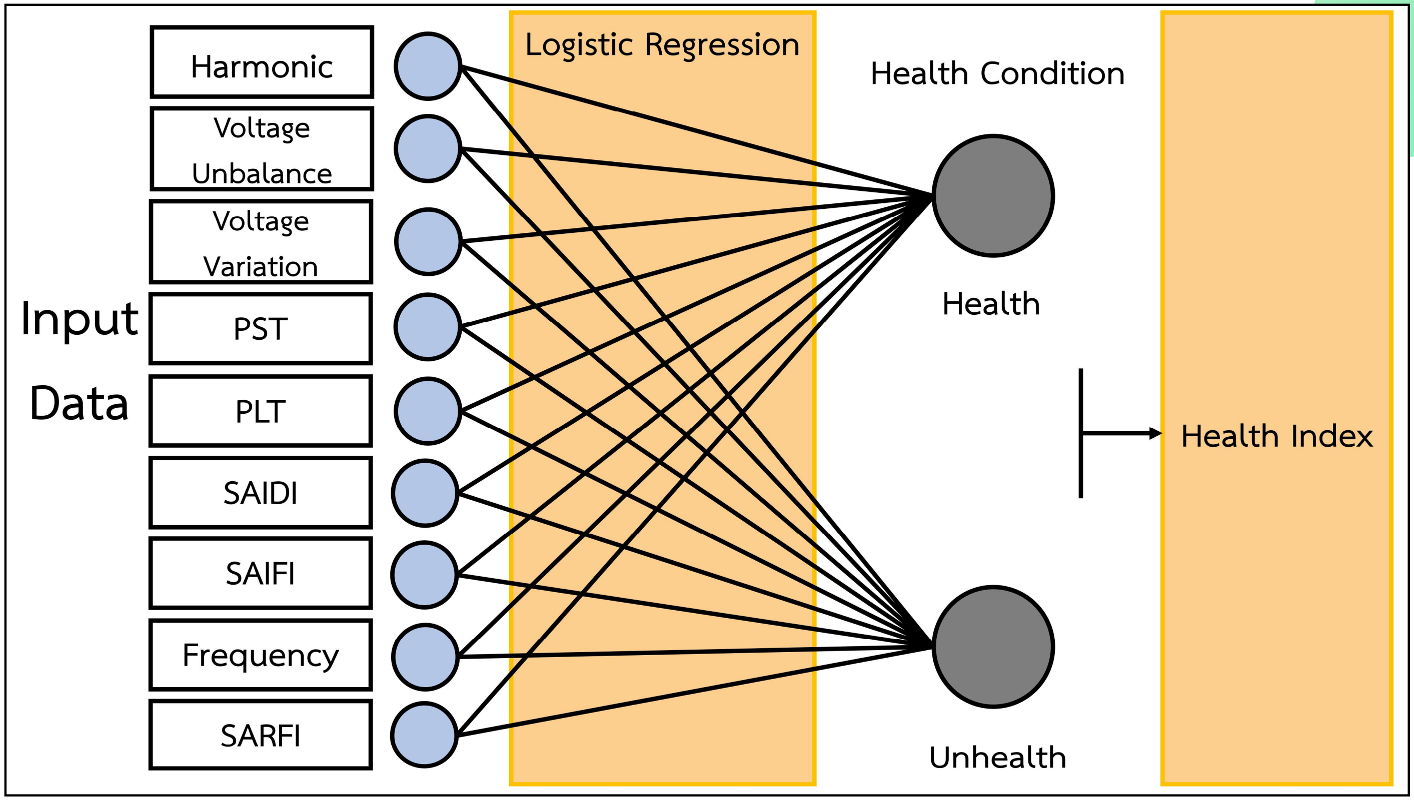
*หมายเหตุ: ต้องการพัก=1, ไม่ต้องการพัก=0

[Data Scientist Model EP.03] Logistic Regression Classification Part1/Pasith Thanapatpisarn

Power Quality Health Index (PQ HI)

The power quality of an electrical system depends on power quality parameters including harmonics, voltage unbalance, Voltage ripple (short term (PST), long term (PLT)), frequency (Frequency), over/under voltage (Over / Under Voltage), SAIFI, SAIDI and SARFI which are independent variables. There are no related parts. Therefore, it is difficult to establish a relationship between various variables

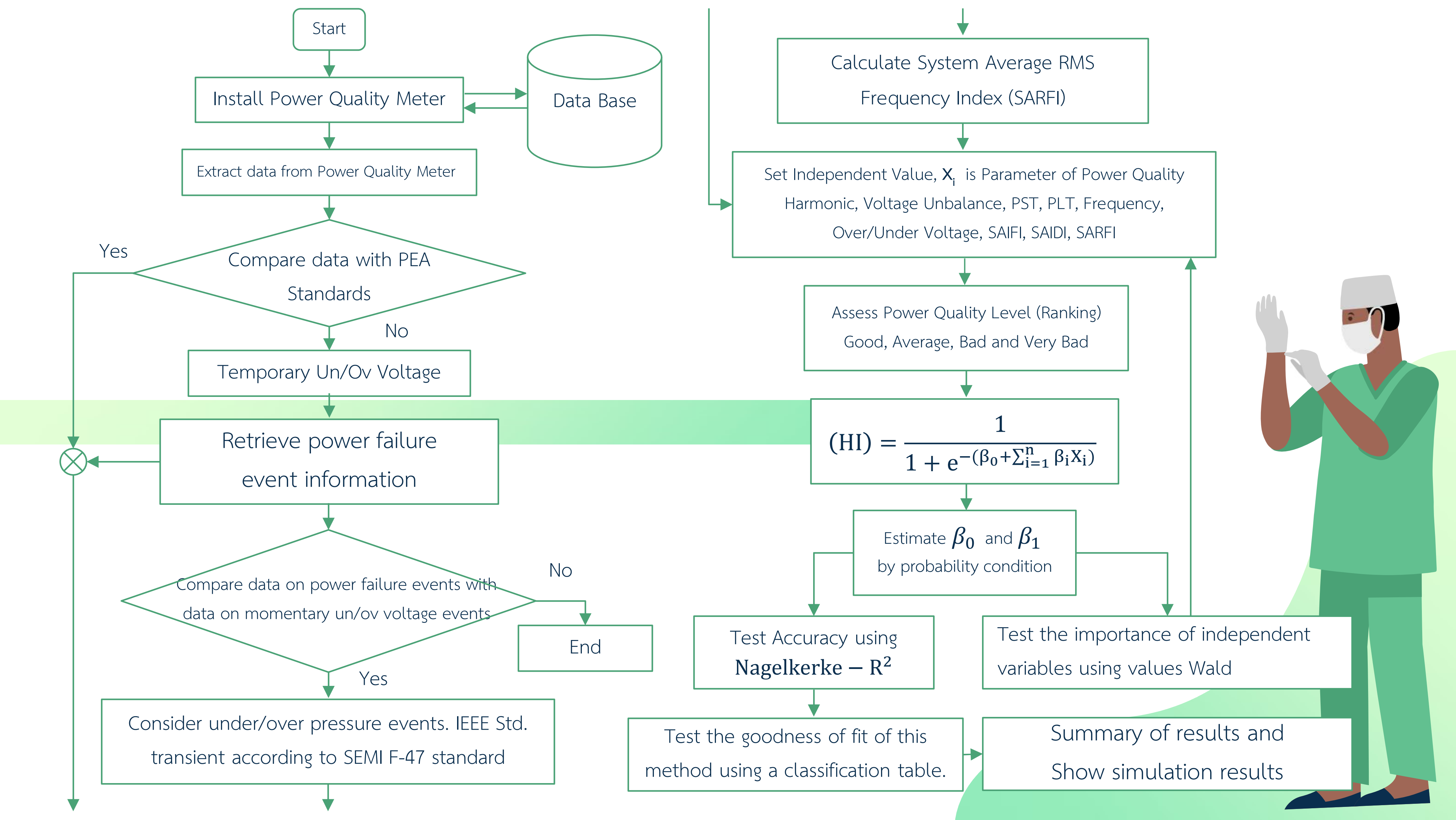
$$Health\ Index\ (HI) = \frac{1}{1 + e^{-(\beta_0 + \sum_{i=1}^{n} \beta_i X_i)}}$$



03

Method

Flow Chart



Start
Install Power Quality Meter
Data Base
Extract data from Power Quality Meter
Compare data with PEA Standards
Yes
No
Temporary Un/Ov Voltage
Retrieve power failure event information
Compare data on power failure events with data on momentary un/ov voltage events
No
End
Yes
Consider under/over pressure events. IEEE Std. transient according to SEMI F-47 standard
Calculate System Average RMS Frequency Index (SARFI)
Set Independent Value, X_i is Parameter of Power Quality Harmonic, Voltage Unbalance, PST, PLT, Frequency, Over/Under Voltage, SAIFI, SAIDI, SARFI
Assess Power Quality Level (Ranking) Good, Average, Bad and Very Bad
$(HI) = \frac{1}{1 + e^{-(\beta_0 + \sum_{i=1}^{n} \beta_i X_i)}}$
Estimate β_0 and β_1 by probability condition
Test Accuracy using Nagelkerke $- R^2$
Test the importance of independent variables using values Wald
Test the goodness of fit of this method using a classification table.
Summary of results and Show simulation results

04

Simulation

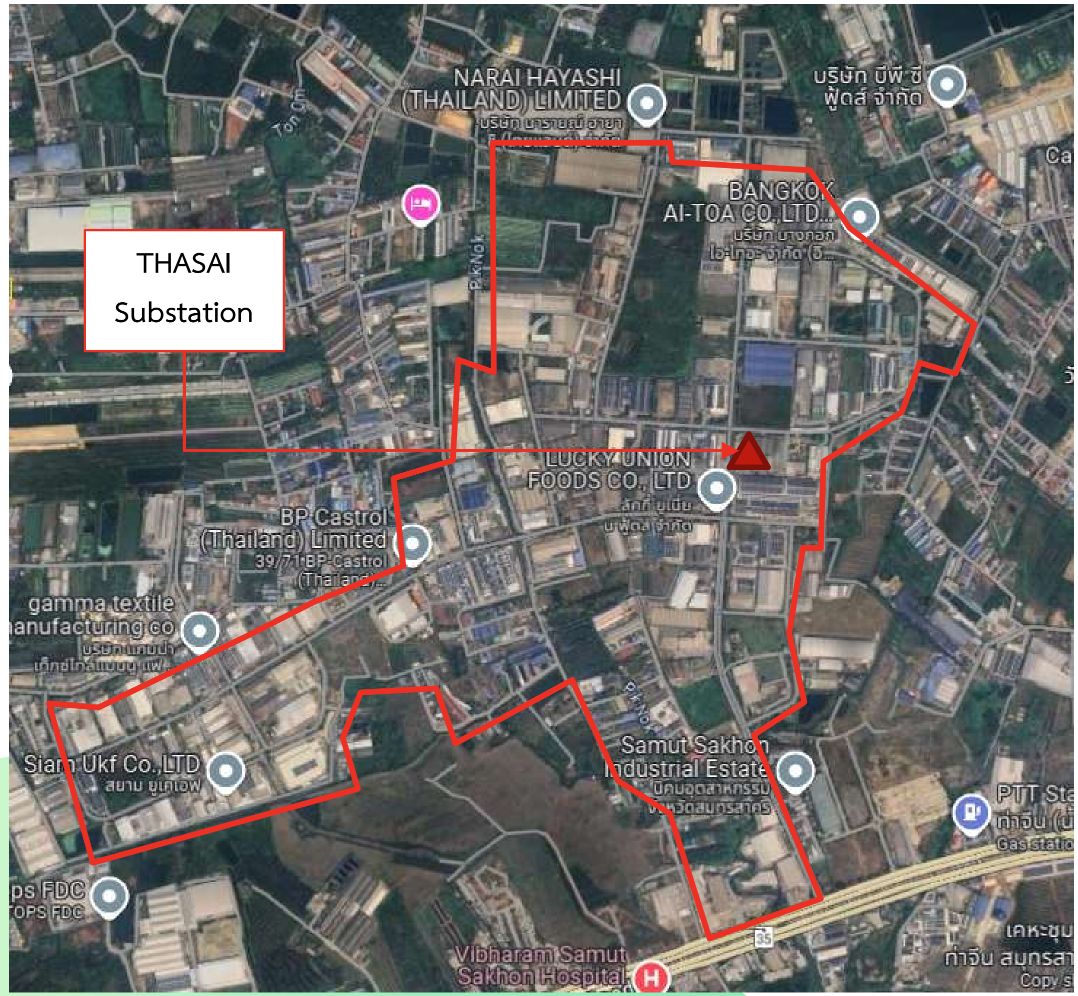
Substation,

Installation Power Quality Meter,

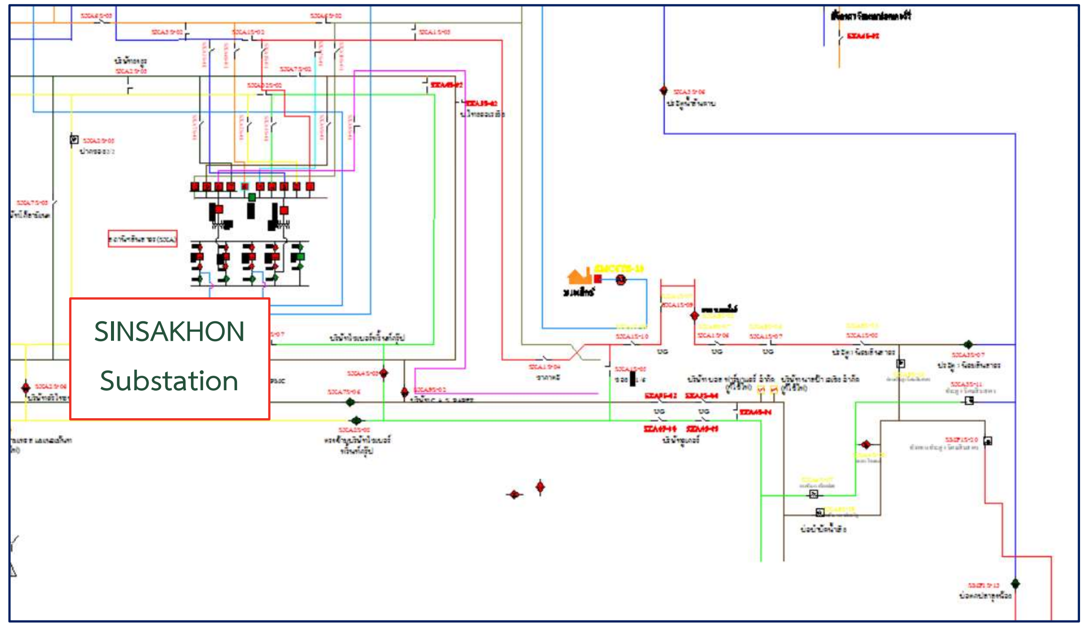
Single Line Diagram

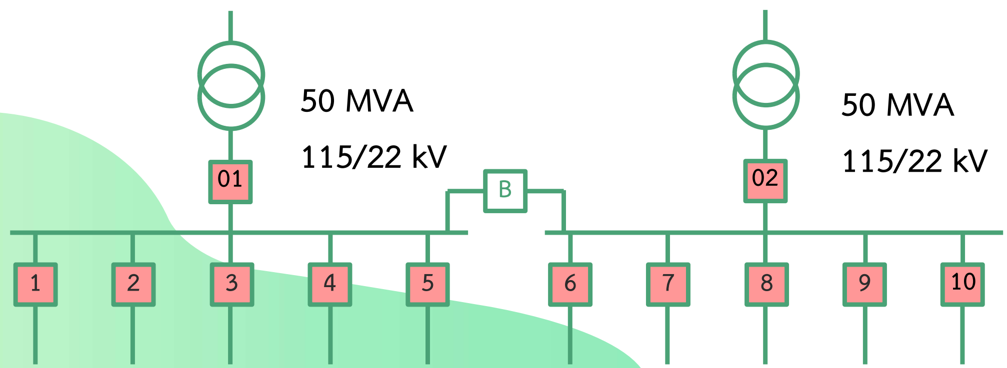
SINSAKHON Substation
and SINSAKHON industrial Estate

THASAI Substation
and SAMUT SAKHON industrial Estate



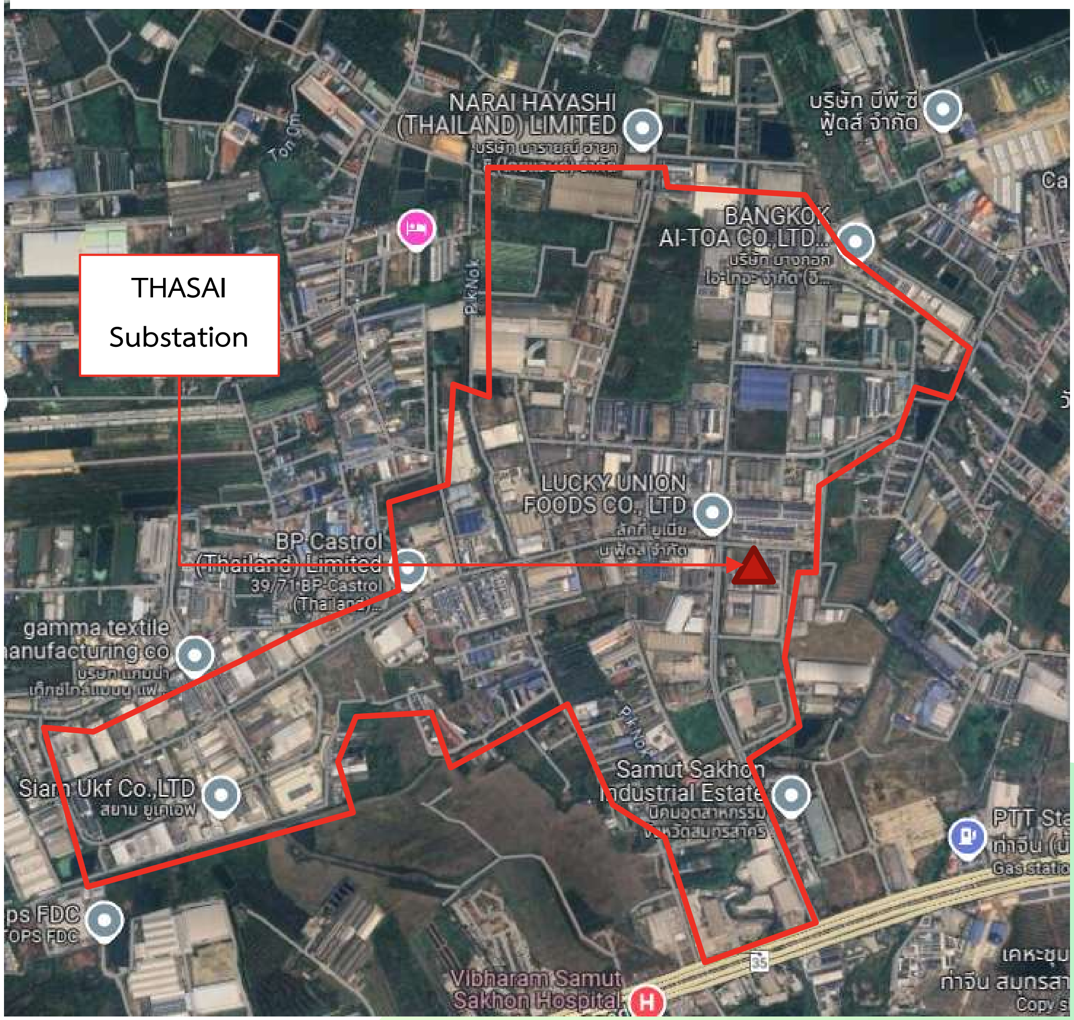
SINSAKHON Substation and SINSAKHON industrial Estate

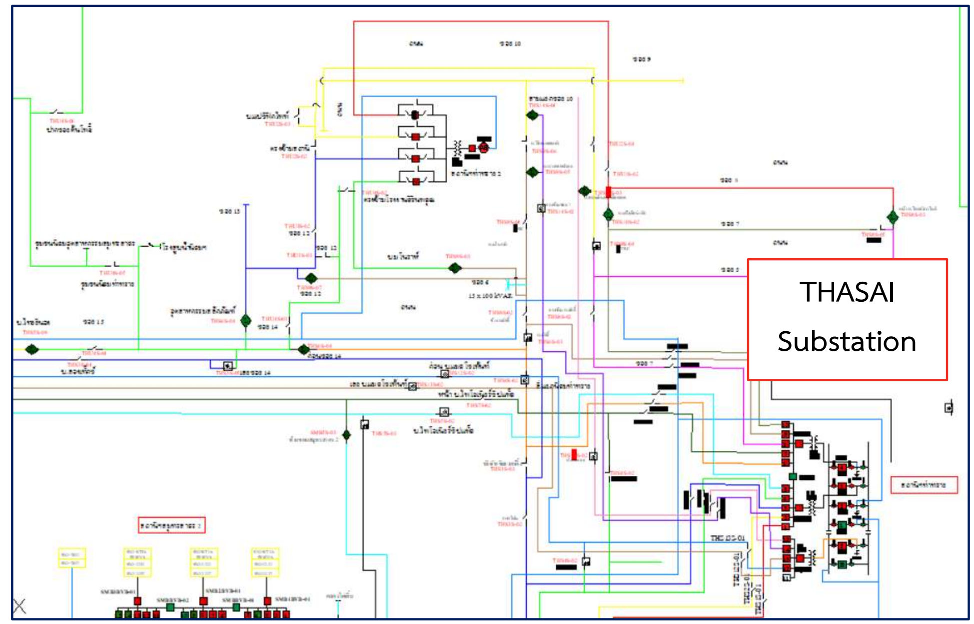


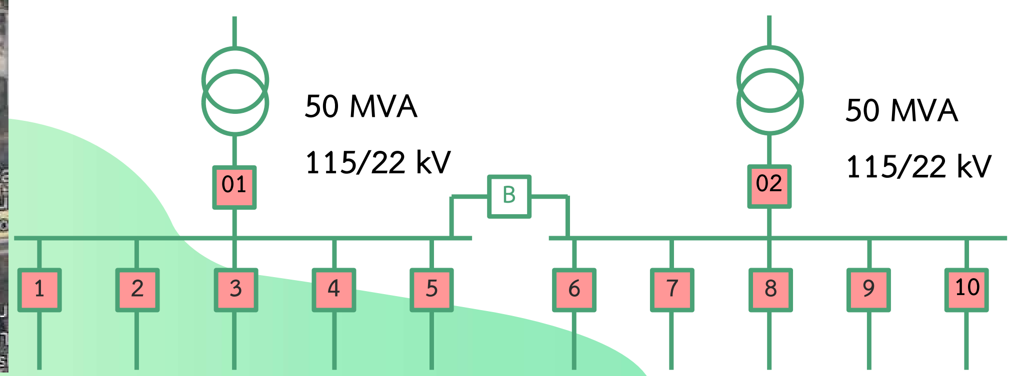


THASAI Substation

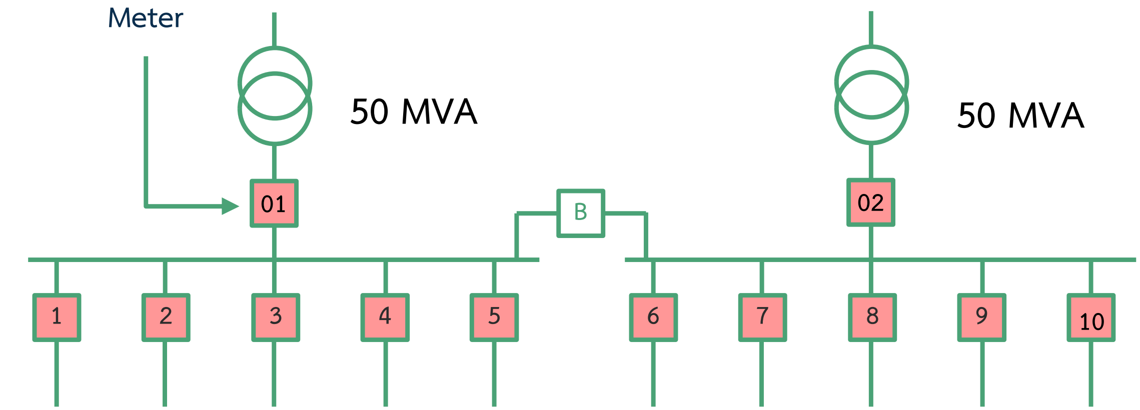
and SAMUT SAKHON industrial Estate

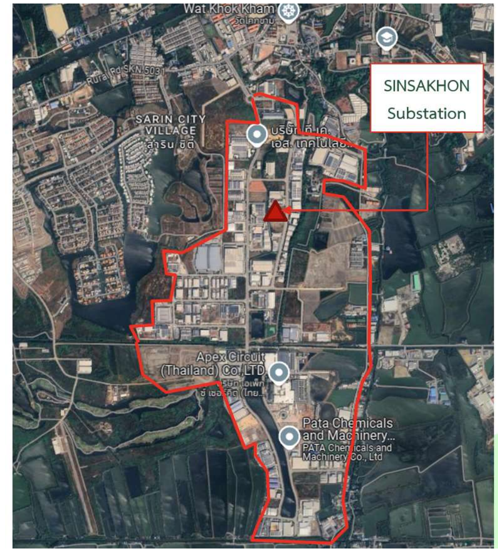




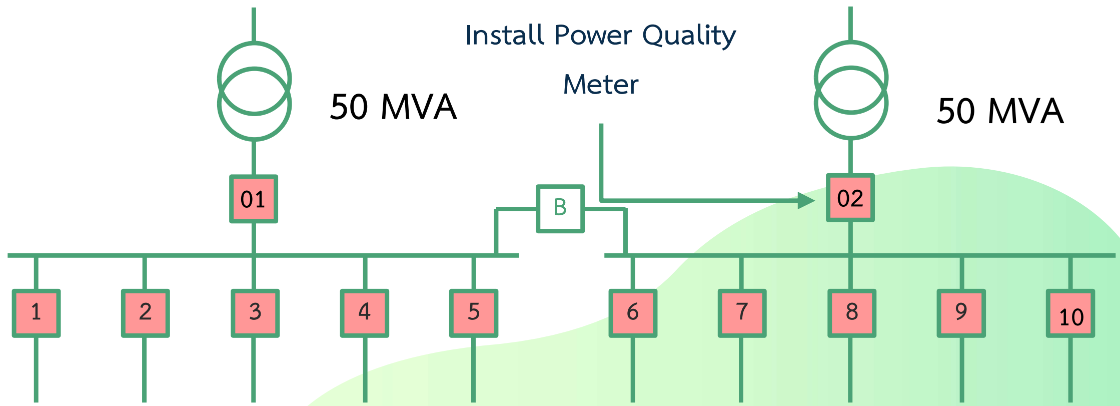


Installation format for Power Quality Meter SINSAKHON Substation (Incoming 1)

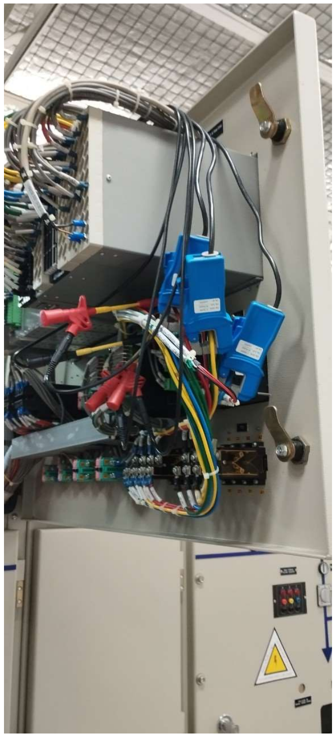




Installation format for Power Quality Meter THASAI Substation (Incoming 2)

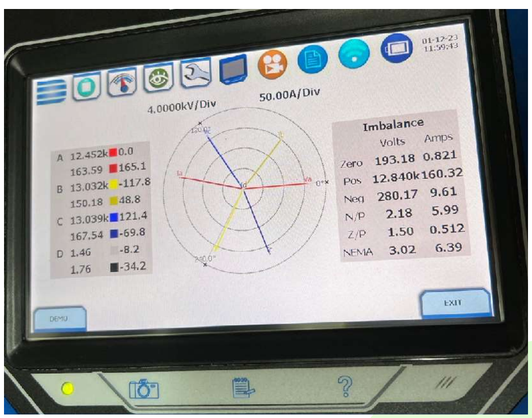


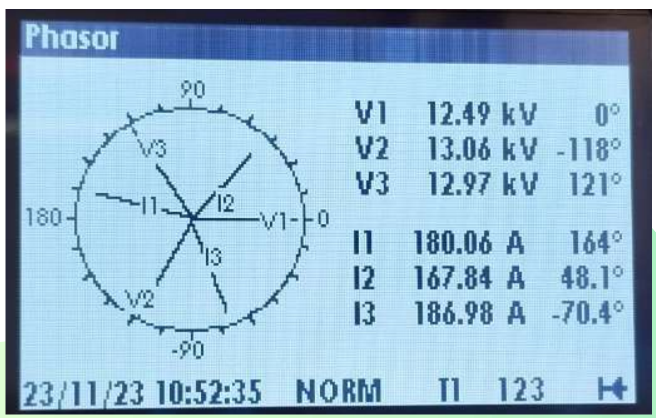

HDPQ
=J04
INCOMING FROM TR. 1



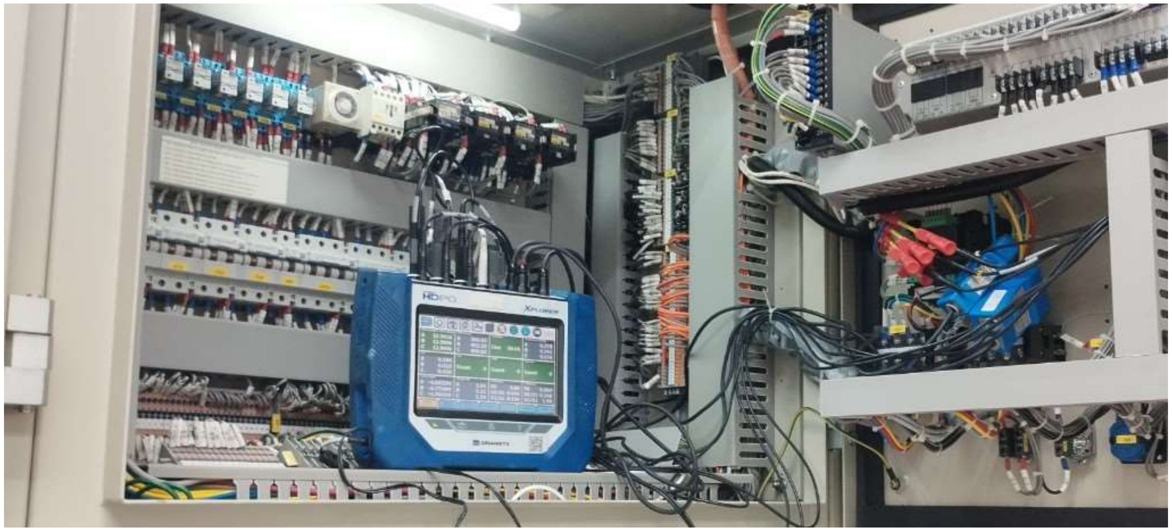

=J03
OUTGOING NO. 3
F3


F5


4.0000kV/Div
50.00A/Div
Imbalance
Volts Amps
Zero 193.18 0.821
Pos 12.840k 160.32
Neg 280.17 9.61
N/P 2.18 5.99
Z/P 1.50 0.512
NEMA 3.02 6.39
EXIT


Phasor
90
180
0
-90
V1
V2
V3
I1
I2
I3
V1 12.49 kV 0°
V2 13.06 kV -118°
V3 12.97 kV 121°
I1 180.06 A 164°
I2 167.84 A 48.1°
I3 186.98 A -70.4°
23/11/23 10:52:35 NORM I1 123


HDPQ
XPLORER
Line 50.04
Count 0
Count 0
Count 0




A 230.91V
152.06A
B
C
D
Freq:
50.00Hz
400.00
200.00
0.00
-200.00
-400.00
Volts
Amps
3.18 ms/div
SELECT
STACKED/ OVERLAY
CHECK RANGE
SNAPSHOT TO DATABASE
EXIT


INC 1

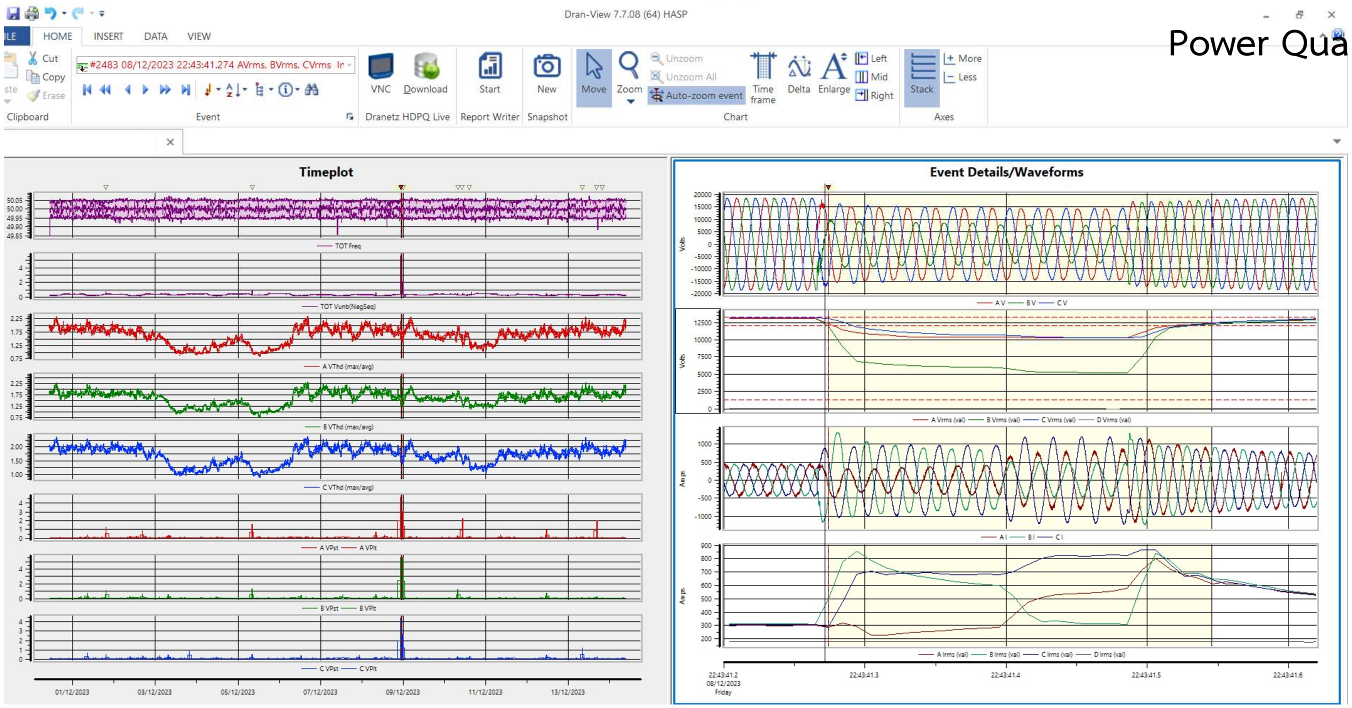

Channel A
THD: 33.6%
TDD: 5.9%
Amps
Harmonic #
CHANNEL PARAMETER
GRAPH/ TABLE
ZOOM
SCALE
OPTIONS
EXIT

05

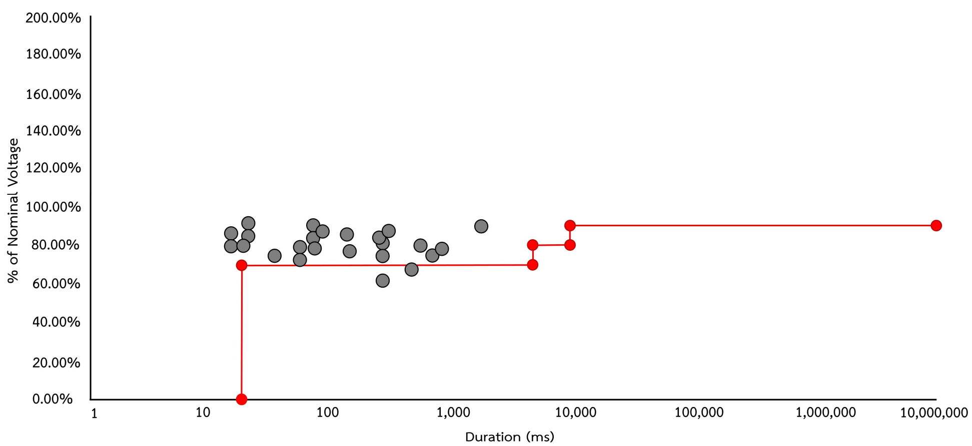
Result

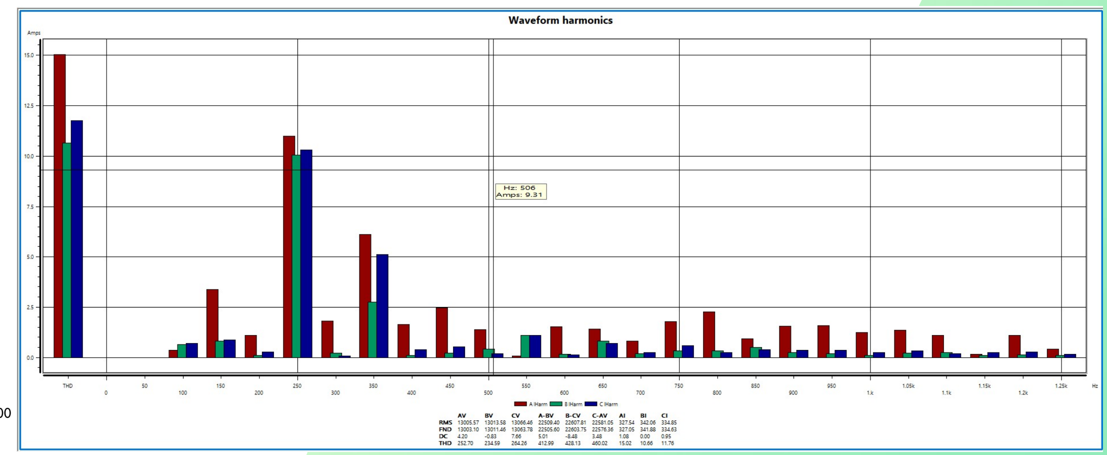
Results from the simulation

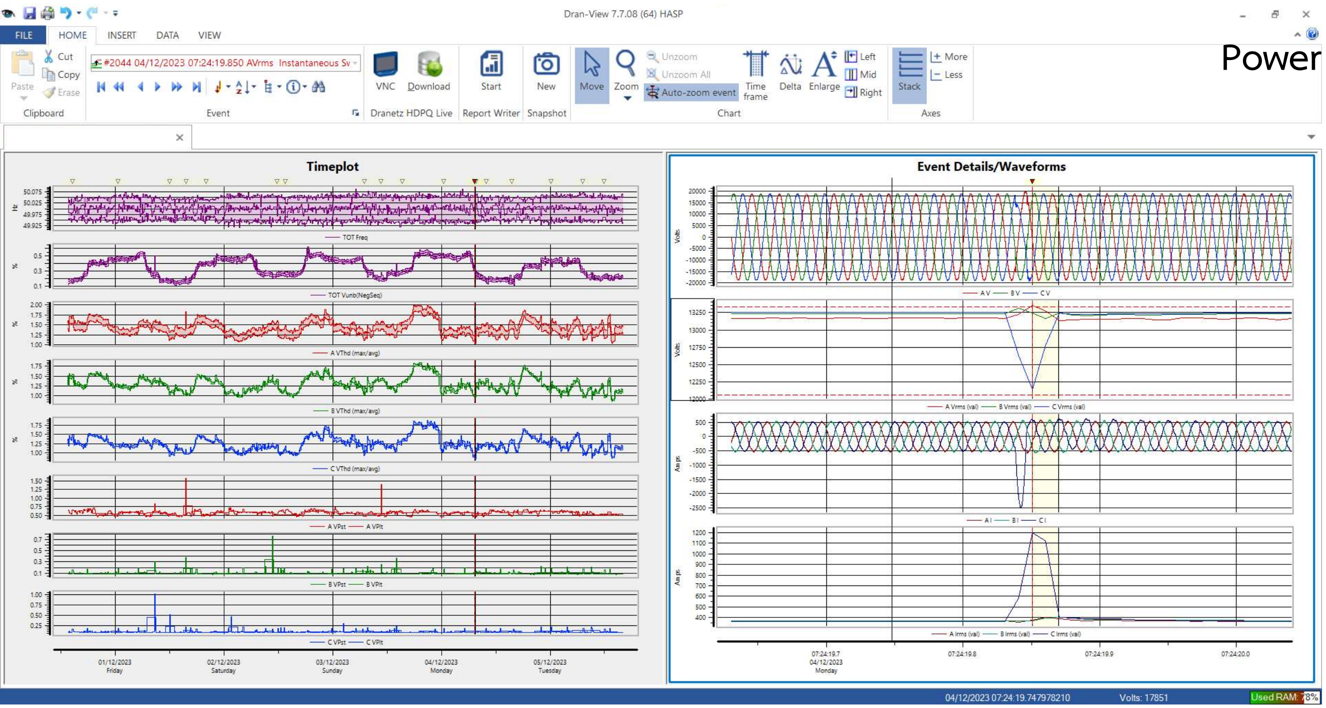
Power Quality information of Sinsakhon Substation



ตัวย่อ	หน่วย	ค่าที่ได้จากการตรวจวัด		เกณฑ์มาตรฐาน	
		CP01/05	CP95/99	Min	Max
Frequency	Hz	49.97	50.02	49.50	50.50
U1 rms	Voltage	22.10	22.53	20.90	23.10
U2 rms	Voltage	22.23	22.70	20.90	23.10
U3 rms	Voltage	22.40	22.83	20.90	23.10
V1 THD	%	0.06	0.16	-	4.00
V2 THD	%	0.06	0.22	-	4.00
V3 THD	%	0.06	0.17	-	4.00
VUN	%	0.33	0.50	-	2.00
PST1	%	0.05	0.15	-	1.00
PST2	%	0.06	0.16	-	1.00
PST3	%	0.05	0.15	-	1.00
PLT1	%	0.06	0.16	-	0.80
PLT2	%	0.06	0.22	-	0.80
PLT3	%	0.06	0.17	-	0.80
SAIFI		0.057			
SAIDI		0.061			
SARFI		23			

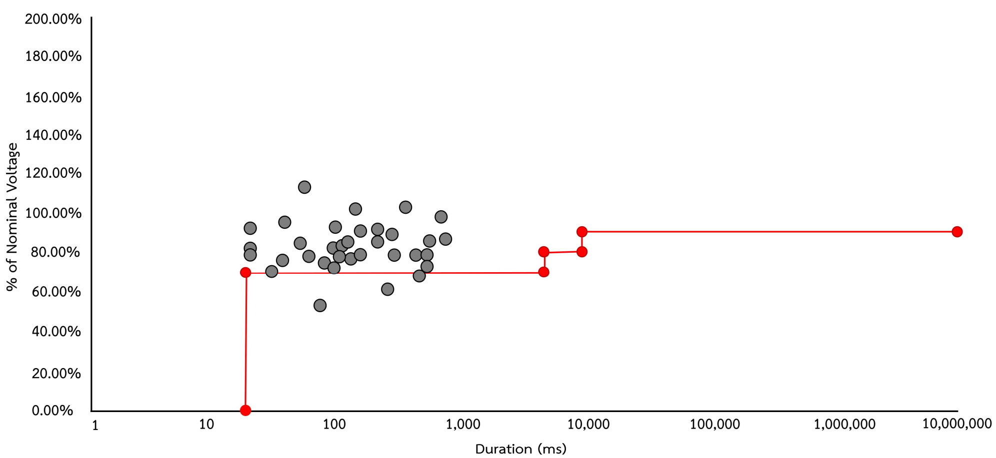


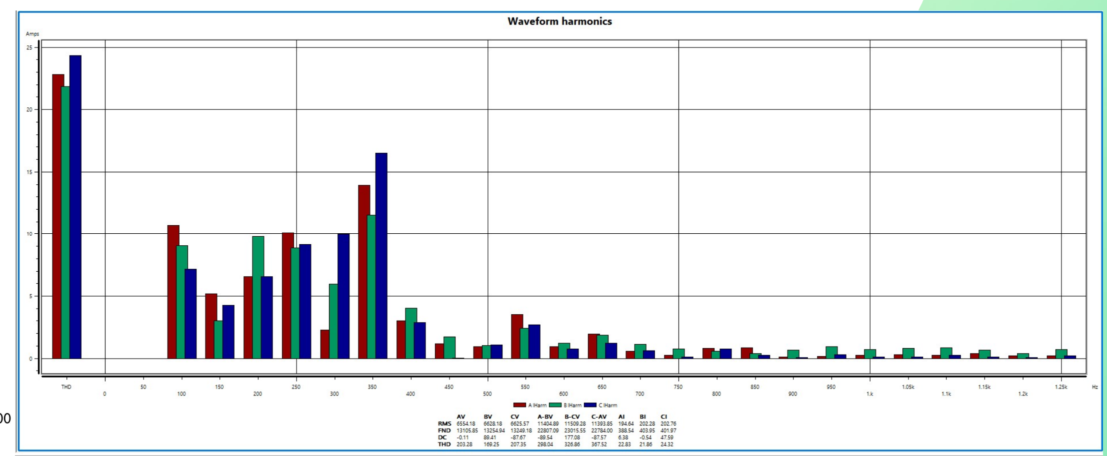




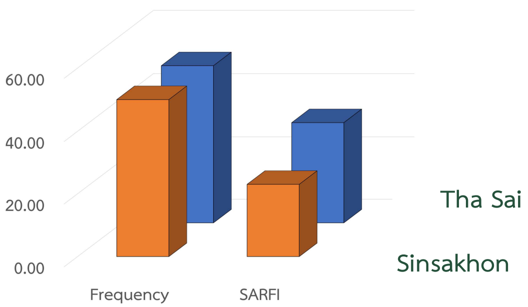
Power Quality information of Tha Sai Substation

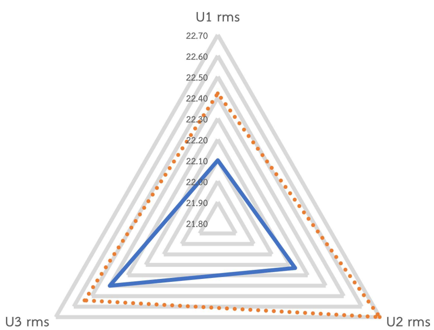
ตัวย่อ	หน่วย	ค่าที่ได้จากการตรวจวัด		เกณฑ์มาตรฐาน	
		CP01/05	CP95/99	Min	Max
Frequency	Hz	49.97	50.02	49.50	50.50
U1 rms	Voltage	22.01	22.42	20.90	23.10
U2 rms	Voltage	22.27	22.70	20.90	23.10
U3 rms	Voltage	22.13	22.54	20.90	23.10
V1 THD	%	1.47	2.52	-	4.00
V2 THD	%	1.13	2.21	-	4.00
V3 THD	%	1.26	2.33	-	4.00
VUN	%		0.38	-	2.00
PST1	%	0.06	0.24	-	1.00
PST2	%	0.05	0.14	-	1.00
PST3	%	0.05	0.14	-	1.00
PLT1	%	0.08	0.28	-	0.80
PLT2	%	0.06	0.26	-	0.80
PLT3	%	0.06	0.16	-	0.80
SAIFI		0.033			
SAIDI		1.65			
SARFI		32			

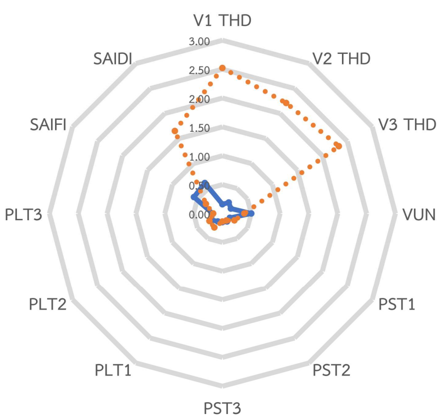


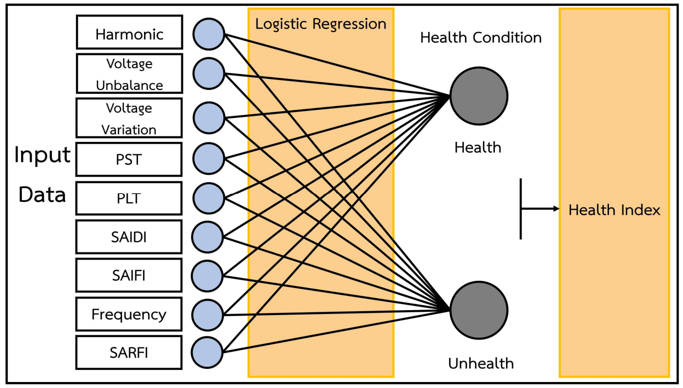


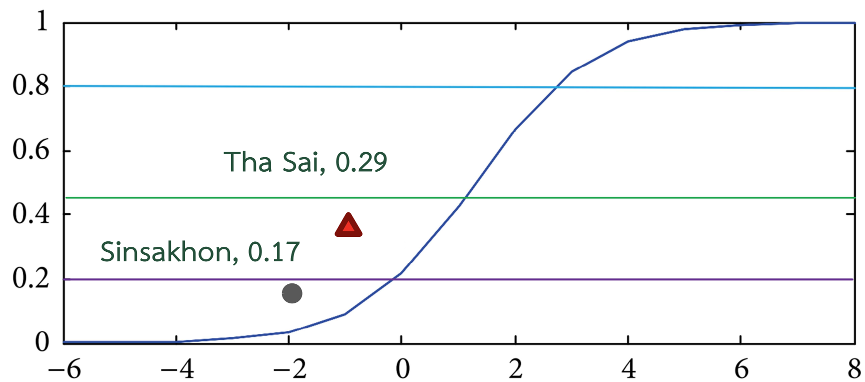
05 Result











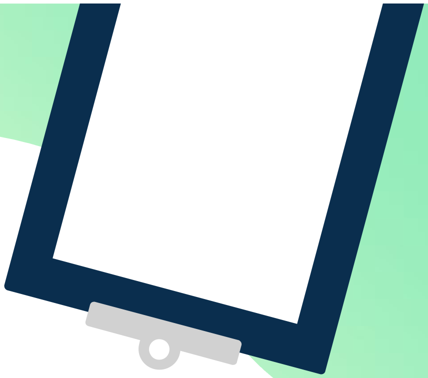
Score level between 0.00 - 0.20 : Good

Score level between 0.20 - 0.45 : Average

Score level between 0.45 - 0.80 : Bad

Score level between 0.80 - 1.00 : Very Bad

Substation	Health Index (HI)	
Sinsakhon	0.17	Good
Tha Sai	0.29	Average



06

Summary

Guidelines

Conclusions

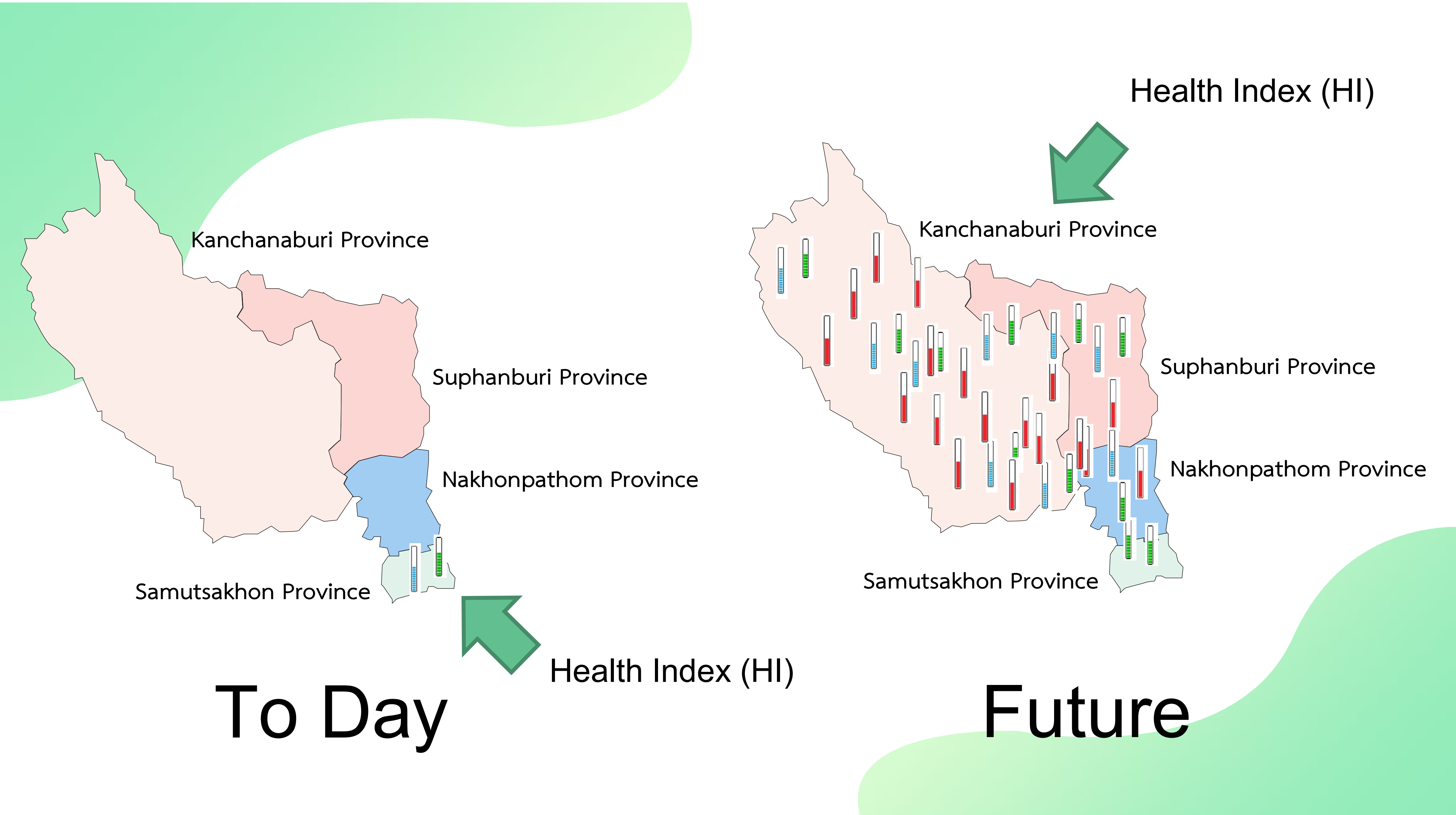
The values of V1 THD, V2 THD, V3 THD and (SAIDI) of THA SAI Power SubStation are high. Consider the solution: consider installing a Load Break Switch type SF6 with a Feeder Remote Terminal Unit (FRTU) device. When a power outage occurs, the EGAT Power Distribution Control Center 3 can command through the SCADA system

Conclusions

Consider improving the quality of electricity. Ready to prioritize To allocate a budget to improve the quality of electricity. To be appropriate according to the importance of the Health Index (HI) power quality index and help improve the operational efficiency of the electricity utility at the site. (Operations Department) makes the work work correctly. and suitable for investment in improving the electrical system

07

Suggestions


Health Index (HI)
Kanchanaburi Province
Suphanburi Province
Nakhonpathom Province
Samutsakhon Province
Kanchanaburi Province
Suphanburi Province
Nakhonpathom Province
Samutsakhon Province
Health Index (HI)
To Day
Future

Reference

[1] IEEE Recommended Practice for Monitoring Electrical Power Quality. IEEE Std 1159-1995 Approved Jun. 14, 1995.

[2] Brooks, D. L.; Dugan, R. C.; Waclawiak, M.; Sundaram, A. Indices for Assessing Utility Distribution System RMS Variation Performance IEEE Trans. on Power Delivery, 13, 1(1998), pp. 254-259.

[3] Weijie, Z., Haiwen, Y., Yuwei, S., Yingyi, L., Tao, C. "Calculation of a Health Index of Oil-Paper Transformers Insulation with Binary Logistic Regression" Hindawi Publishing Corporation Mathematical Problems in Engineering Vol.2016 (1998), 9 pages

Thanks

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