PROVINCIAL ELECTRICITY AUTHORITY

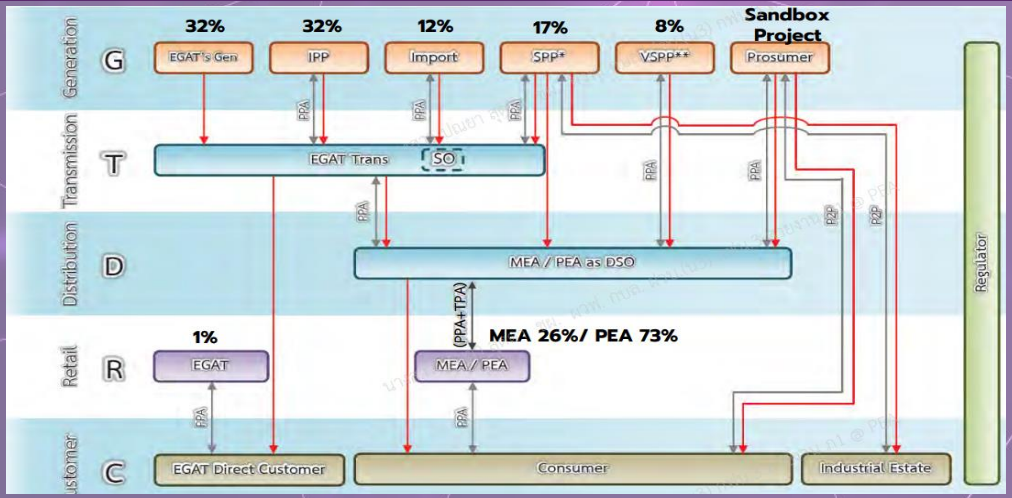
Brightness for Life Quality

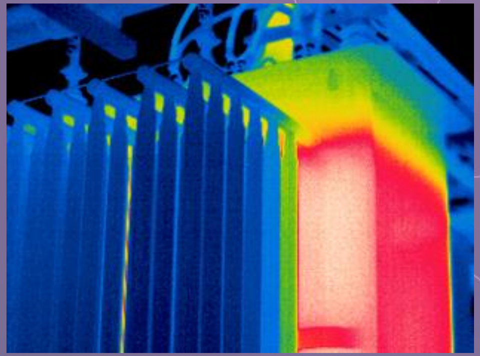
สว่างทั่วทิศ สร้างคุณภาพชีวิตทั่วไทย

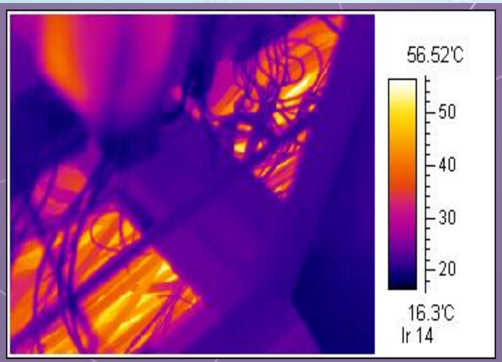
Power Market Transformation

and Power Quality impact of Prosumer on Distribution

Smart Grid







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CUSTOMER SERVICE DIVISION

PEA Area 3 (North) Loburi Province

AGENDA

Power Market Transformation and Power Quality impact of Prosumer on Distribution Smart Grid

- ❖Introduction to PEA Smart grid Roadmap
- ❖Transformation of Power Section
- ❖Third Party Access Framework (in case prosumer)
- ❖Challenge in Changing Distribution network
- ❖Reliability & Power Quality Challenge

PEA Smart grid Roadmap

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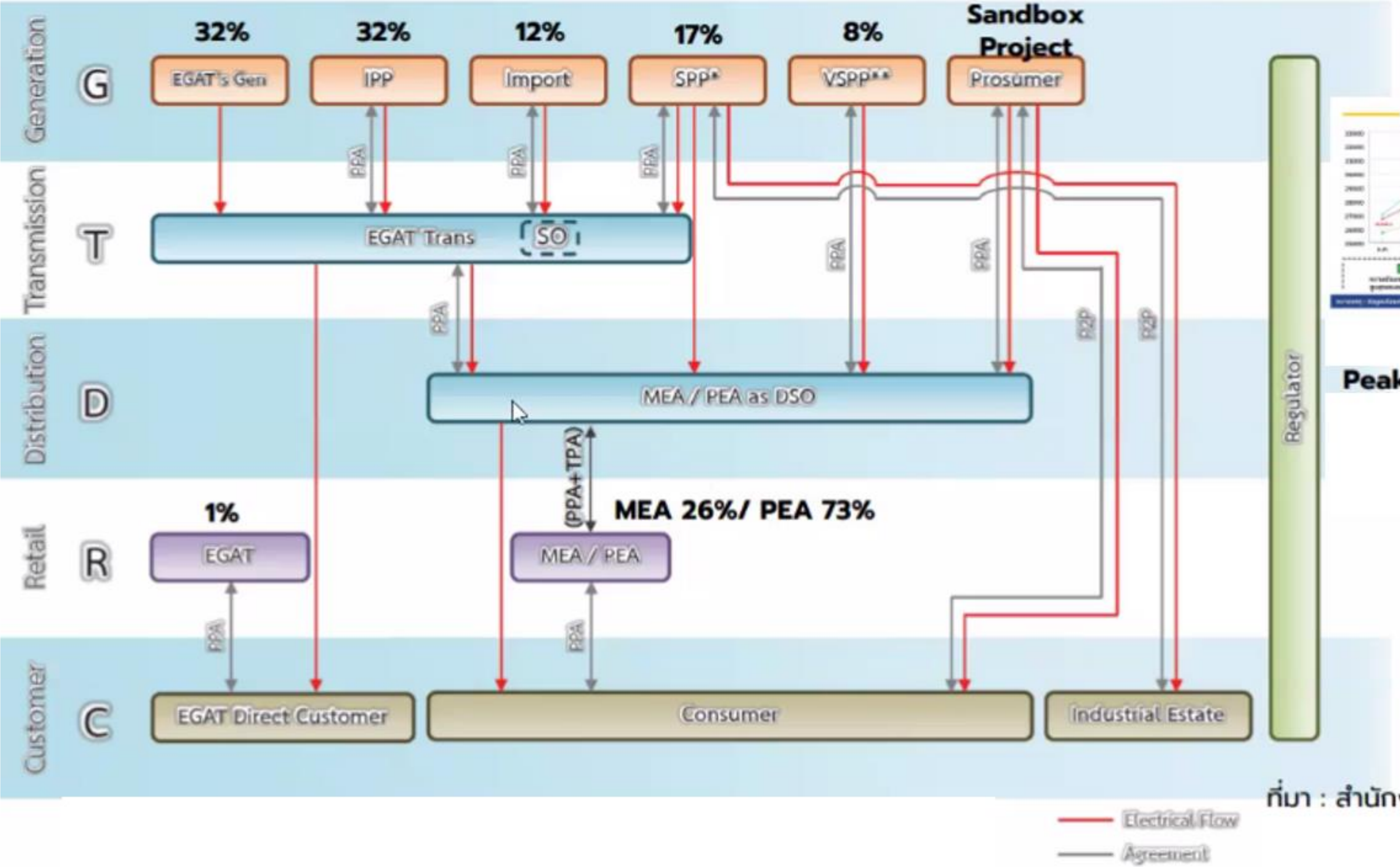
	Planning and Pilot Project	Large Scale Expansion	Power quality and service efficiency improvement
Smart Energy	• Electricity networks in 4 cities automated system. • Unmanned substation • Microgrids • Energy Storage / Solar Rooftop • Network supports of DG • The integration of Enterprise System • Mobile Workforce in 4 cities	• Optimal Asset management • Complete of MWM • Completion of unmanned substation • Expand fully automated network covering major cities across the country • The penetration of renewable energy sources and energy storage in communities	• Automated electricity networks nationwide/self-healing features enabled • Smart community network integrated with a large renewable energy resources • Perfect cyber security system • The balanced and forecast system production corresponds to energy utilization • Virtual power plants created
Smart Life	• Advanced Metering Infrastructure (AMI) in 26 municipalities of PEA service area • Demand response management	• AMI development completion • Energy management completion in all large/medium cities • The system provides power usage information via the internet • Domestic consumers can produce their own electricity; surpluses can be sold to utility • Home/building energy management automation reduces electricity bills	• Power consumers can buy or sell electricity in real time • Users can choose to buy electricity from different supplies • Optimal Energy management
Smart Community	• Public charging station	• The extensive use of electric transportation • The penetration of intelligent public street and community lighting in communities • Bundled services with other utilities (common billing etc.)	• Intelligent electric vehicle charging to reduce peak demand • Two ways power supply of electric vehicles (vehicle to grid –V2G)

2012 Stage 1 : 2017 Stage 2 : 2022 Stage 3 : 2026

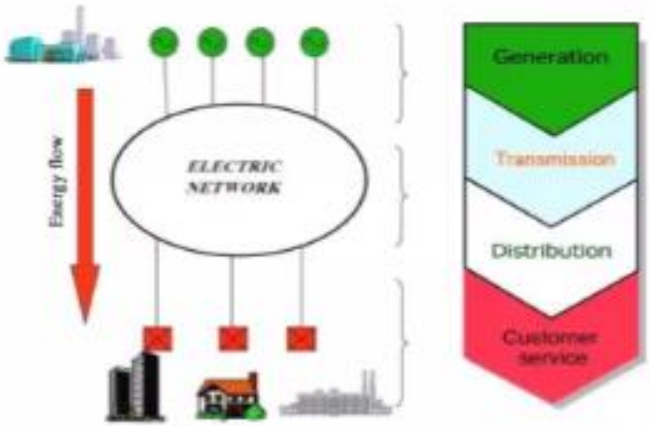
Structure of Power Market in Thailand



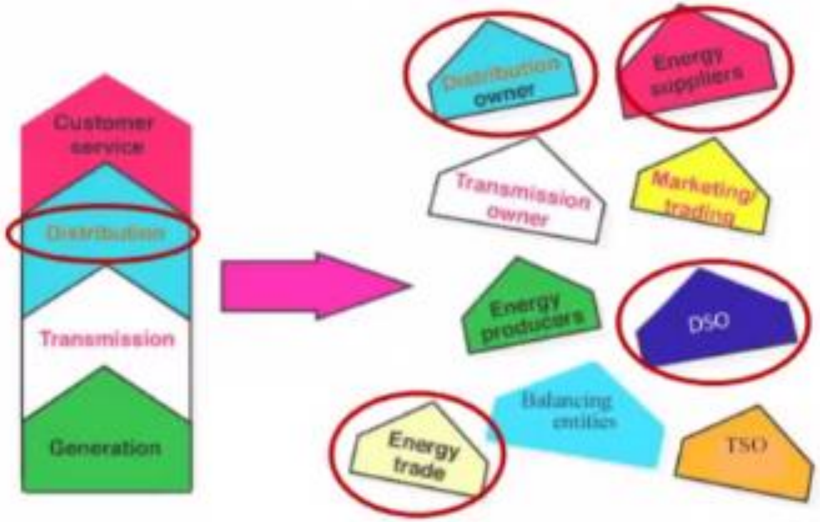
Peak Load: 33,623 MW

ที่มา : สำนักงานนโยบายและแผนพลังงาน

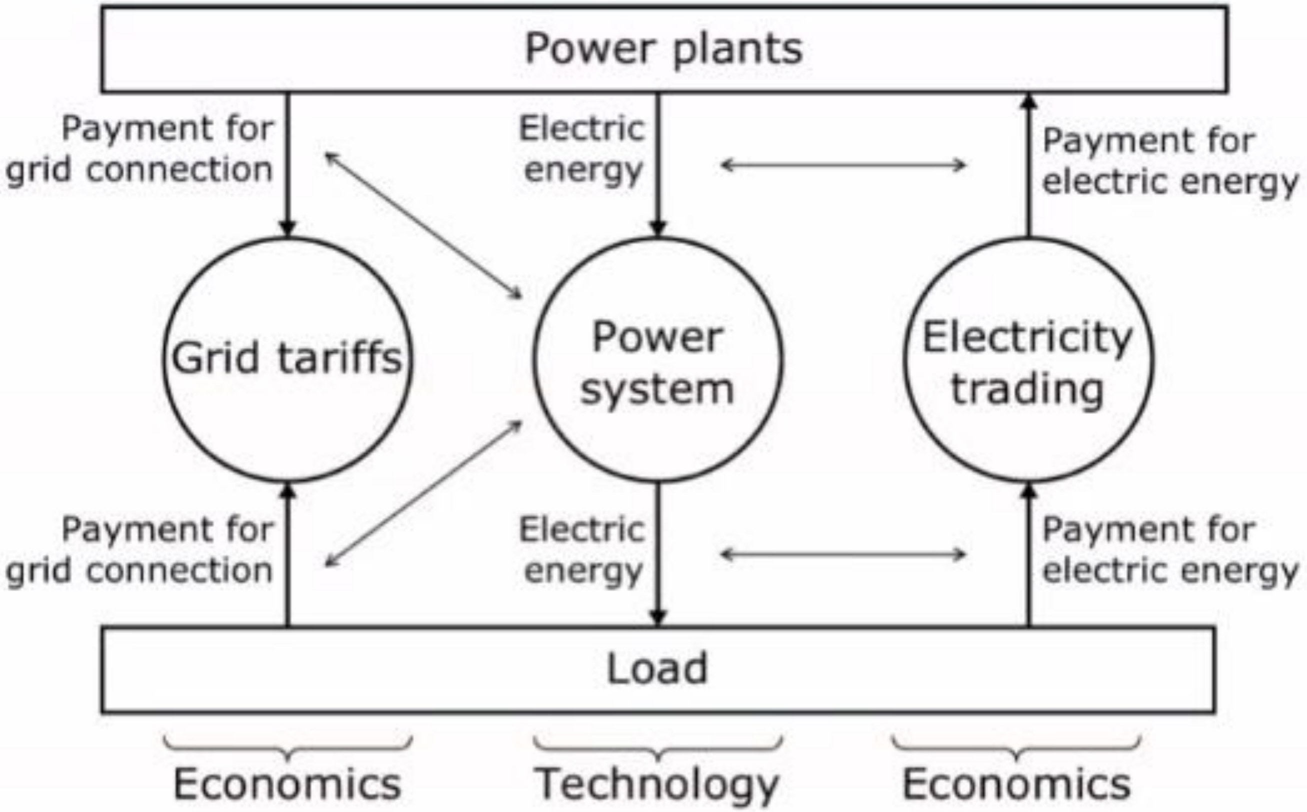
THE ELECTRICITY MARKET



A vertically integrated power system



Disintegration of the vertically integrated structure of electric power companies



Source: The Structure of electricity market by Mikael Amelin

KTH Royal Institute of Technology in Stockholm

Challenges: Changing distribution networks

Increasing penetration of DERs (e.g., PVs, EVs, HPs, BES) connected to medium and low voltage distribution networks.

↓

Problems

Network congestion
Voltage variations (over and under)

↓

Solutions

New investment in cables/transformers: Expensive!

Improved operation:

- Technical: Coordinated operation of OLTCs, capacitor banks, storage, flexibilities from DERs and demand responses.
- Local market for flexibilities/grid services; grid tarrifs

Local Flexibility Services
DER Hosting Capacity (Planning)
Operating Envelope (Operation)

Problems formulations for prosumer management

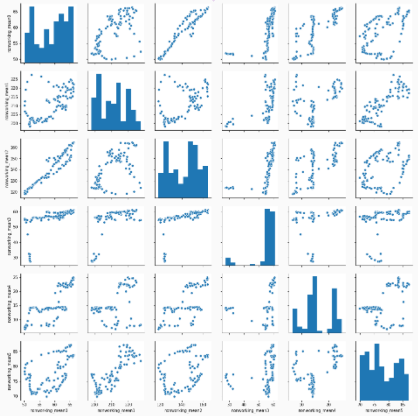
Analyst and cluster the load pattern

DATA EXPLORATION
- Visualize
- Find missing
- Look for correlations

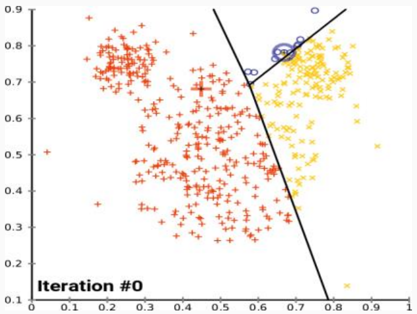
DATA CLEANING
- Check: did I fix potential issues?

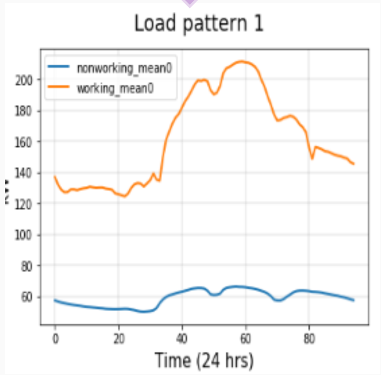
MODEL BUILDING
- Visualize Results
- Model Diagnostics
- Residual diagnositcs
- ROC curves
- etc

PRESENT RESULTS
- Charts
- Graphs
- Tables
- Visualizations to explain model, explain results



9	5000.0	5000.0	5000.0	-0.001698	0.449438	0.451136
10	5500.0	5500.0	5500.0	-0.001708	0.337079	0.338787
11	6000.0	6000.0	6000.0	-0.001701	0.404494	0.406195
12	6500.0	6500.0	6500.0	-0.001700	0.404494	0.406195
~~13~~	~~NaN~~	~~NaN~~	~~NaN~~	~~-0.001696~~	~~0.426966~~	~~0.428663~~
~~14~~	~~NaN~~	~~NaN~~	~~NaN~~	~~-0.001689~~	~~0.370787~~	~~0.372475~~





Details of SPP and VSPP COD in PEAN3

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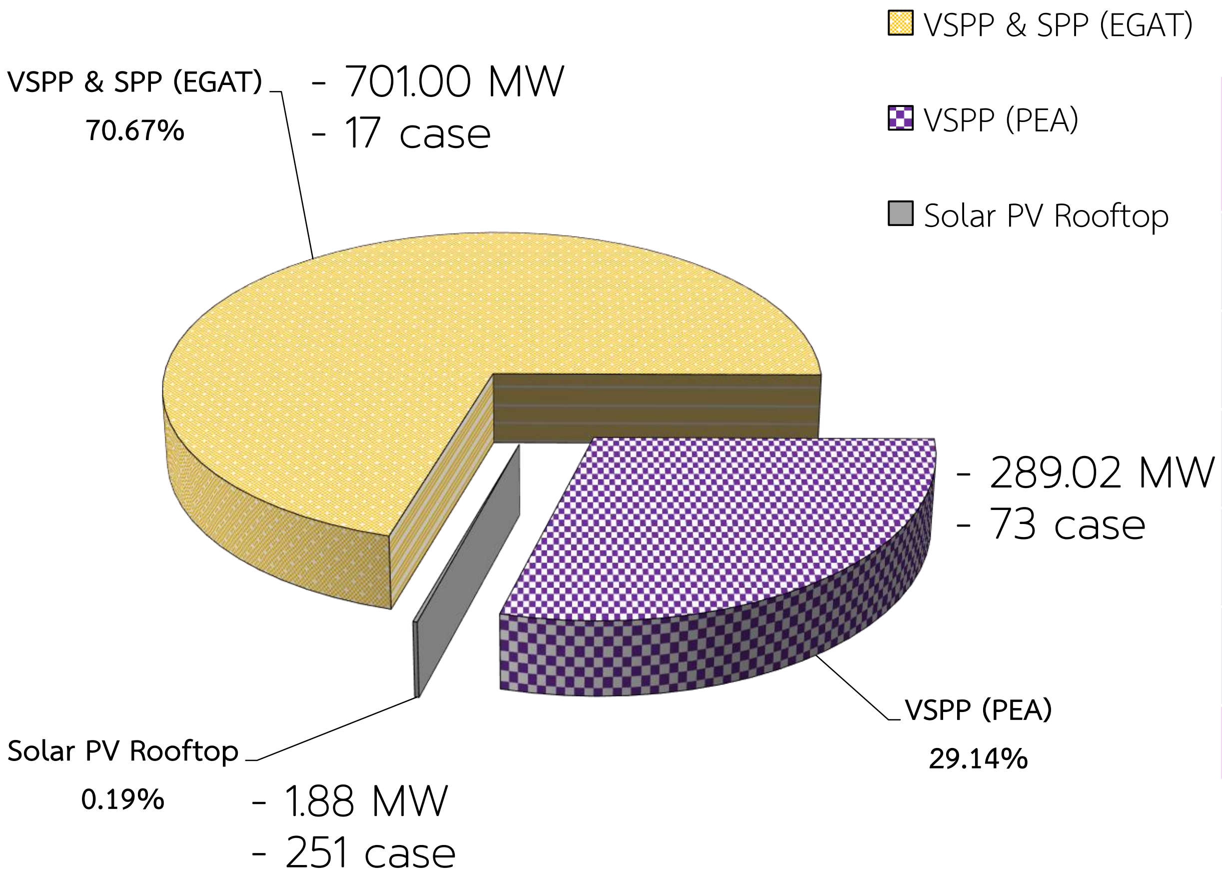


Type	Voltage	Amount (case)	Capacity (MW)
VSPP (EGAT)	22 kV	5	31.00
SPP (EGAT)	115 kV	12	670.00
VSPP (PEA)+PVRT	22 kV	73	289.02
- PVRT	22 kV	9	6.37
Solar PV Rooftop	220/380 V	251	1.88
Sum		341	991.90

14/03/2559

บริษัท เค.จี. เอนเนอร์จี

เบอร์โทรศัพท์
081-8036600, 02-9514455,02-9515535

เลขที่สัญญา
PV-PEA-N3-533/2558

กำลังผลิตติดตั้งจริง (kW)
10

สถานที่ติดตั้งแผง
10 หมู่ที่ 3 ตำบลวังขอนขว้าง อำเภอโคกสำโรง จังหวัดลพบุรี

พิกัด
15.027495 , 100.686533

เลขที่หนังสือใบยกเว้นฯ
5505.3/1013

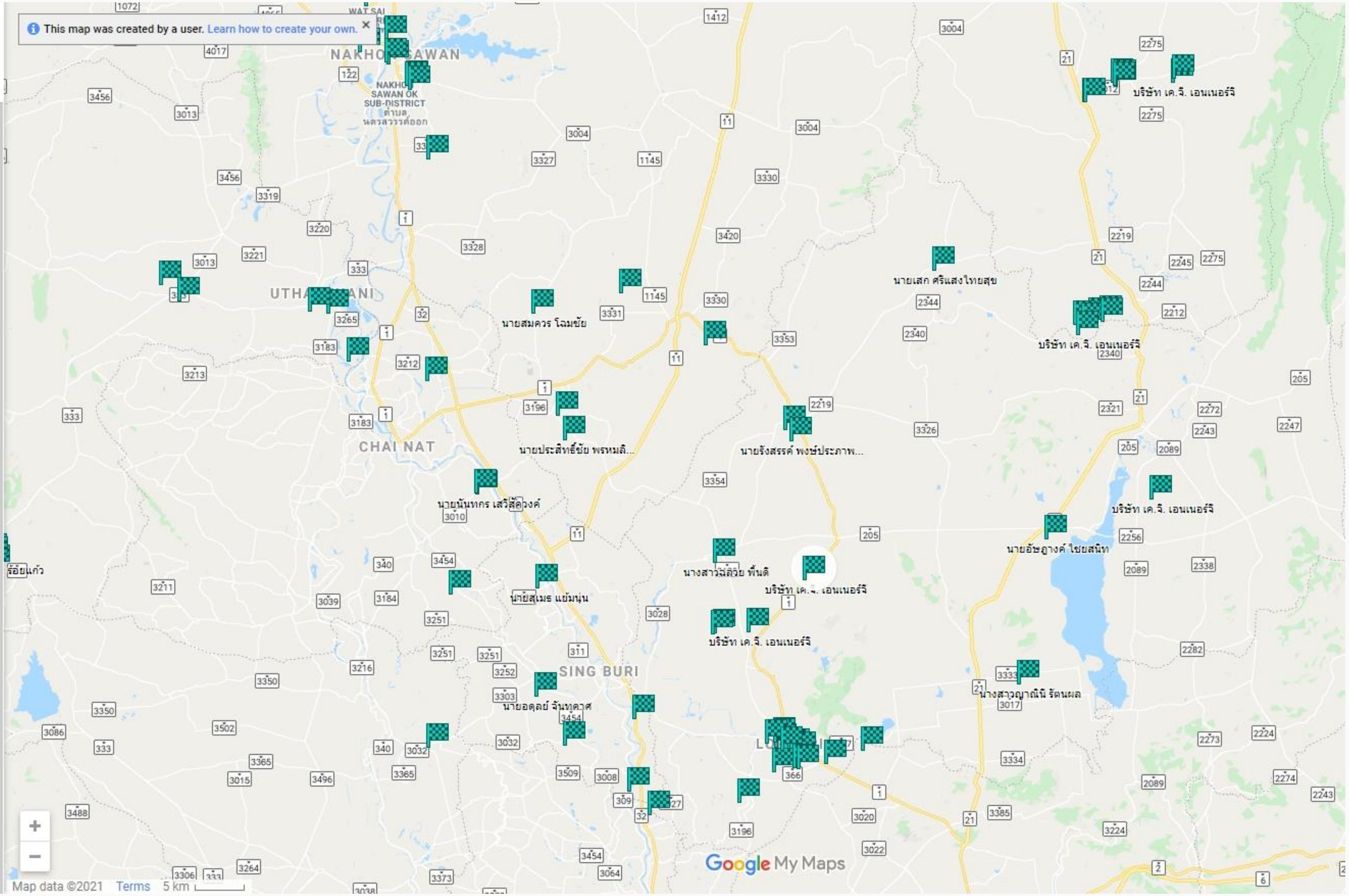
สถานะดำเนินการ
COD แล้ว

พื้นที่ กฟฟ.
กฟอ.โคกสำโรง

PEA No หม้อแปลง
52-920619

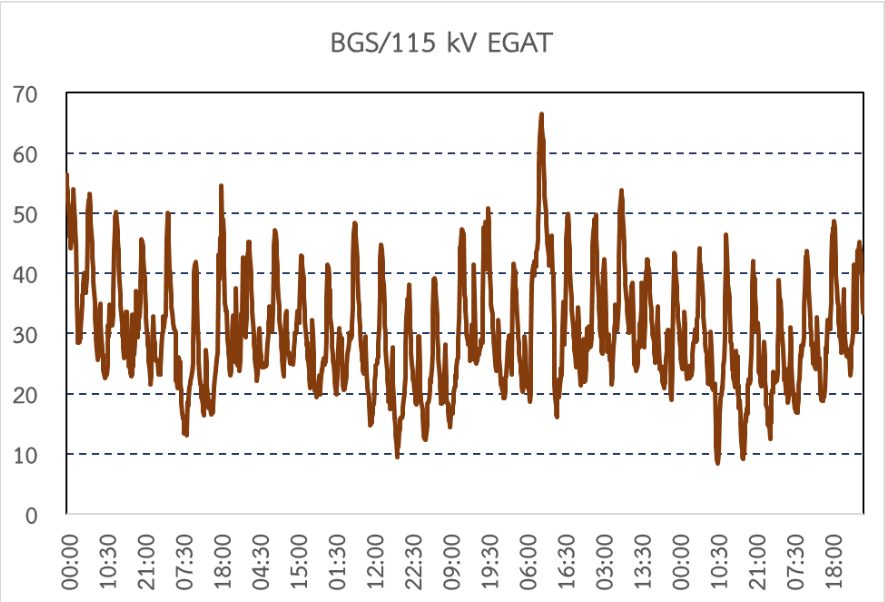
ขนาดหม้อแปลง (kVA)
100

หมายเหตุ
*



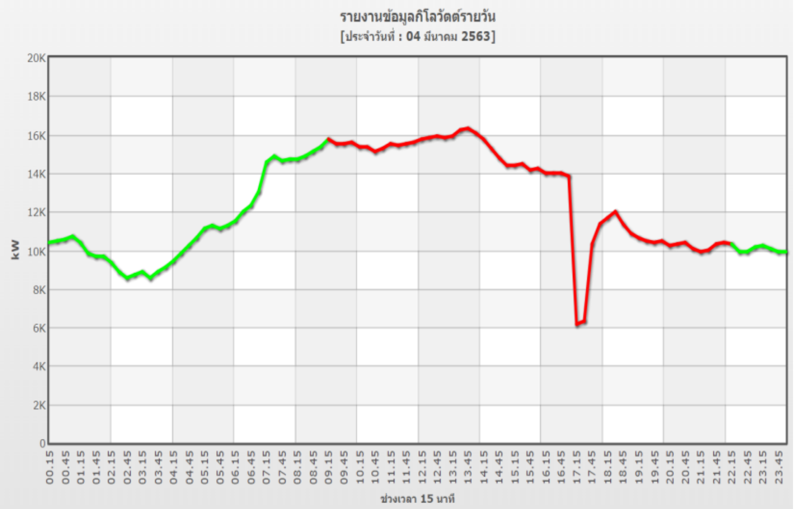
The impact evaluation of SPP & VSPP

EGAT Substation

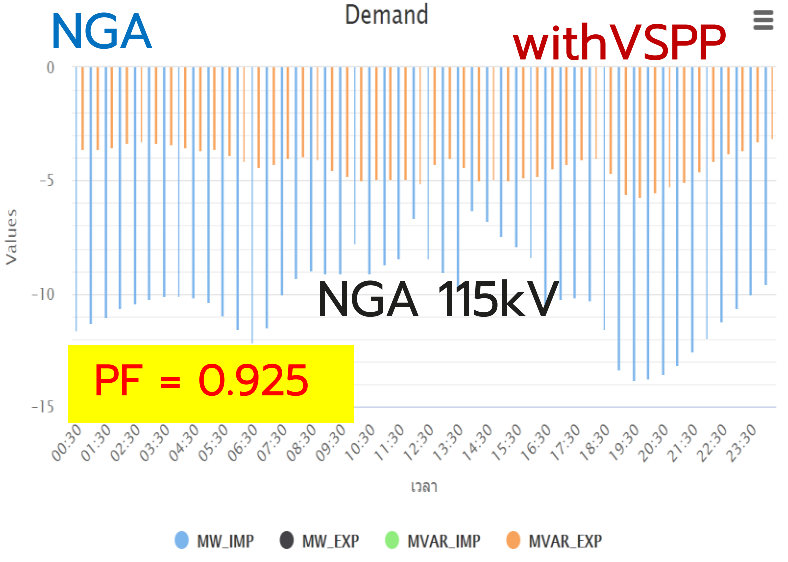


Export 53.50 MWh Import 23.7 MWh

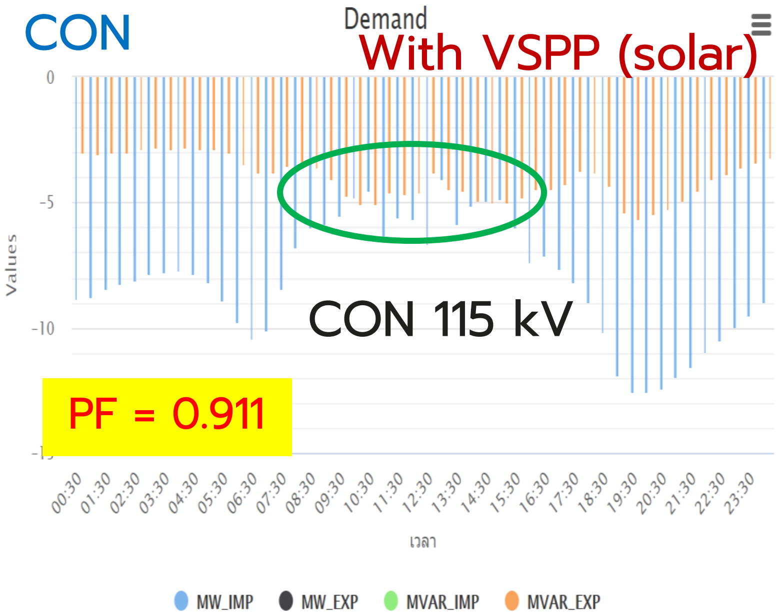
(115 kV)



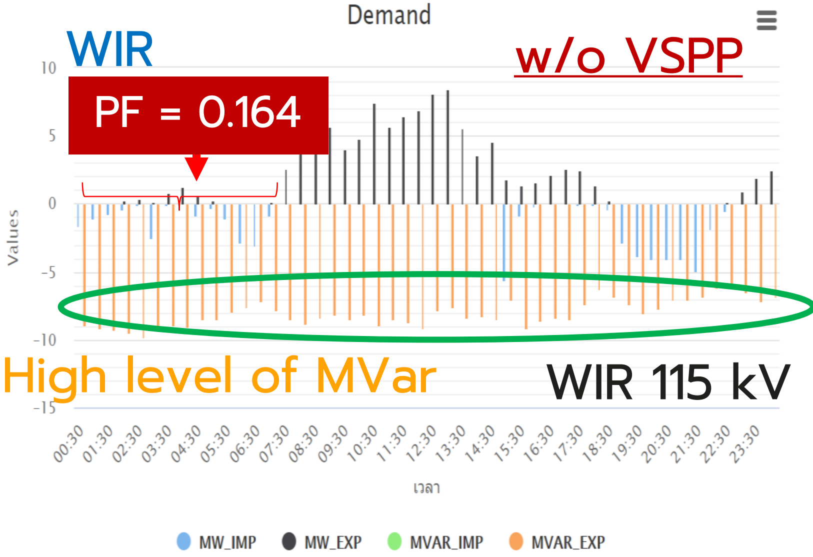
NGA



CON



WIR



Loss in distribution system

Power Quality Problem: Harmonic

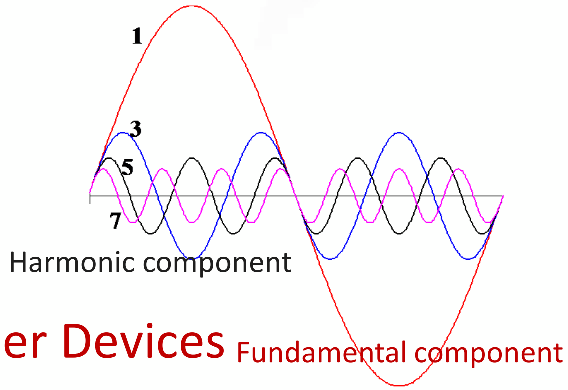
Harmonic is a signal whose frequency is a multiple of the frequency of a reference signal

Harmonics are due to periodic distortion of the voltage or current waveform

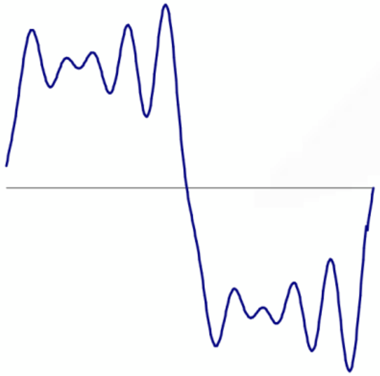
The distortion comes from nonlinear devices, principally loads

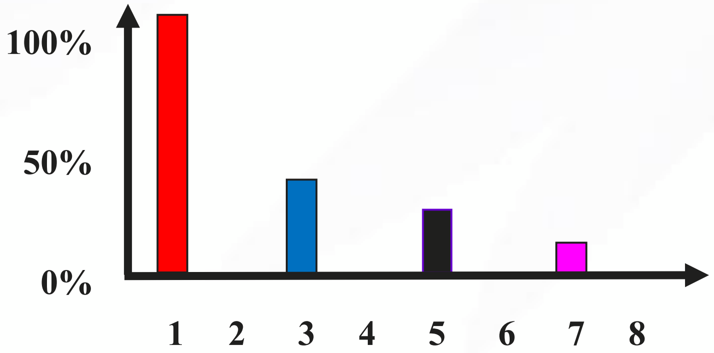
Harmonic Sources

- Ferromagnetic devices-
  - Transformers, motors
- Arcing devices-
  - arc furnaces, fluorescent lighting
- Power converters: Prosumer Devices



Distorted waveform

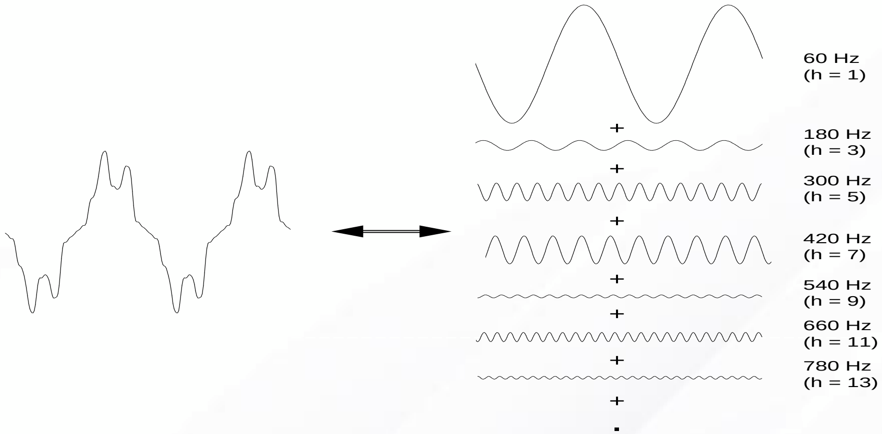




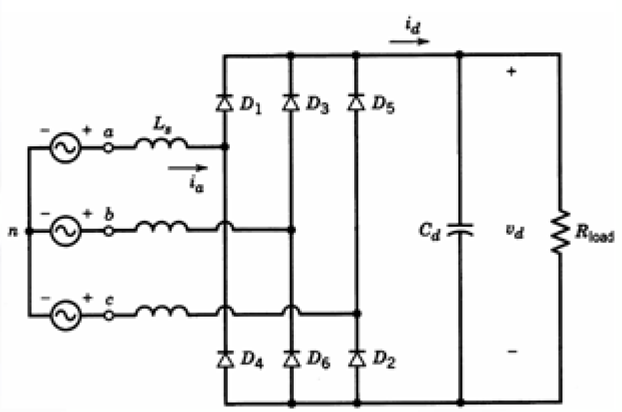
Decomposition into Harmonic Components – Fourier series

$$v(t) = V_{dc} + \sum_{h=1}^{\infty} \sqrt{2} V_h \sin(h\omega_0 t + \theta_h)$$

$$i(t) = I_{dc} + \sum_{h=1}^{\infty} \sqrt{2} V_h \sin(h\omega_0 t + \delta_h)$$



Harmonic Sources – 6-pulse rectifier
e.g. Variable Speed Drives or Medium Frequency Furnaces

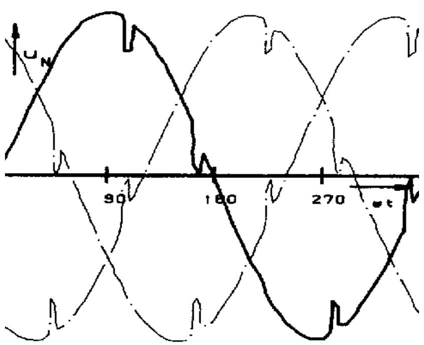


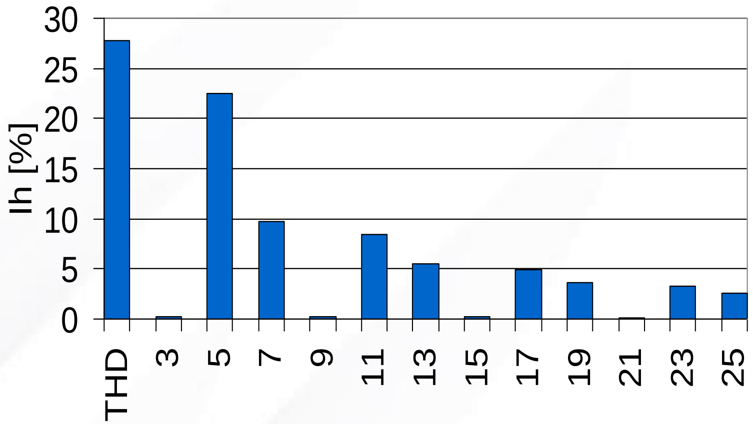
$h = p\,m \pm 1$

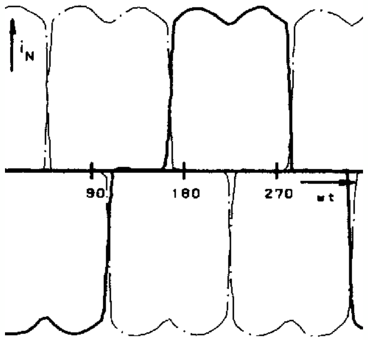
$h = 6\,m \pm 1$

$i_h = I1/h$ *

$\varphi \approx \alpha$





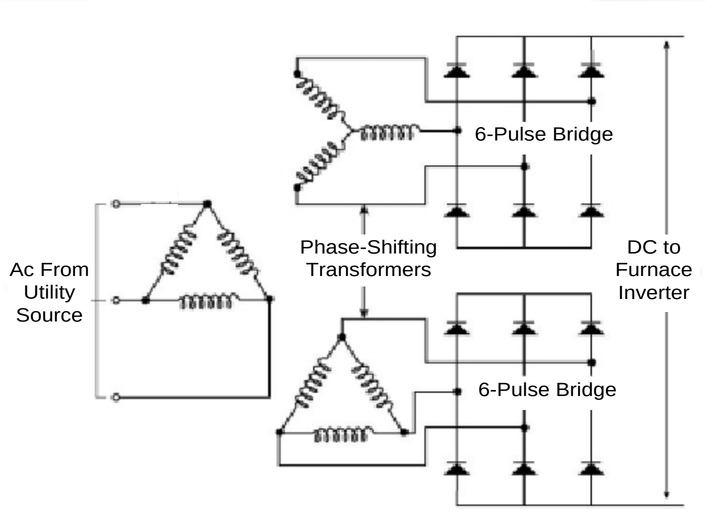


h=harmonic; p=pulse number; m= 1,2,3 ,... ; f_N= system frequency ;

* for smoothed d.c. only

φ = phase displacement between current and voltage; α = converters firing angle

Harmonic Sources – 12-pulse rectifier
e.g. Variable Speed Drives or Medium Frequency Furnaces

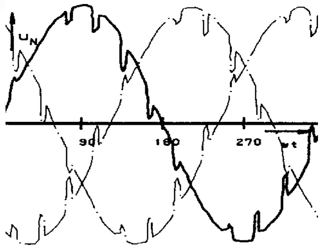


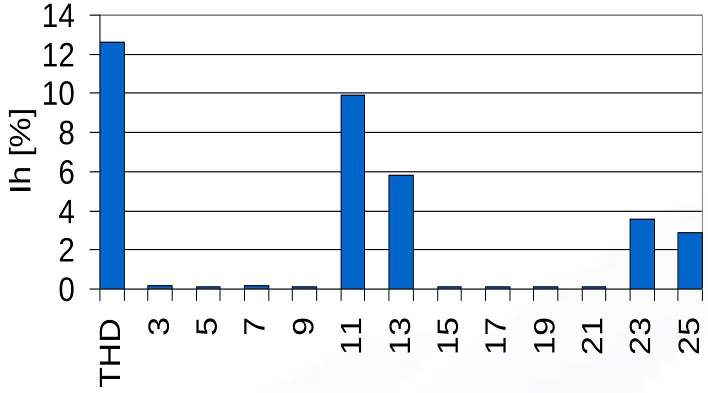
$h = p\,m \pm 1$

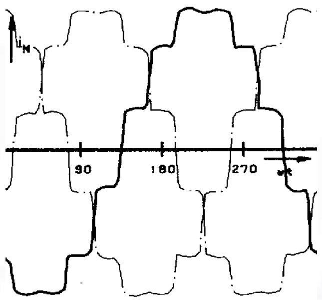
$h = 12\,m \pm 1$

$i_h = I1/h$ *

$\varphi \approx \alpha$







h=harmonic; p=pulse number; m= 1,2,3 ,... ; f_N= system frequency;

* for smoothed d.c. only

Undesirable Effects of Harmonics in Power Systems

Undesirable Effects of Harmonics

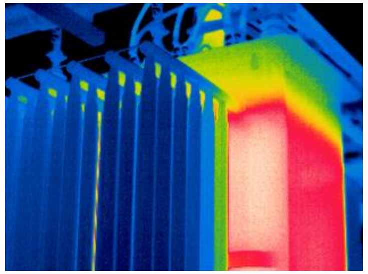
- Overheating resulting in need of derating of the equipment.
- Potential for problems with excessive ground currents (stray voltages, telephone interference, relay mis-operation) on systems with single phase loads.
- Capacitors for power factor correction and cable systems aggravate the problem by causing resonances.

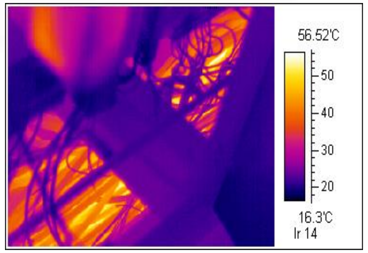
Are harmonic levels increasing?

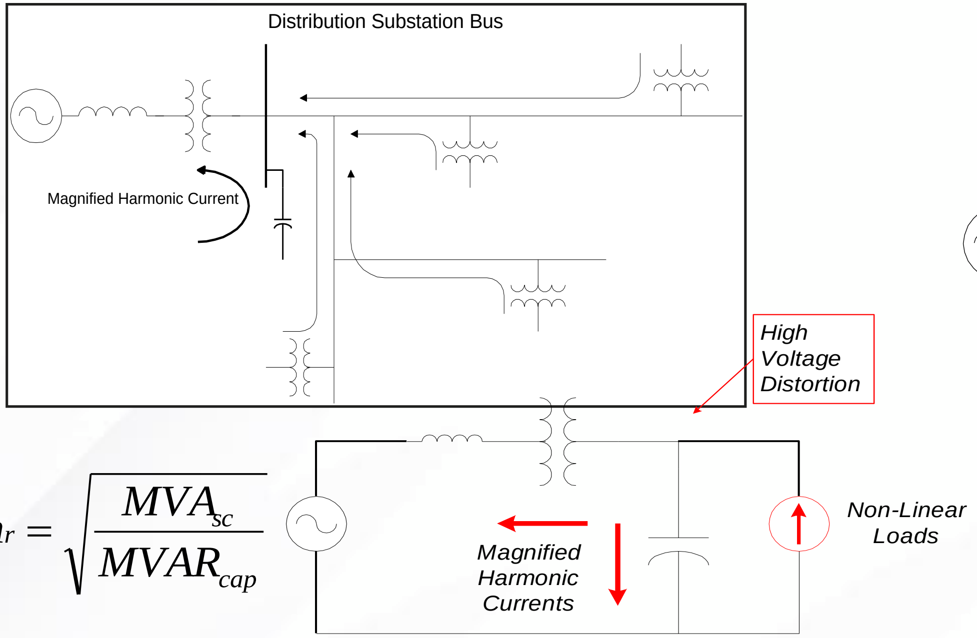
Changing system characteristics
- More power factor correction
- More cable

Changing load
- More harmonic generation
- Less damping

Other characteristics

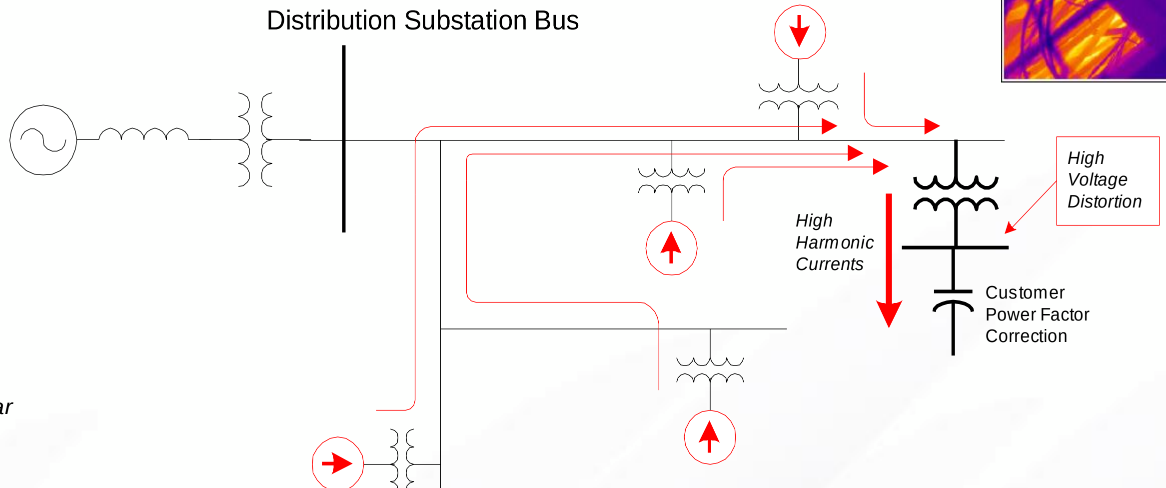






$$h_r = \sqrt{\frac{MVA_{sc}}{MVAR_{cap}}}$$

Parallel Resonance



Series Resonance

Harmonic Standard

IEEE Standard 519-1992- Current Distortion Limits

Odd harmonics Distortion limits ($\%I_L$) for individual customers

Base voltage Limit (kV)	I_{SC}/I_L	h<11	11≤h<17	17≤h<23	23≤h<35	35≤ h
0.12 – 69	<20	4.0	2.0	1.5	0.6	0.3
	20-50	7.0	3.5	2.5	1.0	0.5
	50-100	10.0	4.5	4.0	1.5	0.7
	100-1000	12.0	5.5	5.0	2.0	1.0
	>1000	15.0	7.0	6.0	2.5	1.4
69.001 – 161	<20	2.0	1.0	0.75	0.3	0.15
	20-50	3.5	1.75	1.25	0.5	0.25
	50-100	5.0	2.25	2.0	0.75	0.35
	100-1000	6.0	2.75	2.5	1.0	0.5
	>1000	7.5	3.5	3.0	1.25	0.7
> 161	<50	2.0	1.0	0.75	0.3	0.15
	≥50	3.0	1.5	1.15	0.45	0.22

The limits applicable for normal conditions

For shorter periods (e.g. startup) limits may be exceeded by 50%

Table 11-1—Voltage Distortion Limits

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

NOTE — High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.

Even harmonics are limited to 25% of the odd harmonic limits

The limits applicable for normal conditions

For shorter periods (e.g. startup) limits may be exceeded by 50%

Tables applicable for 6-pulse convertors

For higher pulse number (q), limits may be increased by a factor of sqrt(q/6) provided non-characteristic harmonics are less than 25% of the specified limit.

Current Distortion Limits at point of common coupling

PRC-PQG-01/1998: PEA’s Regulation on the Power Network System Interconnection code B.E.2559(2016)
Current Distortion Limits at point of common coupling

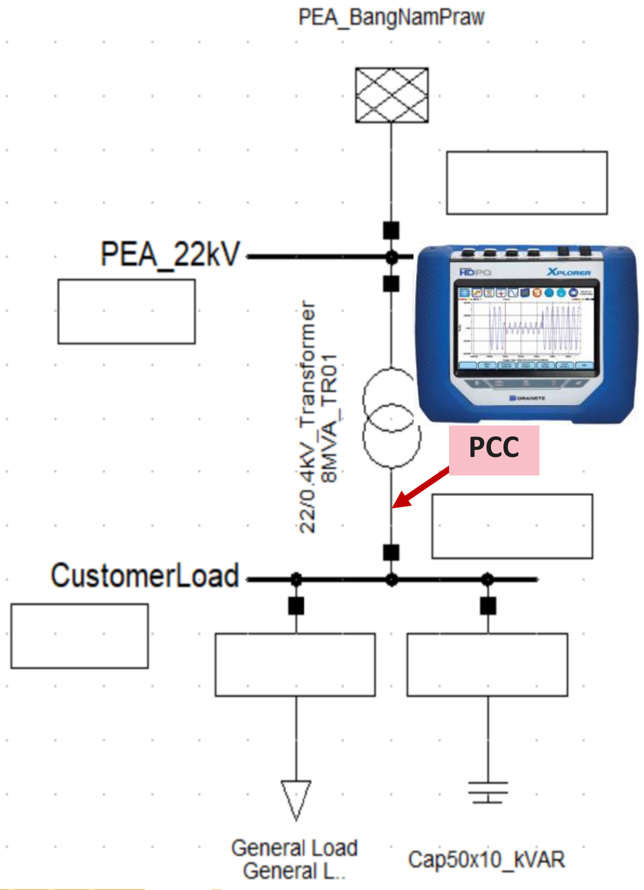
Base voltage limit	MVAsc**	Current Distortion Limits (A rms)																	
PCC Voltage (kV)	Base	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0.400	10	48	34	22	56	11	40	9	8	7	19	6	16	5	5	5	6	4	6
11 and 12	100	13	8	6	10	4	8	3	3	3	7	2	6	2	2	2	2	1	1
22, 24 and 33	500	11	7	5	9	4	6	3	2	2	6	2	5	2	1	1	2	1	1
69	500	8.5	6	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	1,000	5	4	3	4	2	3	1	1	1	3	1	3	1	1	1	1	1	1

$$MVA_{SC1} \neq MVA_{SC-BASE}$$

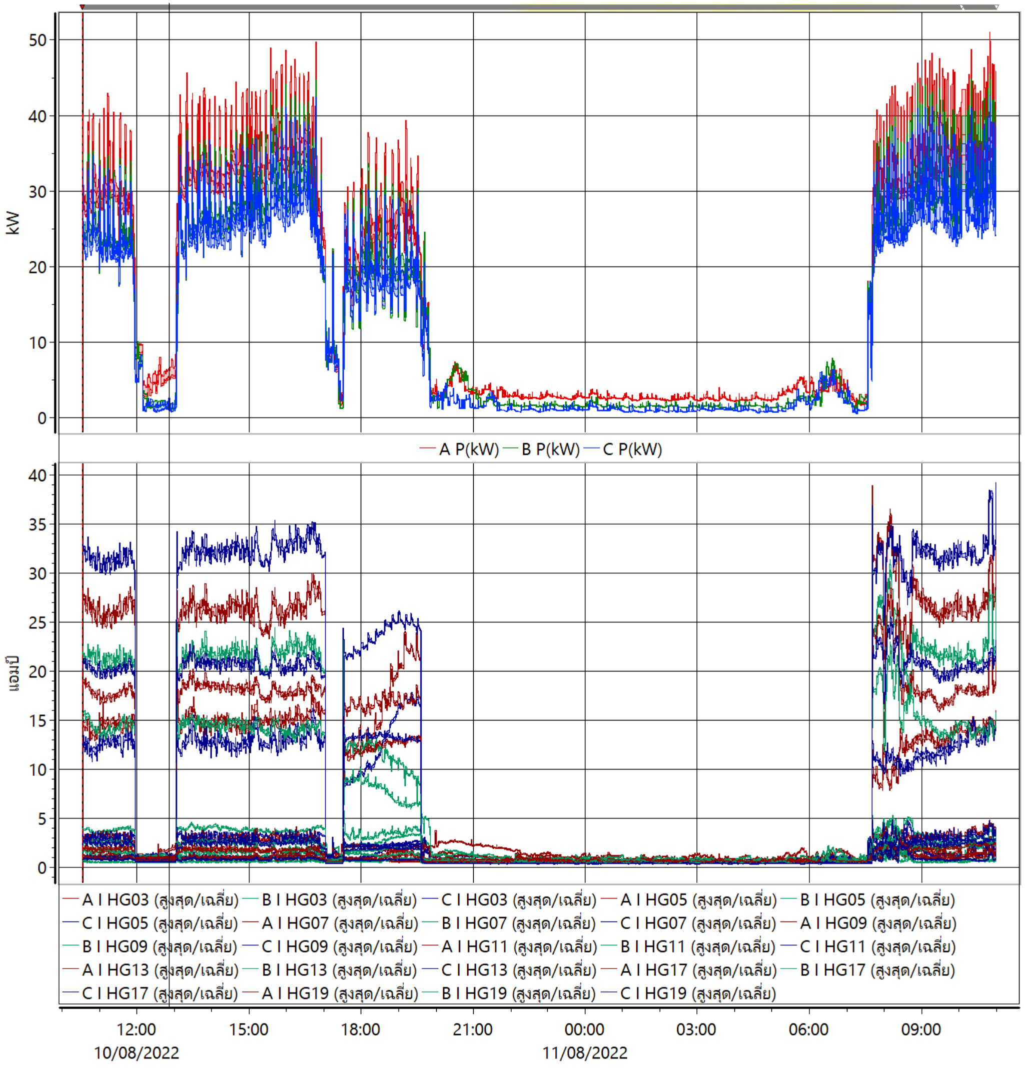
$$\boxed{I_h = \frac{I_{hp} \times MVA_{SC1}}{MVA_{SC-BASE}}}$$

Where;
I_h = Harmonic Current (A) h order that is allowed to flow in the system when $MVA_{sc} = MVA_{sc1}$
I_{hp} = Harmonic Current (A) h order in table 1
MVA_{sc1} = Minimum MVA_{sc} at PCC
$MVA_{sc\text{-}Base}$ = Base MVA_{sc} for harmonic current from table 1

Harmonic Analysis

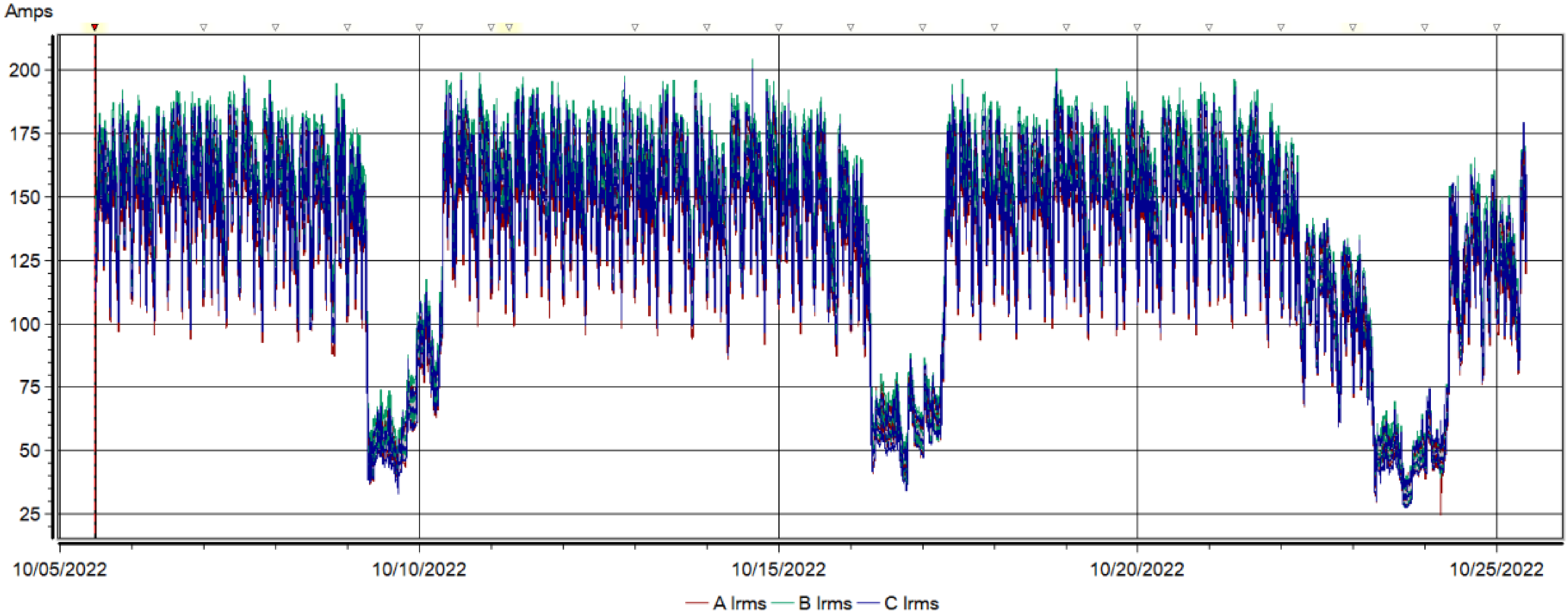


กราฟเทียบกับเวลา



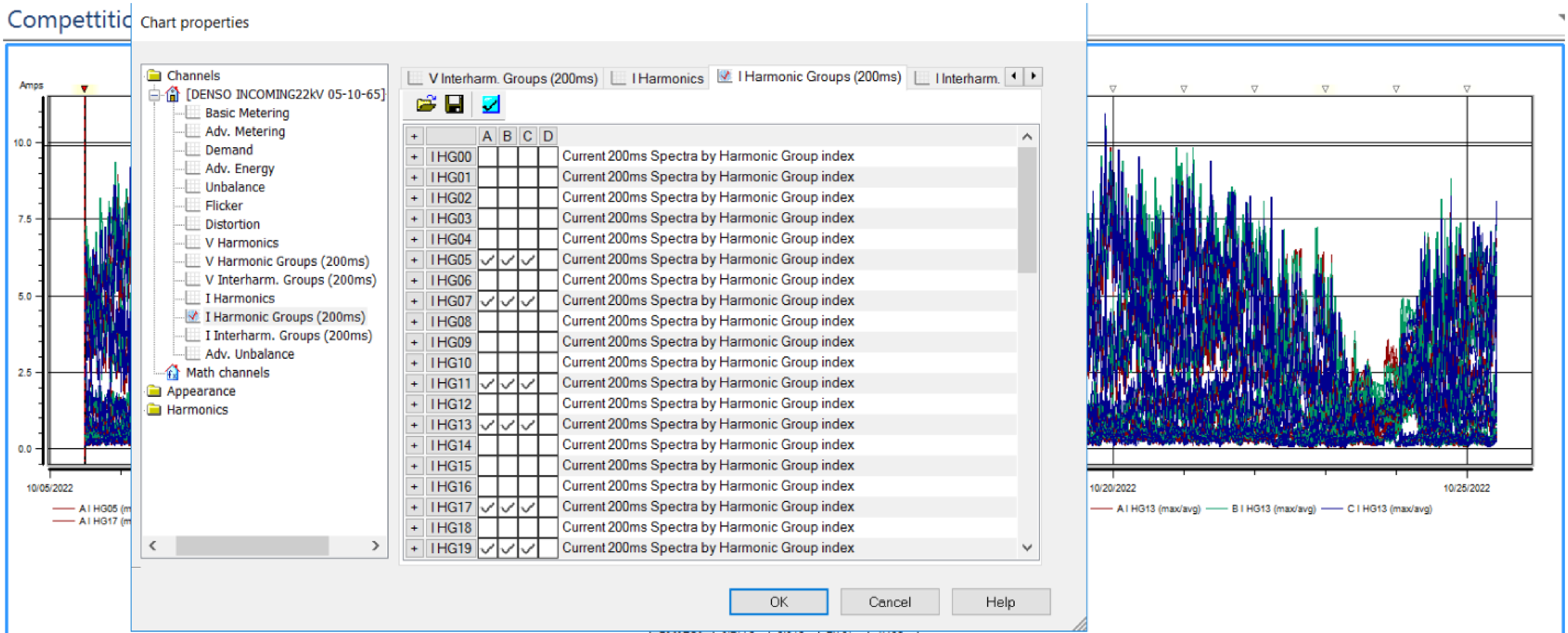
	ต่ำสุด	สูงสุด	เฉลี่ย	95%
AVrms	229.1	23830%	234.3	235.8
BVrms	225.8	235.5	231.6	233
CVrms	225.4	234.4	230.6	231.9
AIrms	25.73	791.2	186.7	225.7
BIrms	11.98	734.4	159.4	197.1
CIrms	10.79	828.3	165	201.3
AP(kW)	5.213	49.74	33.97	41.64
BP(kW)	1.22	44.73	28.47	36.45
CP(kW)	0.9054	42.47	26.4	33.93
AI HG03	1.834	18.95	14.49	15.98
BI HG03	0.5621	3.704	0.8732	1.328
CI HG03	1.052	16.23	12.45	14.04
AI HG05	0.6056	30.03	25.48	27.63
BI HG05	0.9695	24.91	21.09	22.73
CI HG05	0.5204	35.35	31.54	33.52
AI HG07	0.9075	20.19	17.7	18.85
BI HG07	0.7344	16.5	13.93	15
CI HG07	0.7152	22.77	20.1	21.37
AI HG09	0.5403	2.257	0.741	0.981
BI HG09	0.5693	1.361	0.8734	1.096
CI HG09	0.5433	3.514	0.9988	1.315
AI HG11	1.058	3.604	1.718	2.14
BI HG11	0.5512	4.571	3.715	4.129
CI HG11	0.6652	4.075	2.882	3.382
AI HG13	0.8249	4.108	2.799	3.234
BI HG13	0.4974	2.751	1.497	1.854
CI HG13	0.7068	3.852	2.471	2.777
AI HG17	0.6039	2.162	1.645	1.82
BI HG17	0.451	2.969	2.364	2.571
CI HG17	0.618	3.062	2.351	2.688
AI HG19	0.6282	1.548	0.9736	1.261
BI HG19	0.4346	1.246	0.5168	0.6135
CI HG19	0.4887	1.232	0.7574	0.9028

Timeplot



	Min	Max	Avg	95%
AIrms	24.51	192.7	127.7	165.8
BIrms	27.78	204.4	135.3	174.7
CIrms	27.42	200.4	130.7	169.7

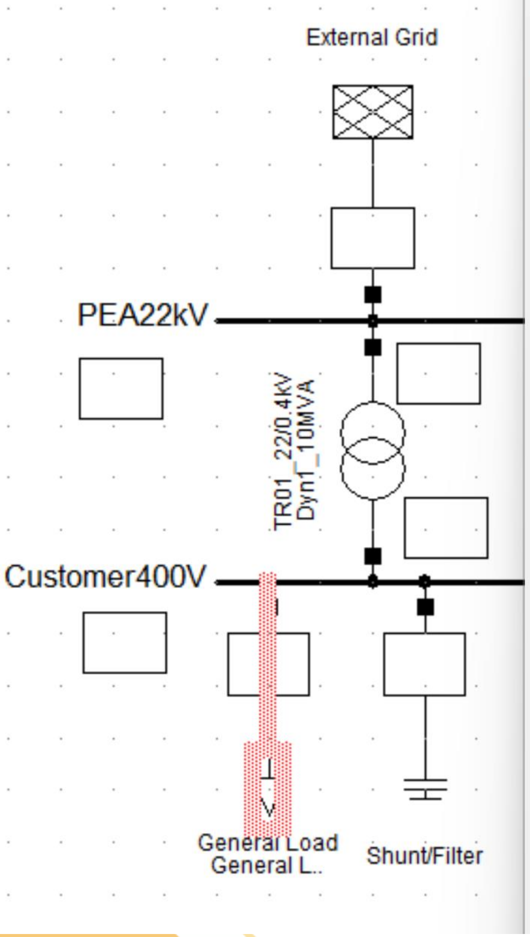
Competttitic

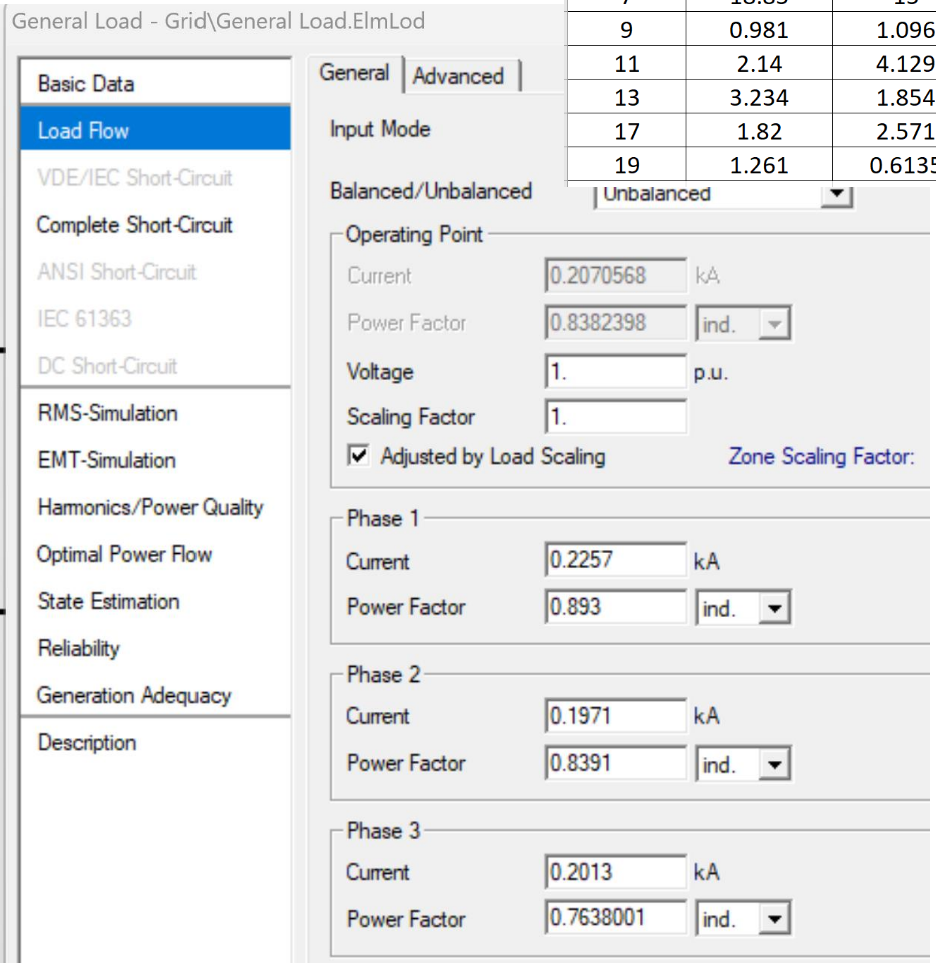


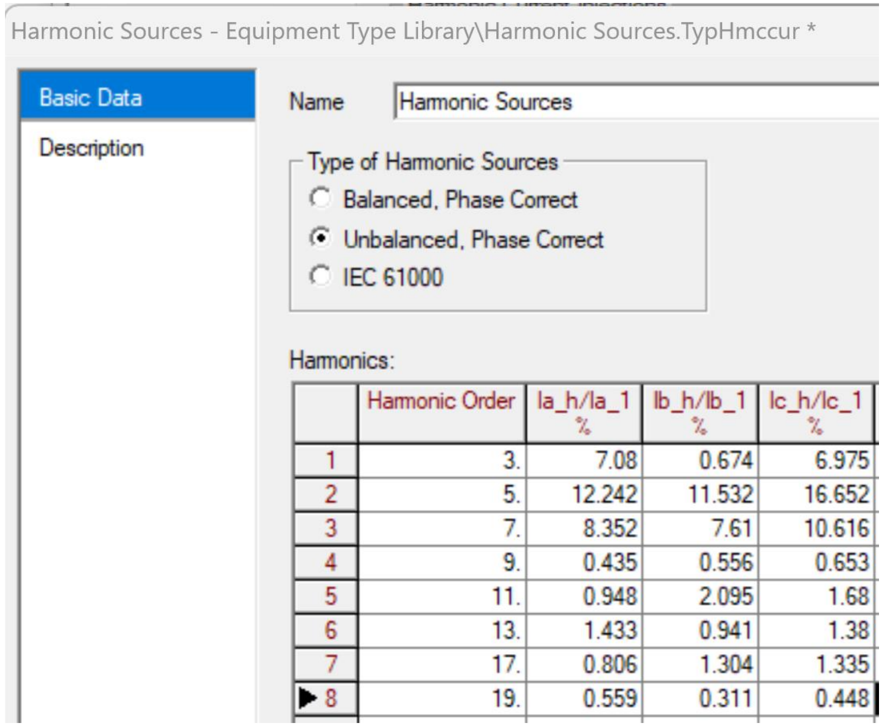
AI HG11	0.2177	3.660	0.8967	1.576
BI HG11	0.2986	4.169	0.9312	1.564
CI HG11	0.1957	4.237	1.034	1.748
AI HG13	0.1195	2.750	0.5233	1.182
BI HG13	0.1546	3.571	0.6131	1.617
CI HG13	0.1165	3.256	0.6053	1.479
AI HG17	0.06373	0.9965	0.2996	0.4638
BI HG17	0.07872	1.321	0.2873	0.4673
CI HG17	0.06452	0.9980	0.2647	0.4209
AI HG19	0.04638	0.8052	0.2284	0.3769
BI HG19	0.05853	0.9500	0.2707	0.4466
CI HG19	0.04734	0.9432	0.2711	0.4810

Add Harmonic load

Order	Current (A)			%Fund			Fund (A)		
	A	B	C	A	B	C	A	B	C
3	15.98	1.328	14.04	7.080	0.674	6.975	225.7	197.1	201.3
5	27.63	22.73	33.52	12.242	11.532	16.652			
7	18.85	15	21.37	8.352	7.610	10.616			
9	0.981	1.096	1.315	0.435	0.556	0.653			
11	2.14	4.129	3.382	0.948	2.095	1.680			
13	3.234	1.854	2.777	1.433	0.941	1.380			
17	1.82	2.571	2.688	0.806	1.304	1.335			
19	1.261	0.6135	0.9028	0.559	0.311	0.448			



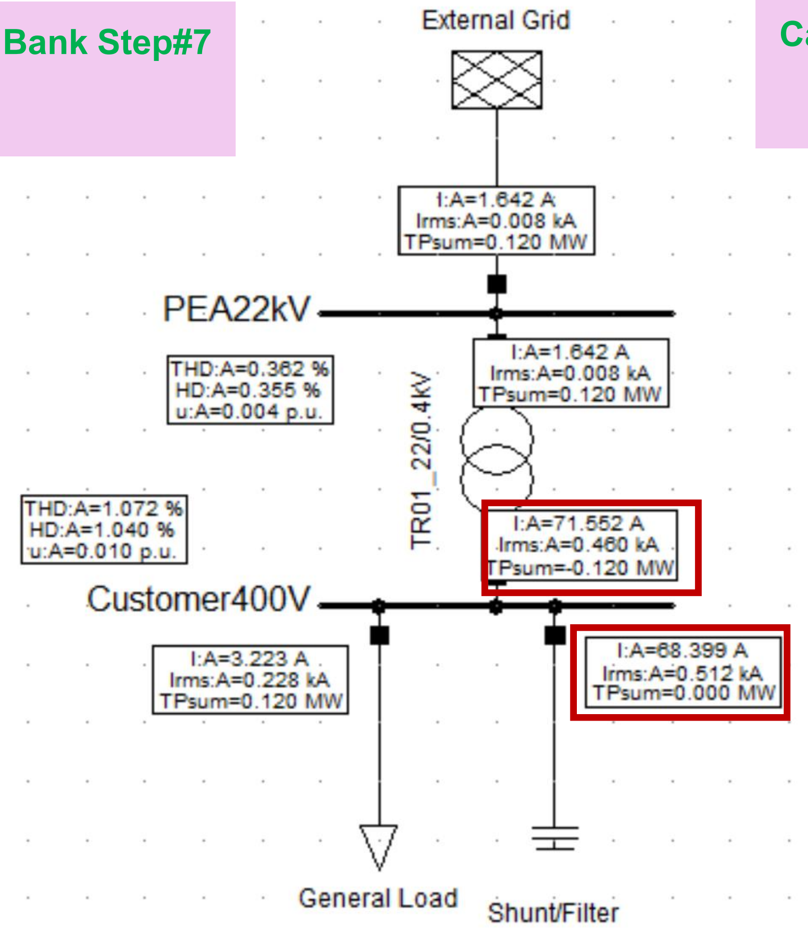




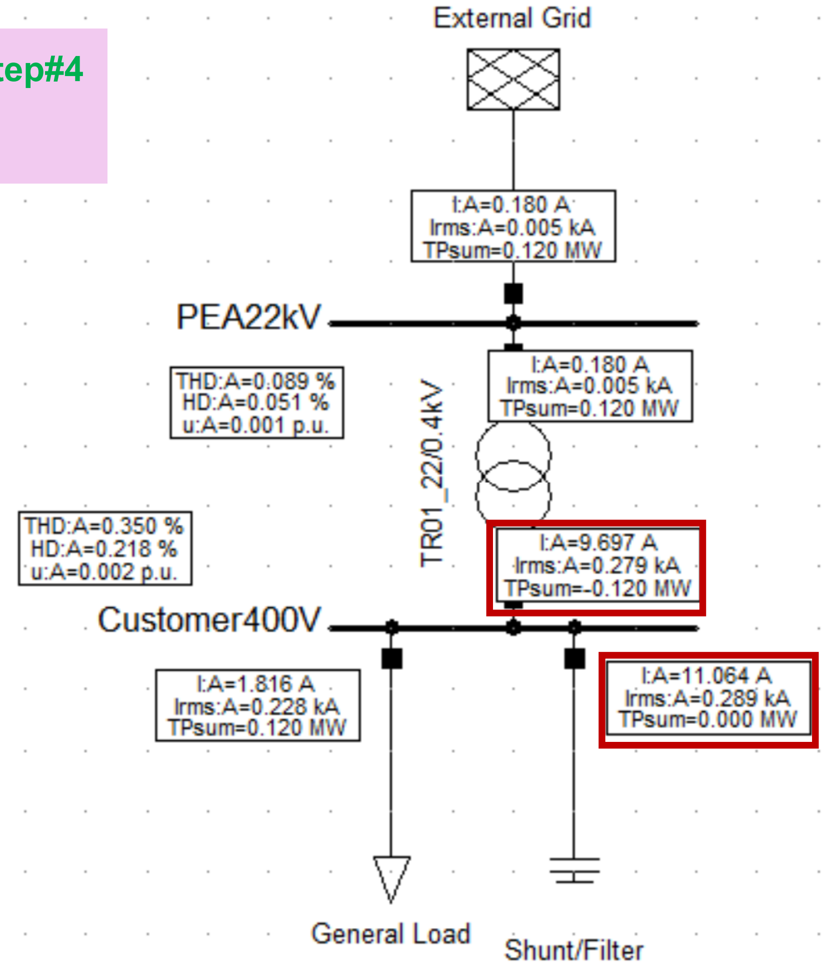
Harmonic Case Study in Power Systems

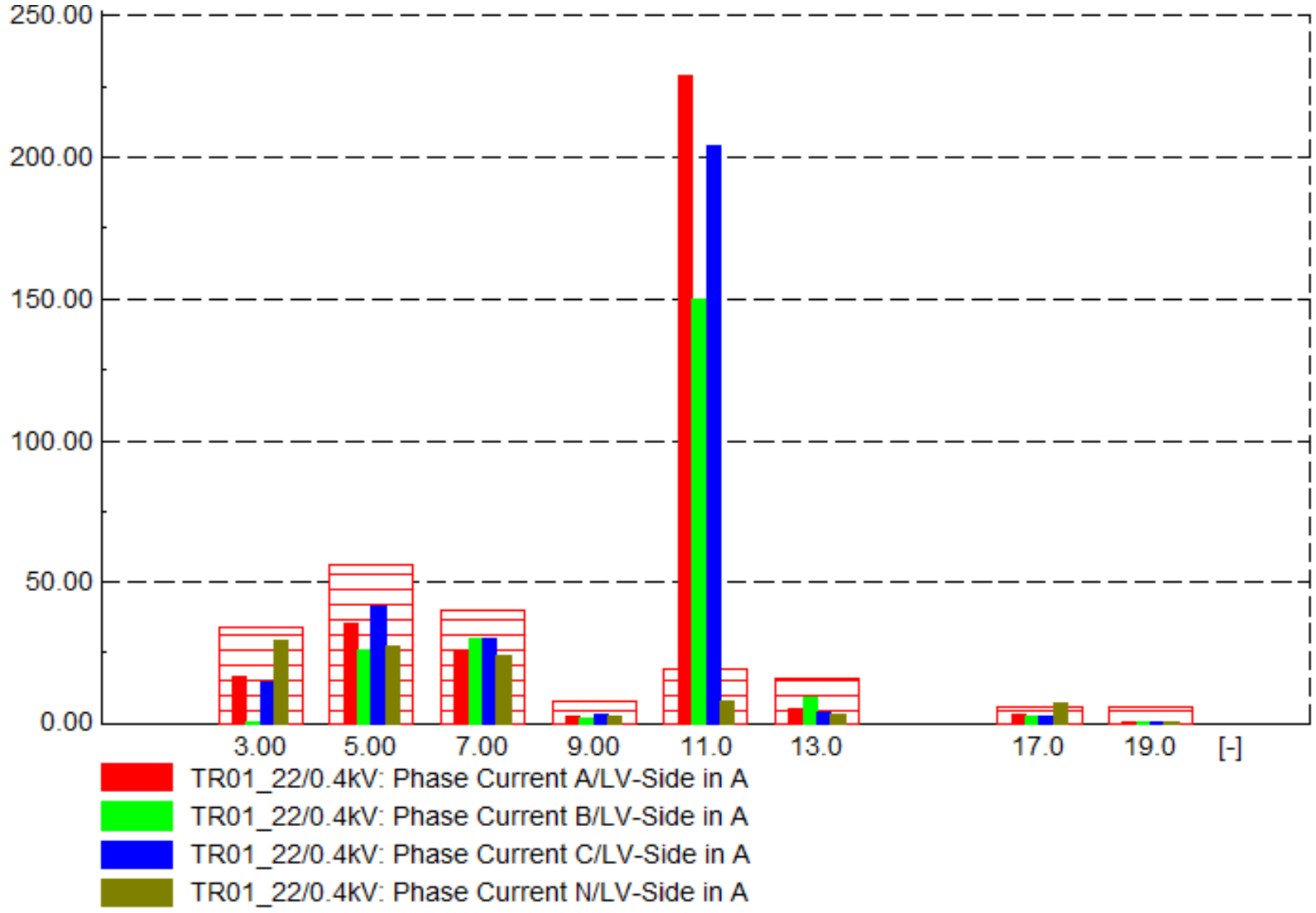
Harmonic Load Flow Running

Cap Bank Step#7



Cap Bank Step#4

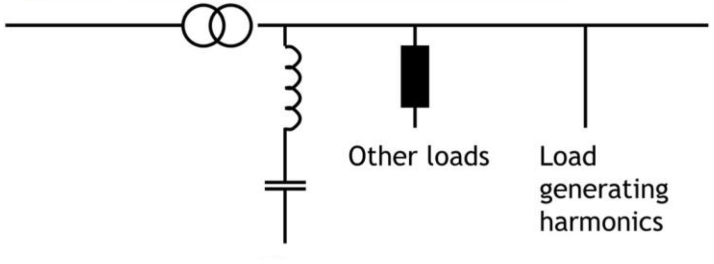


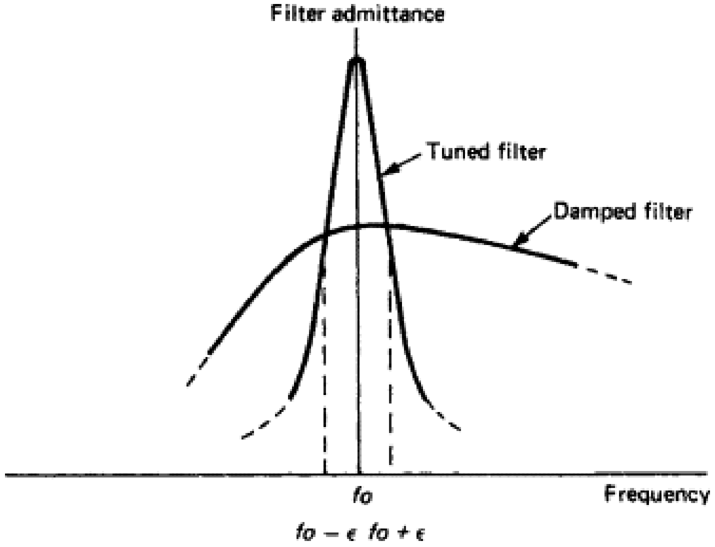

250.00
200.00
150.00
100.00
50.00
0.00
3.00
5.00
7.00
9.00
11.0
13.0
17.0
19.0
[-]
TR01_22/0.4kV: Phase Current A/LV-Side in A
TR01_22/0.4kV: Phase Current B/LV-Side in A
TR01_22/0.4kV: Phase Current C/LV-Side in A
TR01_22/0.4kV: Phase Current N/LV-Side in A

Harmonic Case Study: Challenge

Tune Filter

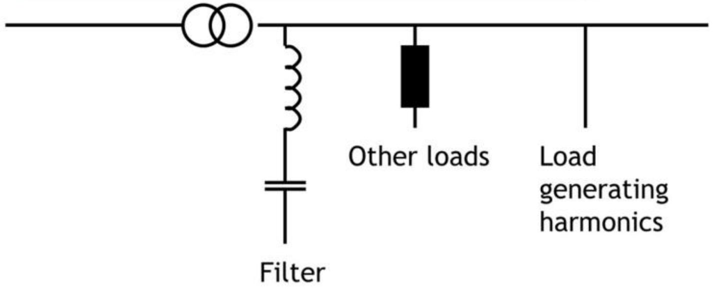
Passive filters are tuned to specific frequencies to reduce current- and voltage-harmonics.

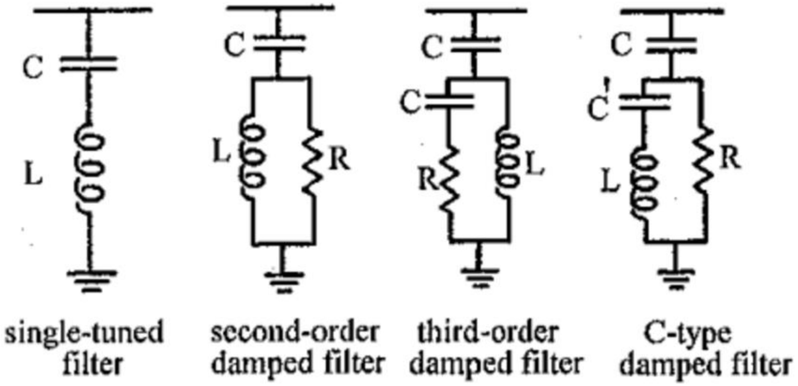




Detune Filter

Detune filters are tuned to specific frequencies to avoid current- and voltage-harmonics.



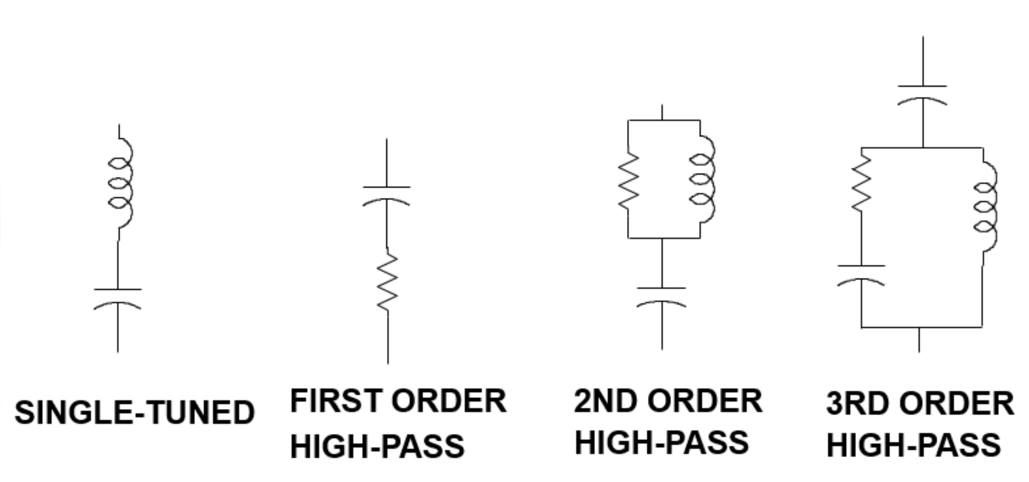


Frequency Response Characteristics

Devices for Controlling Harmonic Distortion

- Chokes for ASD applications
- Zig-zag transformers
- Passive Filters
- Active filters

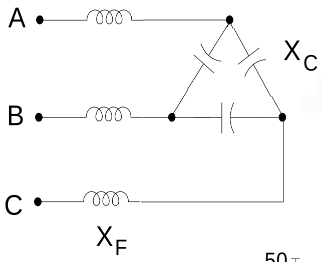
Shunt Passive Filter Configurations



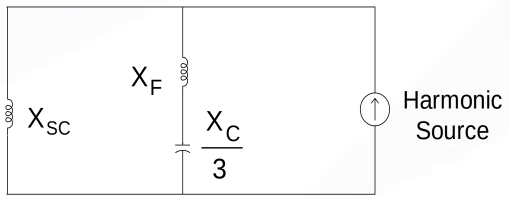
Effect of Notch Filter on the Frequency Response Characteristics

$$h_{notch} = \sqrt{\frac{X_C}{3X_F}}$$

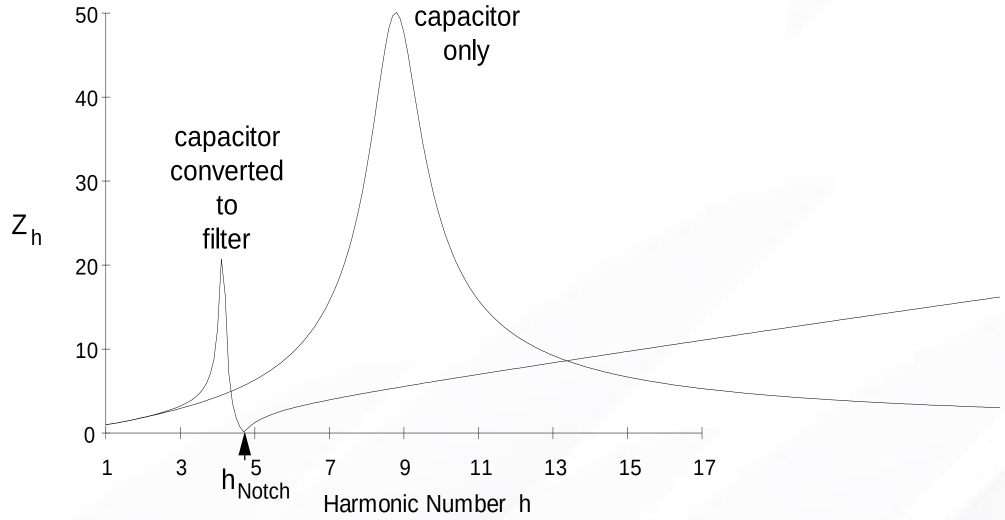
(a) Typical low voltage filter configuation.

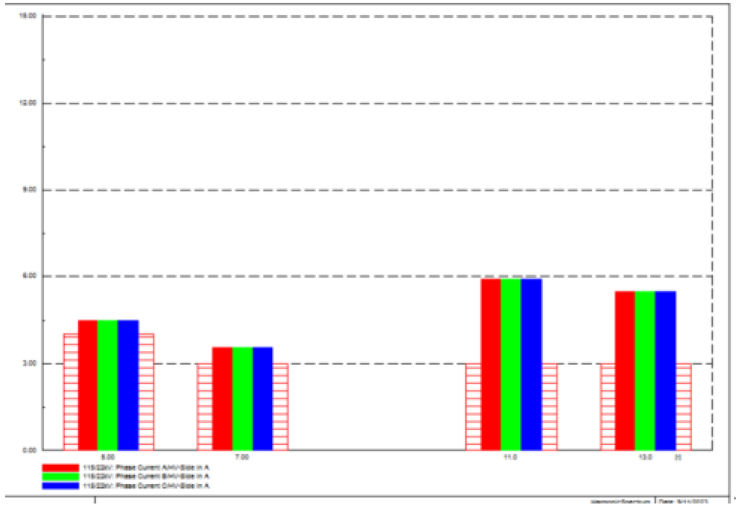


(b) Equivalent circuit of system with filter.

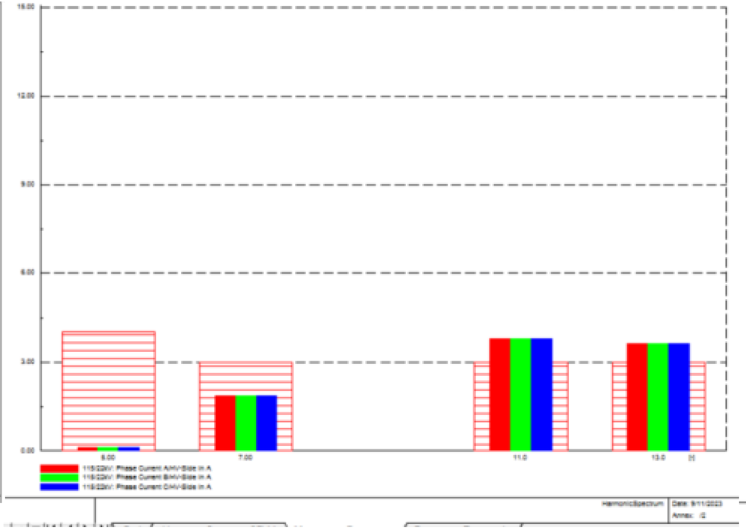


(c) System frequency response ($Z_1 = 1.0$).

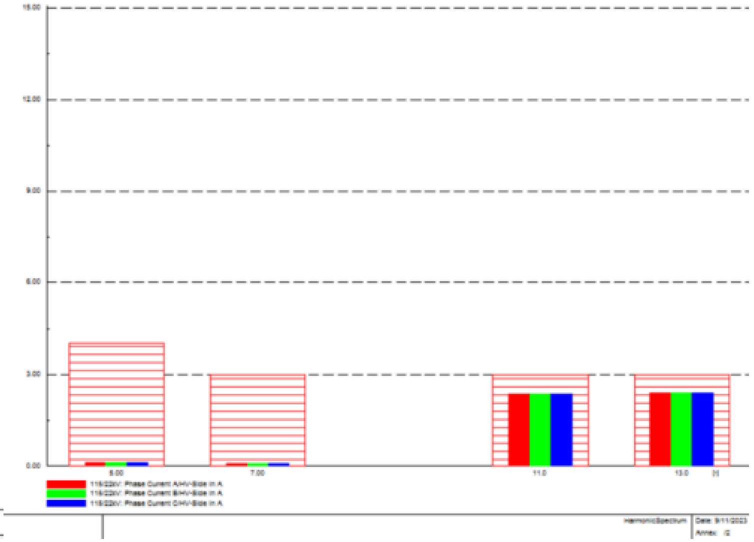




Non linear load only



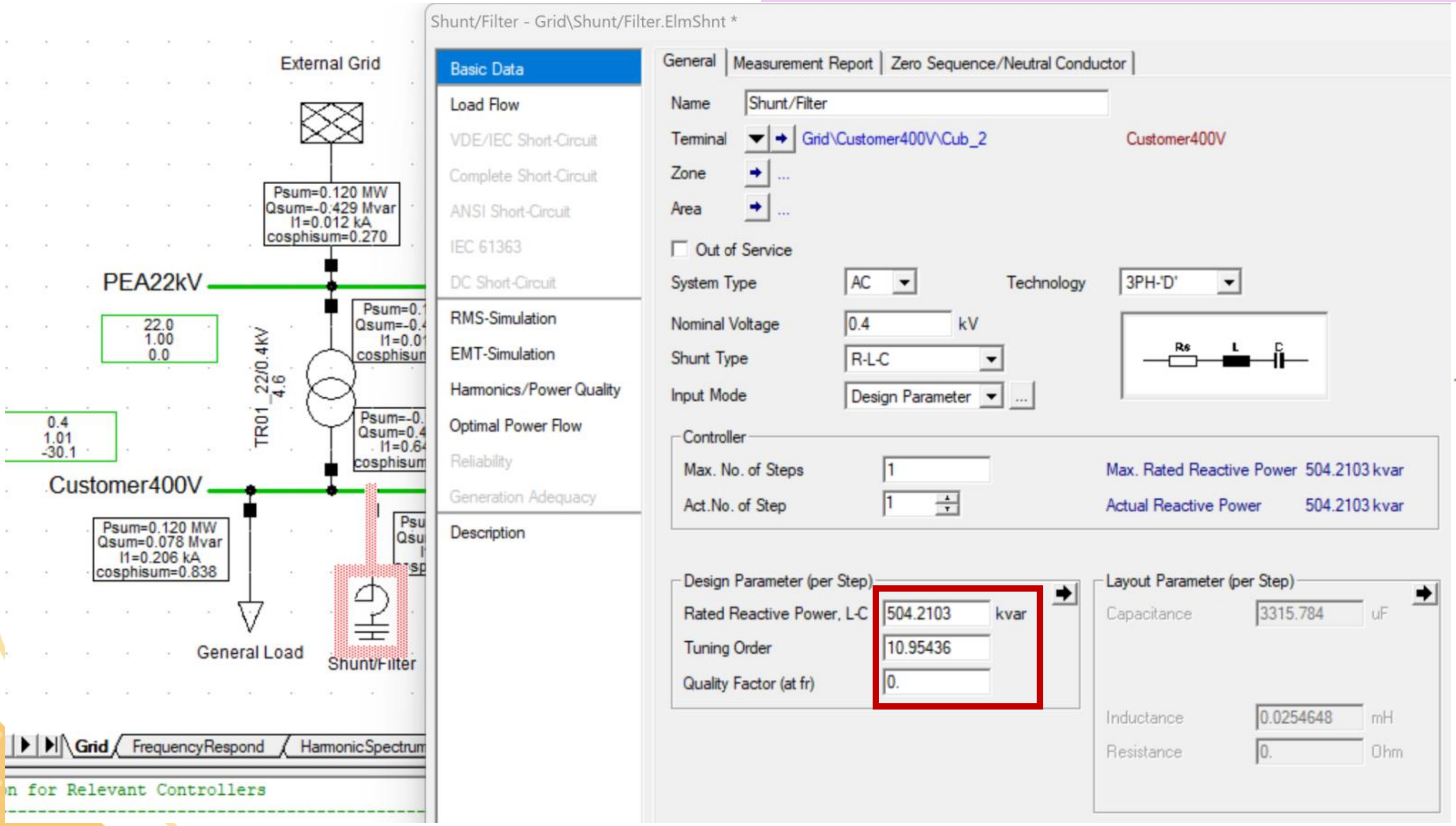
Non linear load with Tune filter order 5

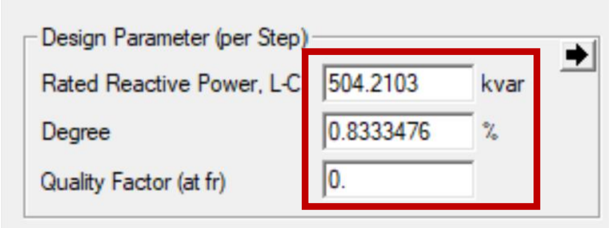


Non linear load with Tune filter order 5 and 7

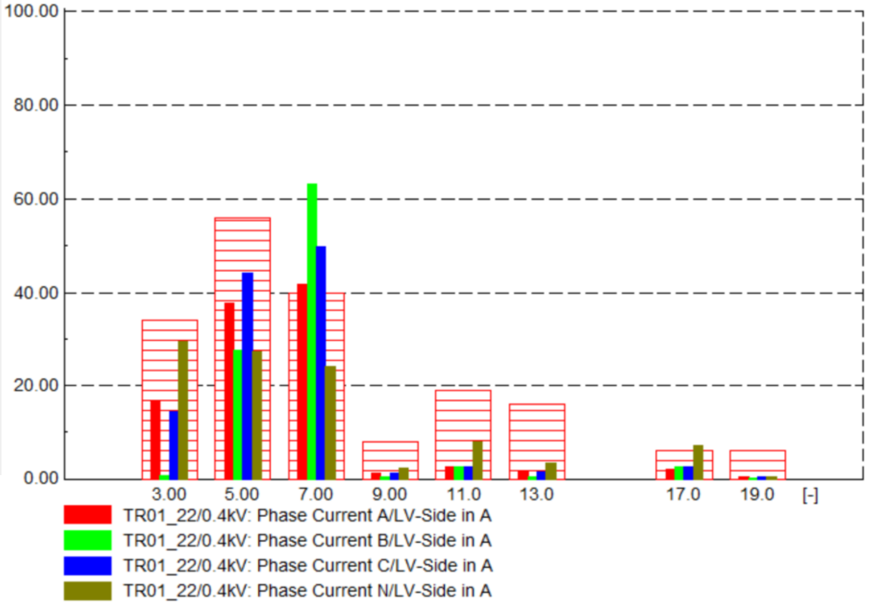
Harmonic Case Study: Solve by Tune Filter

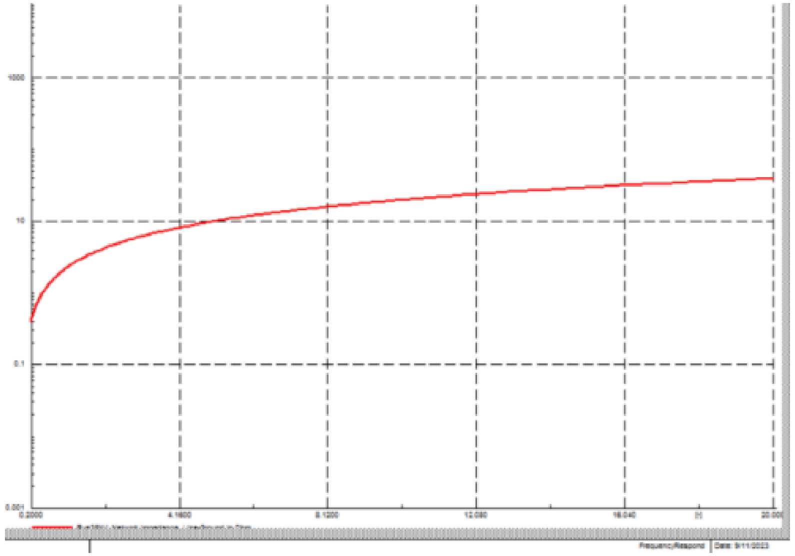
Change Cap Bank to Tune Filter Order#11



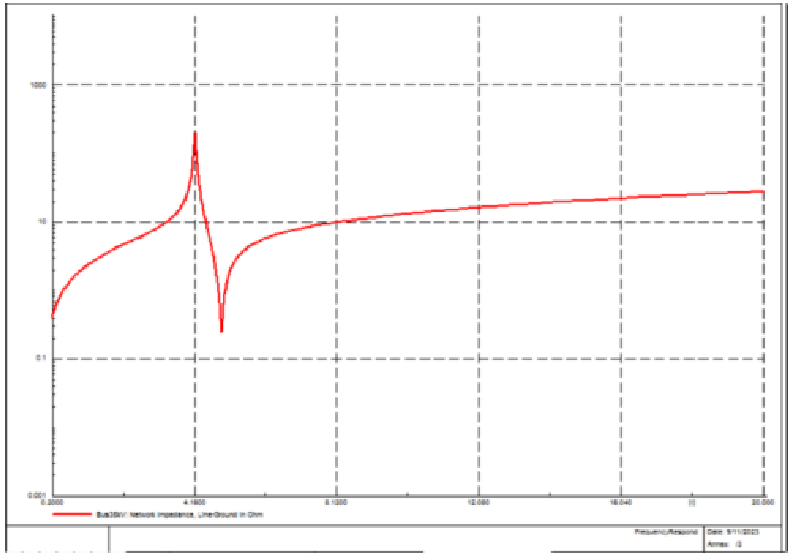


$$V_C = \frac{Vs}{(1-\%XL)} = \frac{400}{(1-0.0083)} = 403.3\ V$$

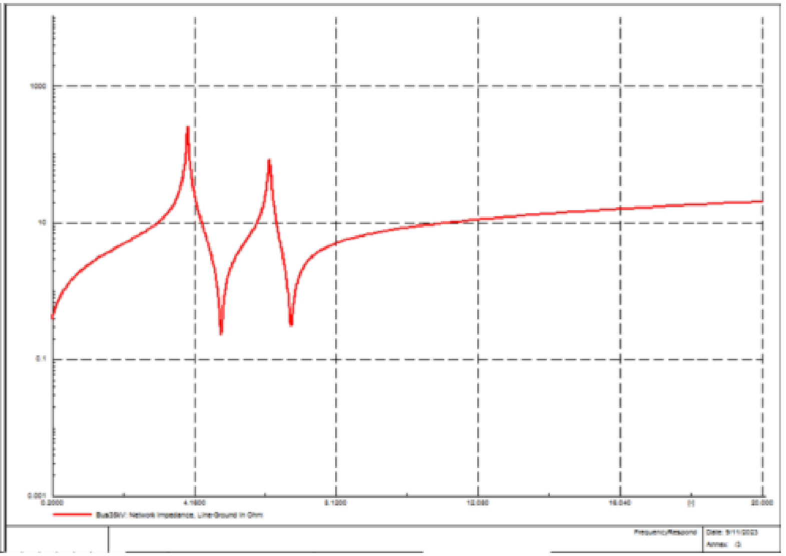




Non linear load only

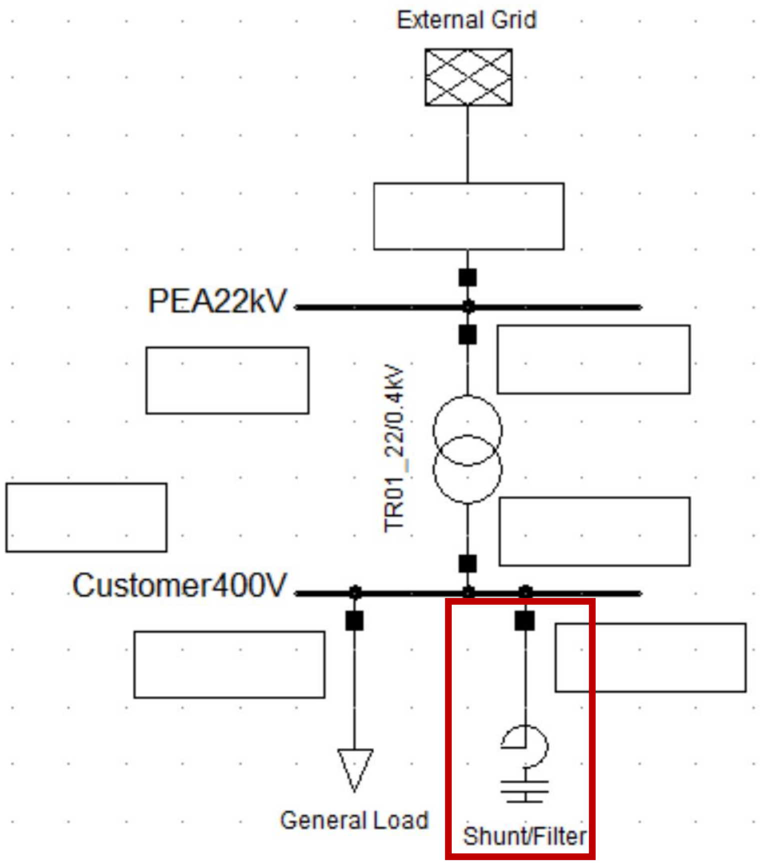


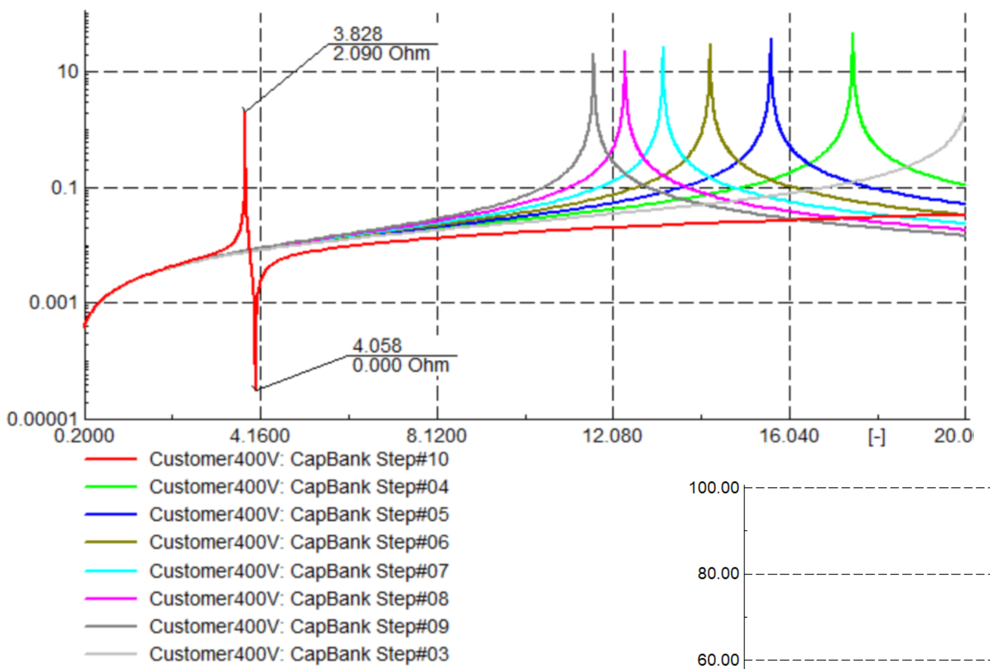
Non linear load with Tune filter order 5

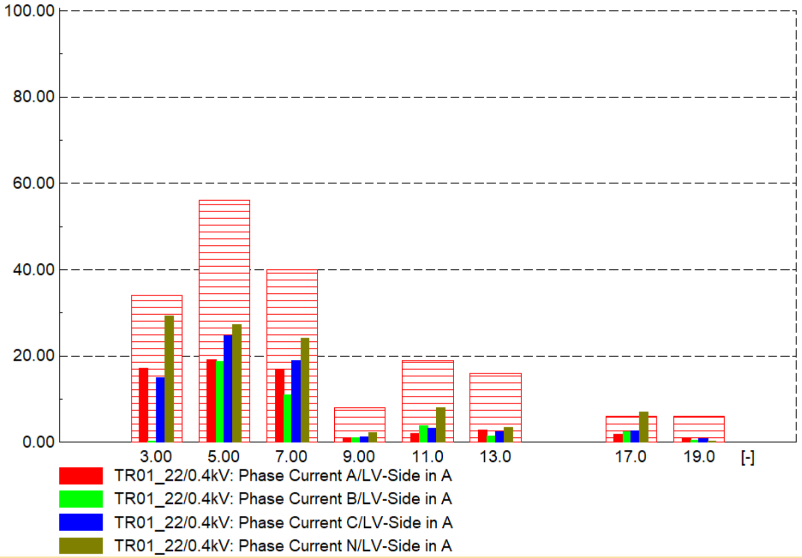


Non linear load with Tune filter order 5 and 7

Harmonic Case Study: Solve by Detune Filter







Thank you for your attention

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Brightness for Life Quality

สว่างทั่วทิศ สร้างคุณภาพชีวิตทั่วไทย