Effect of harmonics from DC arc furnace on 115 kV capacitor equipment in PEA N3

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Provincial Electricity Authority: PEA 2013

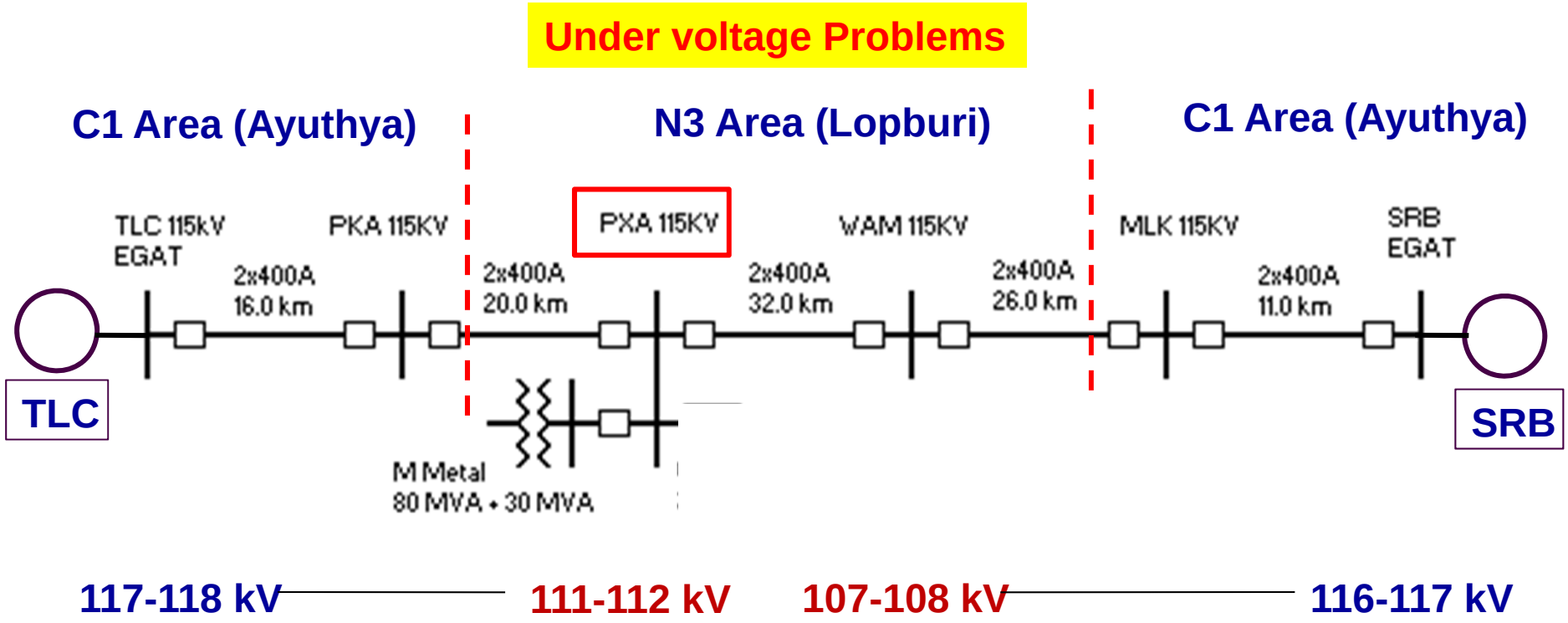
- Distribution System: 22, 33 kV 298,346 cc-km
- Transmission System: 115 kV 11,191 cc-km, 520 Substations
- Customer: 17.29 millions, Personnel: 27,804
- Electrified villages: 99.98%, Peak load: 17,293 MW
- Sales electricity: 112,606.77 millions of KWh

Outlines

- Introduction
- Problem
- Monitoring
- Testing
- Conclusion
- Q&A

Introduction

•The PXA is at the end of transmission line system which receive power one at a time from the TLC or SRB substation as shown in the figure

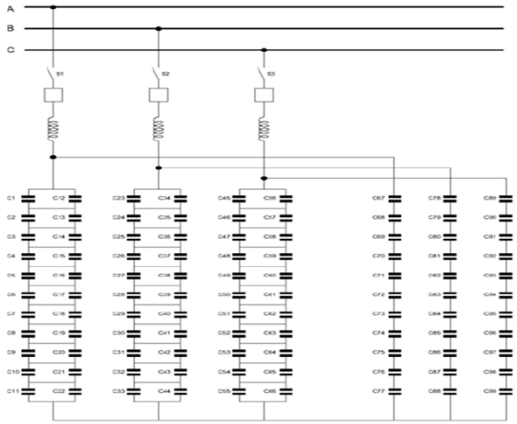


Introduction

- The first 115 kV capacitor bank of PEA has been implemented in PXA substation. (2013)
- 115 kV customer of PXA is sometime encounter with undervoltage problem during the peak period. As a result, PEA set a project to install the first 115 kV capacitor bank to maintain the voltage stability.
- The capacitor bank is designed with 6% reactor. It is one type of detuned harmonic filter, 2 steps of 39.6 MVAr of capacitor at 131.46 kV with 85.35 mH

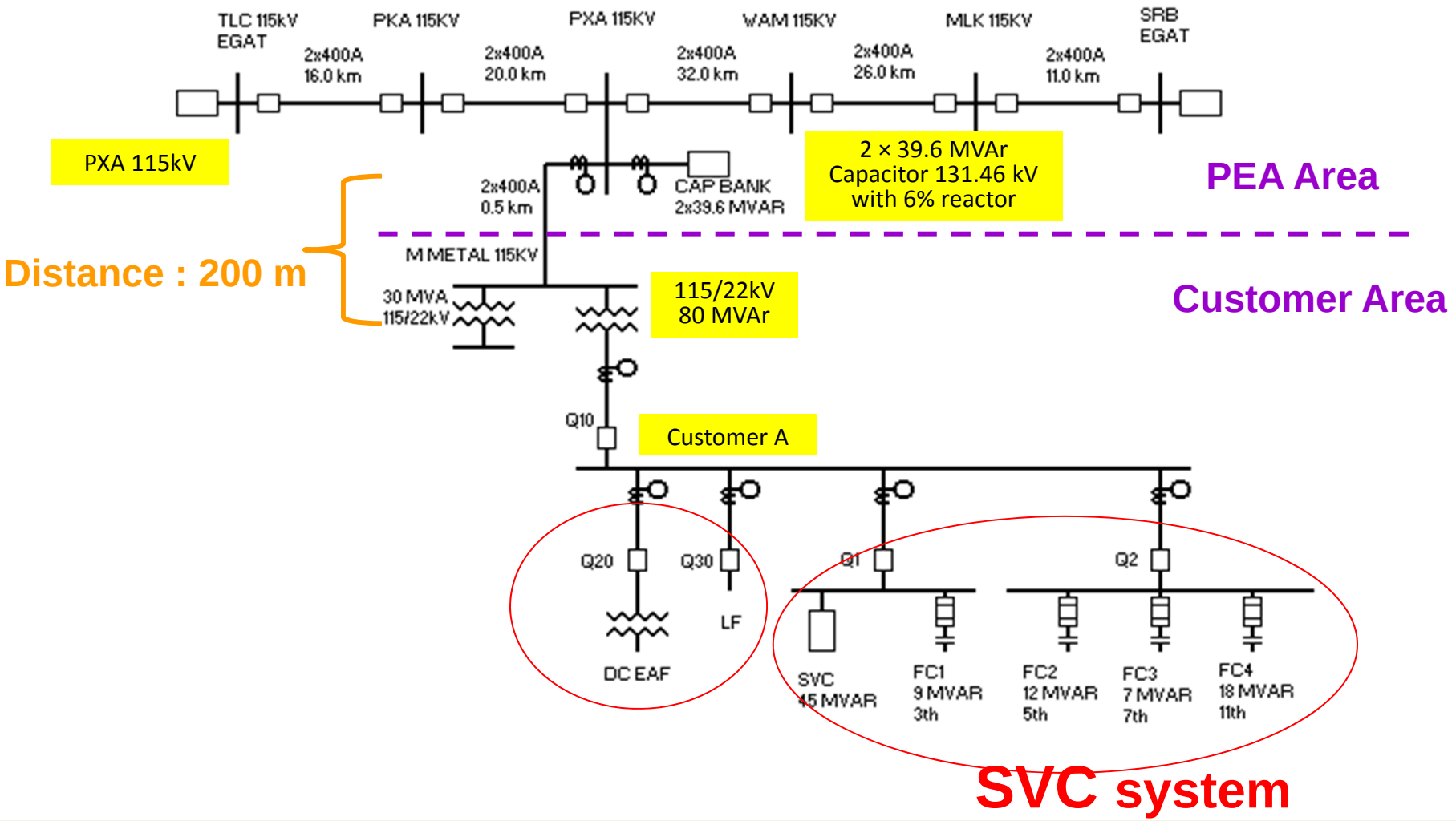
Capacitor Specifications

C-Bank Data (at C-Unit Rated)		39.6 MVAR		
- System Faulted Current	$I_{SC,sys}$	-	kA	31.5
- Maximum Parallel Banks	N_{max}	-	Banks	4
- Rated Voltage	kV_{bank}	$kV_{bank} = 1.732 \cdot n_{series} \cdot kV_{unit}$	kV	131.46
- Rated Power	$MVAR_{bank}$	$MVAR_{bank} = n_{total} \cdot (kVAR_{unit}/1000)$	MVAR	39.6
- Total Power (Maximum)	$MVAR_{max}$	$MVAR_{max} = N_{max} \cdot MVAR_{bank}$	MVAR	158.4
- Capacitive Reactance	$X_{C\text{-}bank}$	$X_{C\text{-}bank} = (kV_{bank})^2/MVAR_{bank}$	Ω	436.43
- Capacitance	C_{bank}	$C_{bank} = 10^6/(2\pi \cdot f \cdot X_{C\text{-}bank})$	μF	7.294
Harmonics Blocking Reactor				
- Inductive Reactance	$X_{L\text{-}bank}$	$X_{L\text{-}bank} = 6\%\ X_{C\text{-}bank}$	Ω	26.186
- Inductance	L_{bank}	$L_{bank} = 1000 \cdot X_{L\text{-}bank}/(2\pi \cdot f)$	mH	83.351



The purpose of 6% reactor to reduce inrush current and detune filter.

Problem


TLC 115kV
EGAT
PKA 115KV
PXA 115KV
WAM 115KV
MLK 115KV
SRB
EGAT
2x400A
16.0 km
2x400A
20.0 km
2x400A
32.0 km
2x400A
26.0 km
2x400A
11.0 km
PXA 115kV
2 × 39.6 MVAr
Capacitor 131.46 kV
with 6% reactor
PEA Area
2x400A
0.5 km
CAP BANK
2x39.6 MVAR
Distance : 200 m
M METAL 115KV
30 MVA
115/22kV
115/22kV
80 MVAr
Customer Area
Q10
Customer A
Q20
Q30
Q1
Q2
LF
DC EAF
SVC
45 MVAR
FC1
9 MVAR
3th
FC2
12 MVAR
5th
FC3
7 MVAR
7th
FC4
18 MVAR
11th
SVC system

SVC system of customer

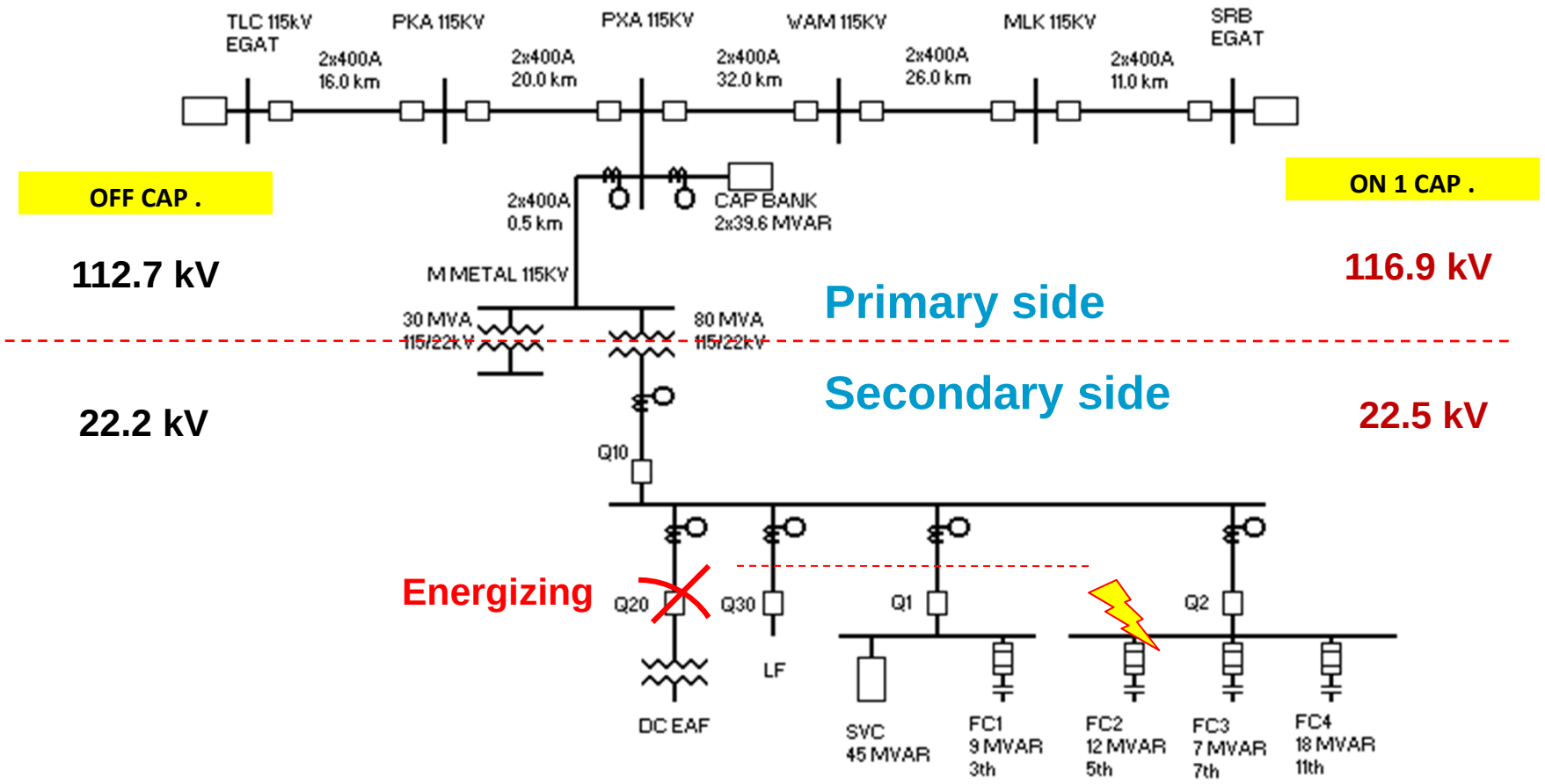
•The SVC system, which is rated for 45 MVAr at 22 kV, consists of a TCR and four harmonic filters. The TCR is continuously adjusted in response to the arc furnace power fluctuation. The filter capacitor banks provide the leading reactive power to improve the load power factor.

(a) Thyristor

(b) Reactor

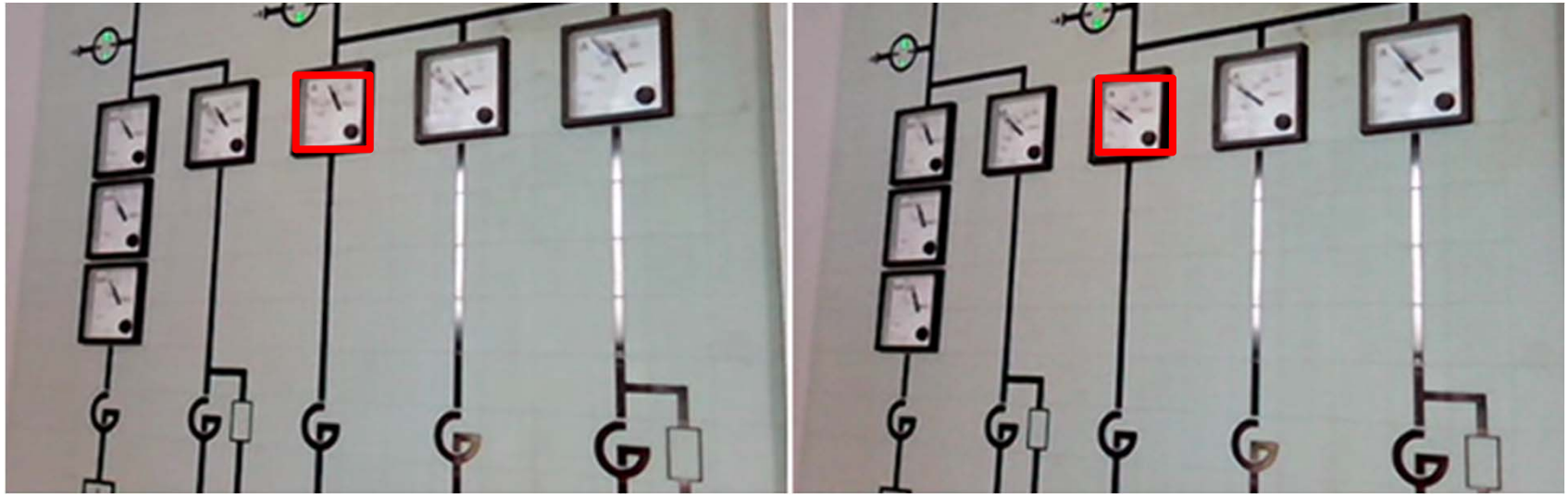
(c) Harmonic Filter

Effect 115 kV capacitors to Customer



HF No. 5th tripped

5th harmonic filter current



(a). Tripping State **(b). Normal State**

When on Q20, Q2 trip which show over current at 5th harmonic filter just in case of PEA on one step of 115kV capacitor. In the red box show current amplitude of harmonic filter No.5 that over the setting level.

Setting & Operating

Table1 :Setting time for tripping

HF order.	3rd	5th	7th	11th
65 sec	327 A.	542 A.	384 A.	655 A.
10 sec	339 A.	561 A.	397 A.	678 A.
1.0 sec	406 A.	672 A.	476 A.	812 A.
0.1 sec	522 A.	864 A.	612 A.	1,044 A.

Table2 : Operating current

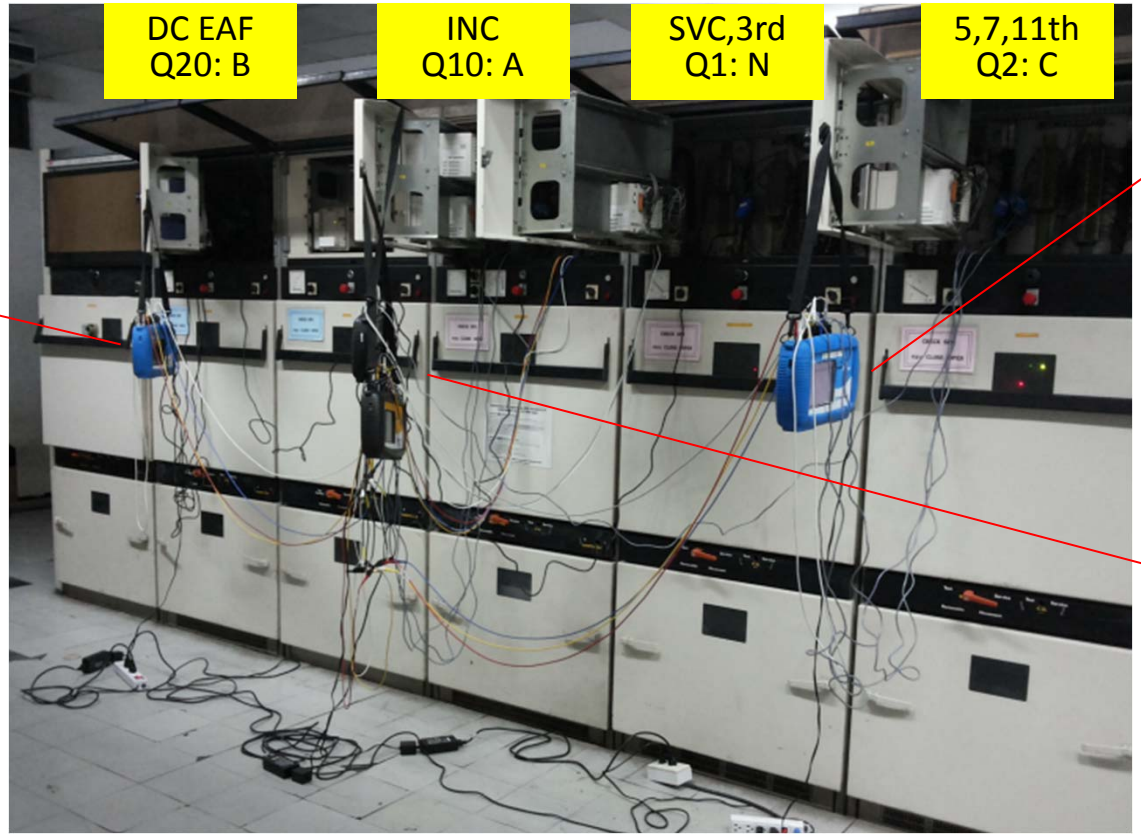
HF order.	3rd	5th	7th	11th
Design	250 A.	312 A.	203 A.	481 A.
Actual	~240 A.	~240 A.*	~200 A.	~470 A.

Effect115 kV capacitors to Customer

The tap of power transformer of Customer A has been changed from 12 to 9 by the operation of OLTC to maintain the voltage level to the setting value.

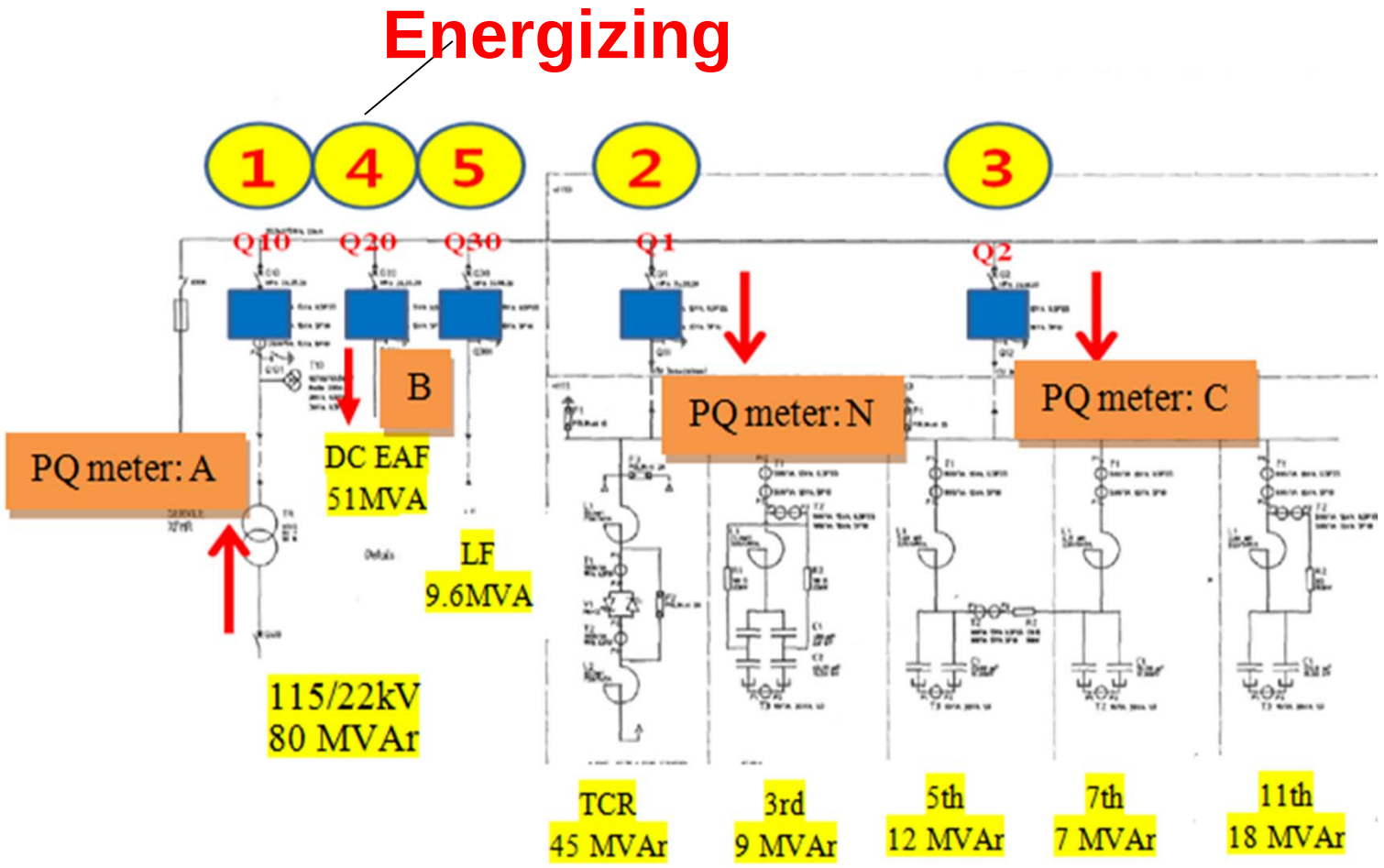
On Load Tap Changer : OLTC

Monitoring @ Customer

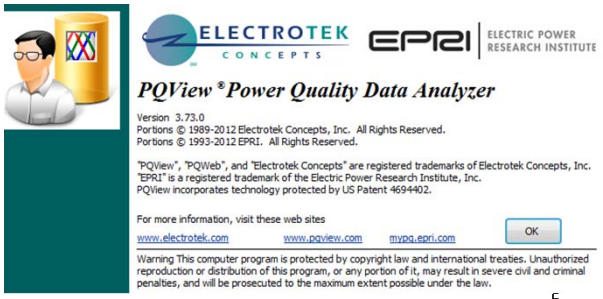


Monitoring @ Customer

Monitoring location and Operation problem



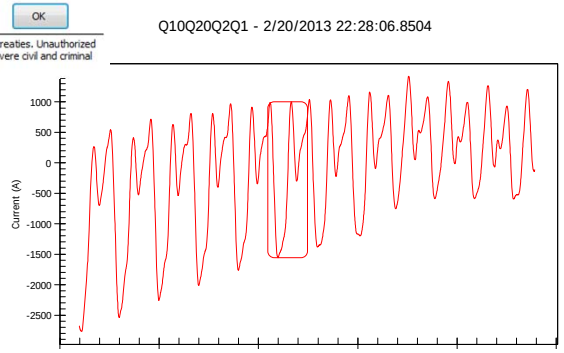
Operation w/o CAP bank.

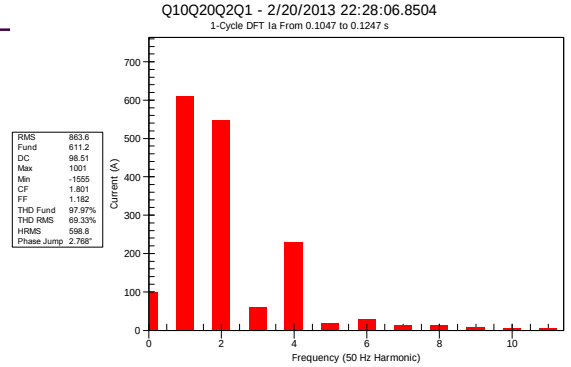


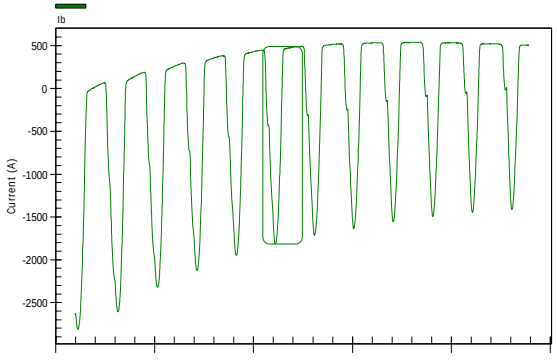
1.Q10
Main breaker

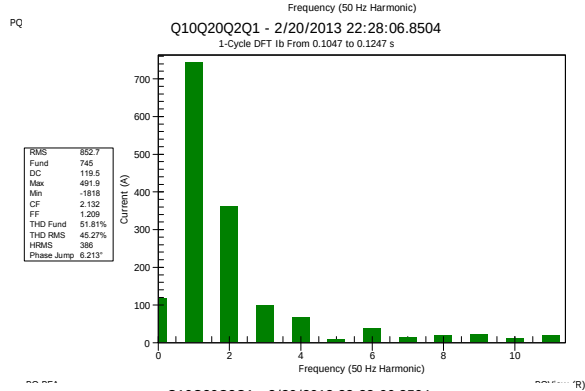
(b) Q20
DC EAF

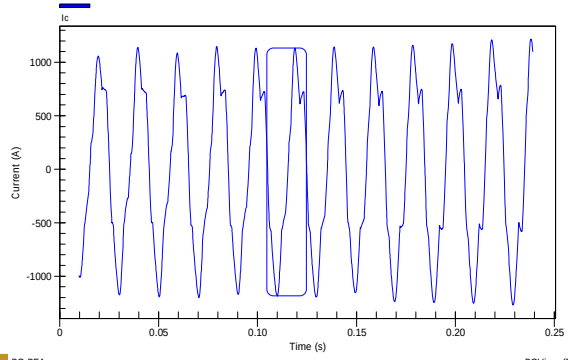
(c) Q2
5th, 7th, 11th order

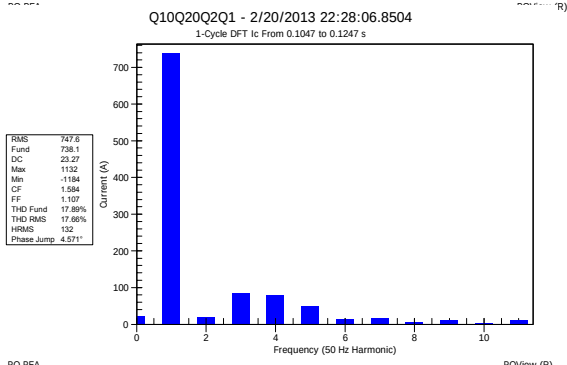


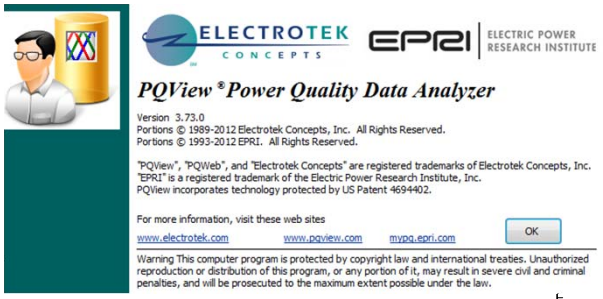










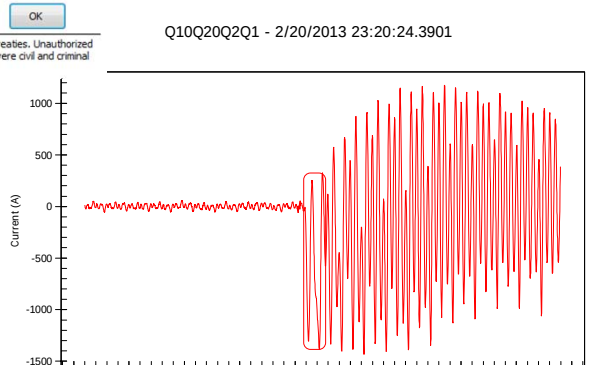


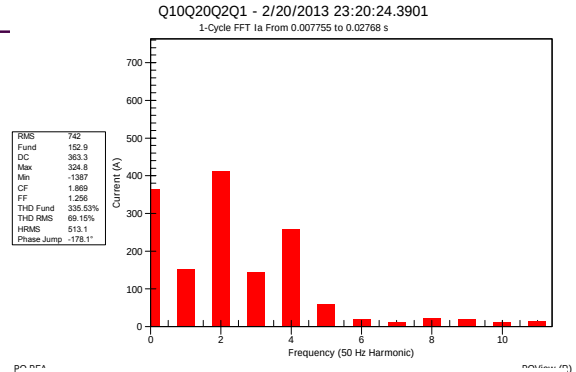
Operation with CAP bank.

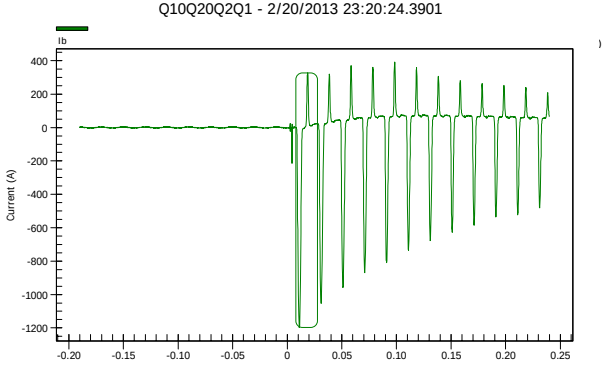
1.Q10
Main breaker

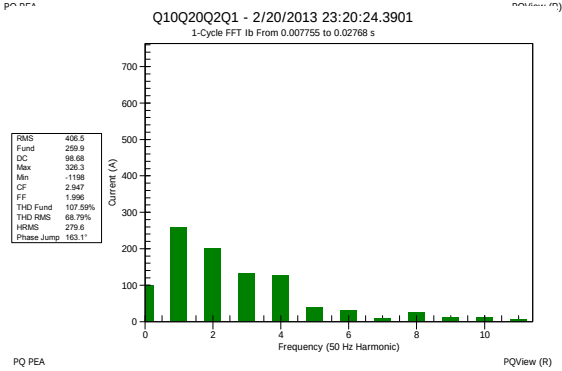
(b) Q20
DC EAF

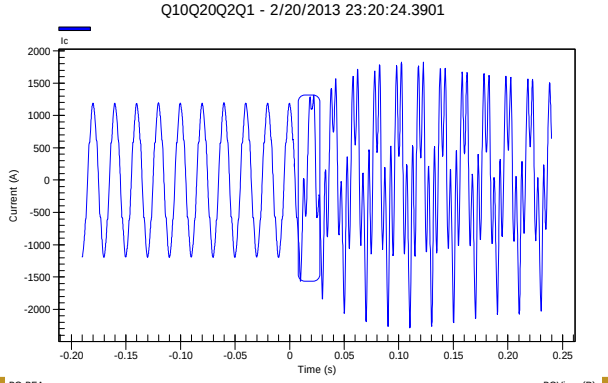
(c) Q2
5th, 7th, 11th order

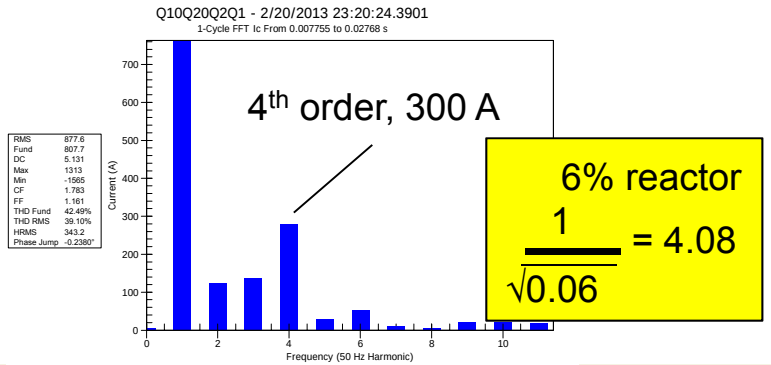










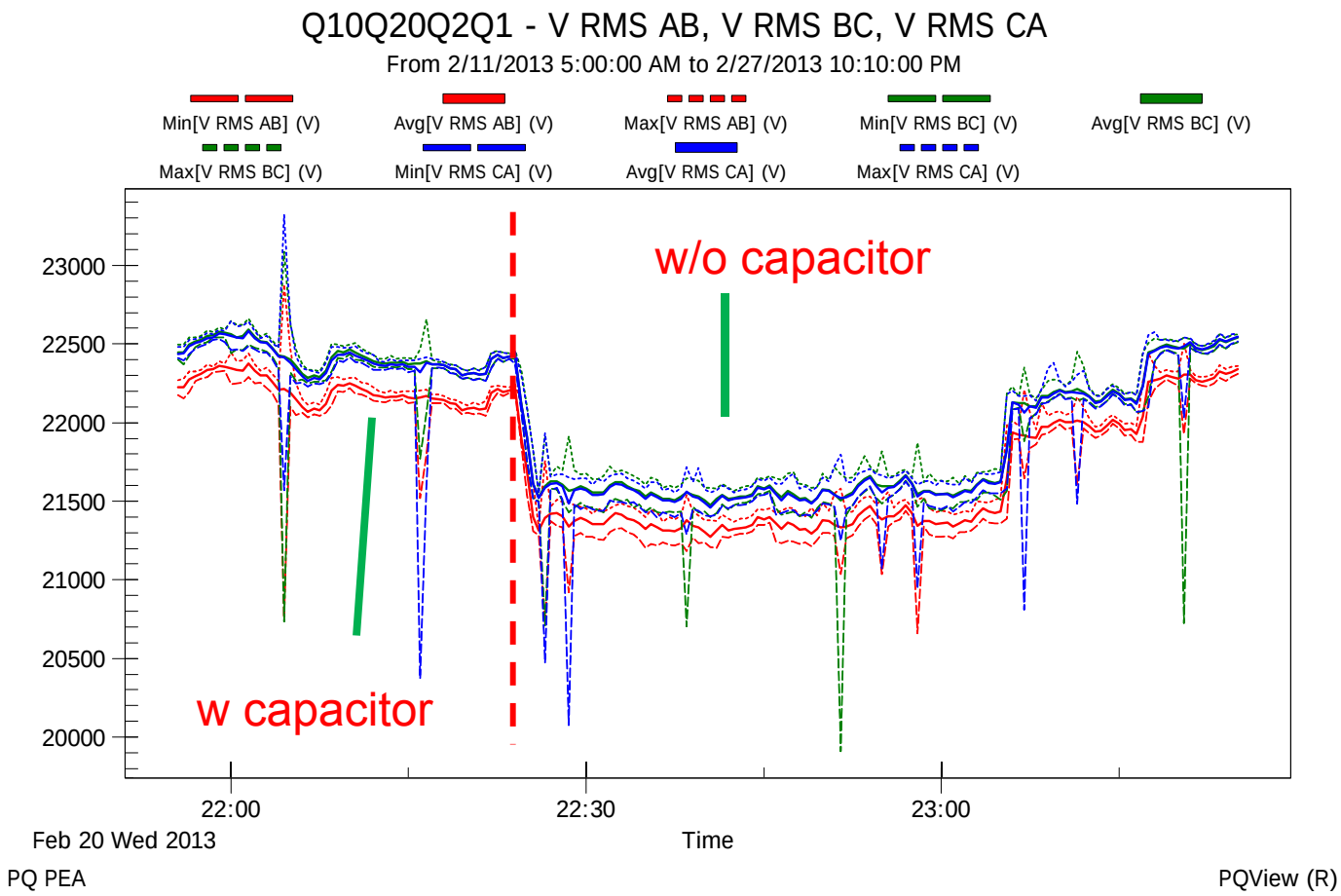


4th order, 300 A

6% reactor

$$\frac{1}{\sqrt{0.06}} = 4.08$$

Voltage Level



For testing, to control voltage level 22 kV at secondary side of Tr. 80 MVA

Testing Table

Time	Tap	OLTC	Vab	Vbc	Vca	Remark
11.20	13	Auto	22.24 kV	22.42 kV	22.42 kV	
12.20	9	Auto	22.28 kV	22.46 kV	22.45 kV	
22.54	9	Auto	22.45 kV	22.48 kV	22.24 kV	Trip
22.58	6	Manual	21.29 kV	21.50 kV	21.49 kV	
23.07	8	Manual	21.96 kV	22.15 kV	22.07 kV	
23.18	9	Manual	22.27 kV	22.46 kV	22.46 kV	Trip

OLTC setting has modified by ABB (February 2013)

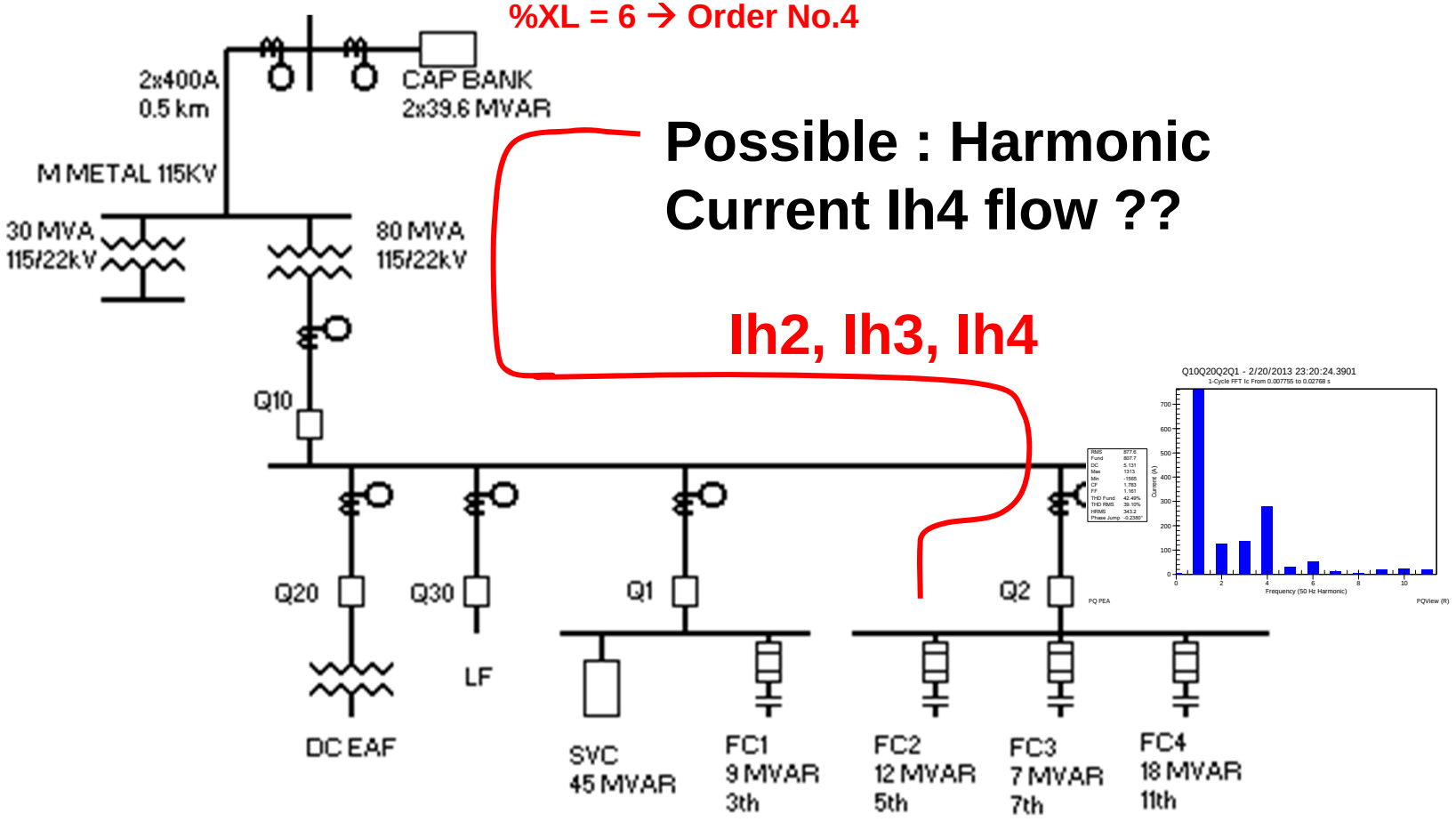
Old : set point V= 1.0, BW= +/-2%

New : set point V= 0.98, BW= +/-2%

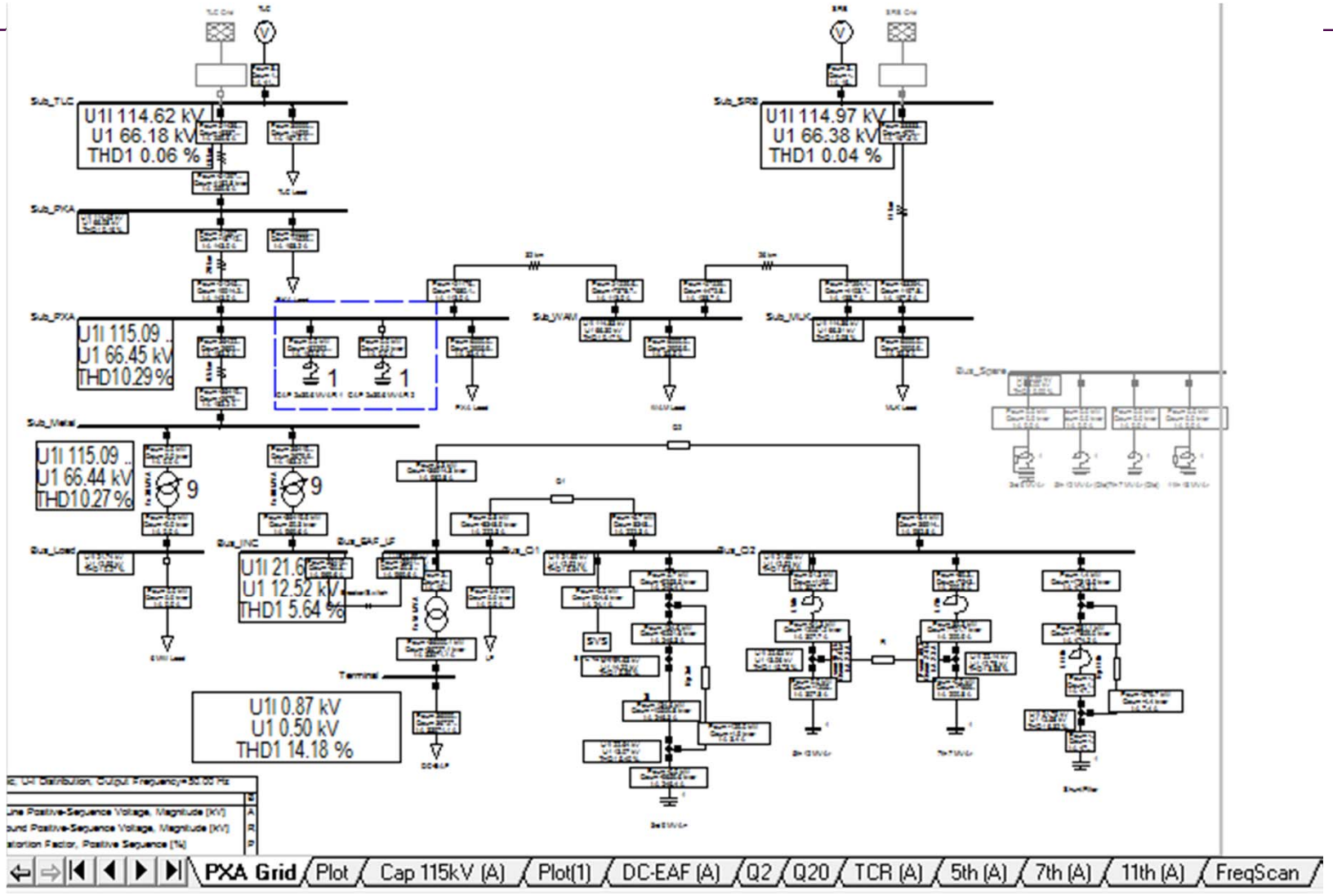
Event @ March 8, 2015

Short Circuit @ CAP BANK No.1 Phase C

Assumption ???


%XL = 6 → Order No.4
2x400A
0.5 km
CAP BANK
2x39.6 MVAR
M METAL 115KV
30 MVA
115/22kV
80 MVA
115/22kV
Q10
Q20
Q30
Q1
Q2
LF
DC EAF
SVC
45 MVAR
FC1
9 MVAR
3th
FC2
12 MVAR
5th
FC3
7 MVAR
7th
FC4
18 MVAR
11th
Possible : Harmonic
Current Ih4 flow ??
Ih2, Ih3, Ih4
Q10Q20Q2Q1 - 2/20/2013 23:20:24.3901
1-Cycle FFT Ic From 0.007755 to 0.02768 s
Frequency (50 Hz Harmonic)
PQ PEA
PQView (R)

Simulation

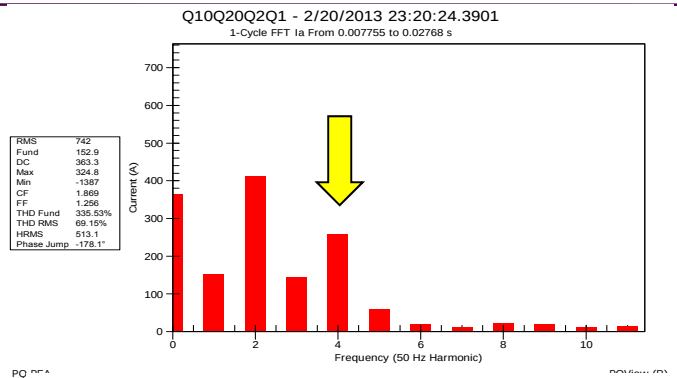

Sub_TUC
U1l 114.62 kV
U1 66.18 kV
THD1 0.06 %
Sub_SRB
U1l 114.97 kV
U1 66.38 kV
THD1 0.04 %
Sub_PXA
U1l 115.09 ..
U1 66.45 kV
THD10.29 %
Sub_WAN
Sub_MLK
Sub_Metal
U1l 115.09 ..
U1 66.44 kV
THD10.27 %
Bus_INC
U1l 21.6
U1 12.52 kV
THD1 5.64 %
Bus_C1
Bus_C2
SVS
Terminal
U1l 0.87 kV
U1 0.50 kV
THD1 14.18 %
PXA Grid
Plot
Cap 115kV (A)
Plot(1)
DC-EAF (A)
Q2
Q20
TCR (A)
5th (A)
7th (A)
11th (A)
FreqScan

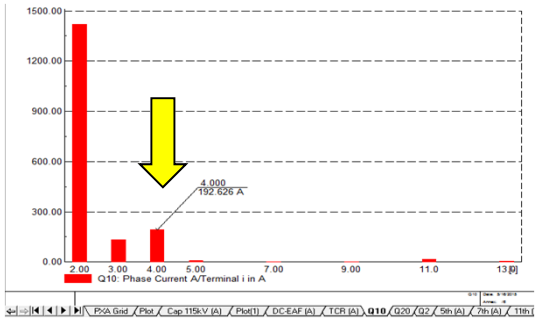
Results

Measured

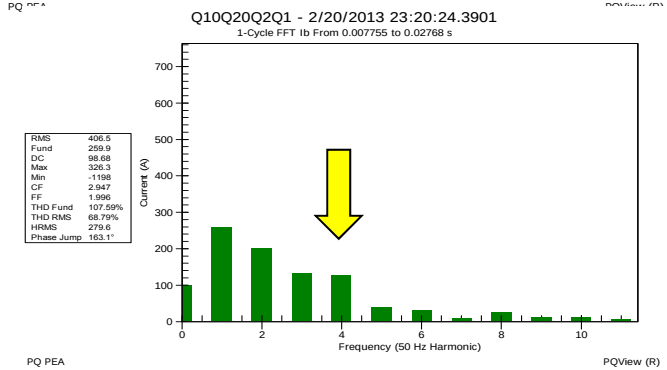
Simulated

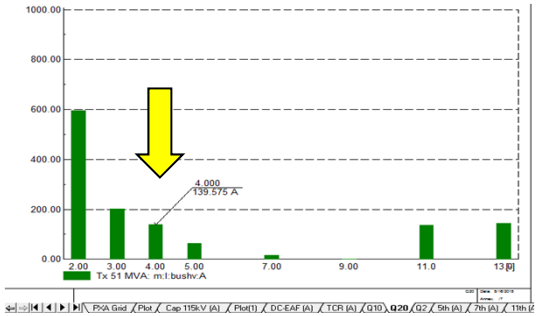
1.Q10
Main breaker



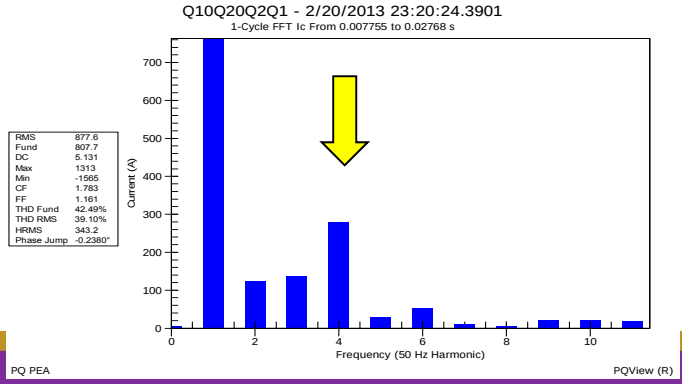


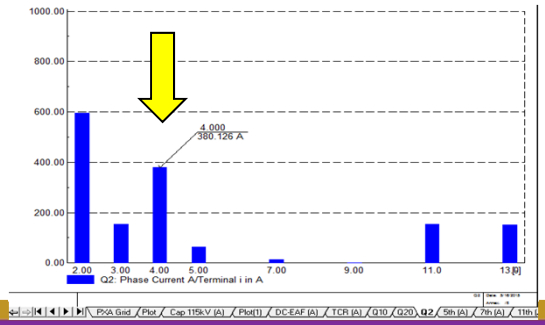
(b) Q20
DC EAF



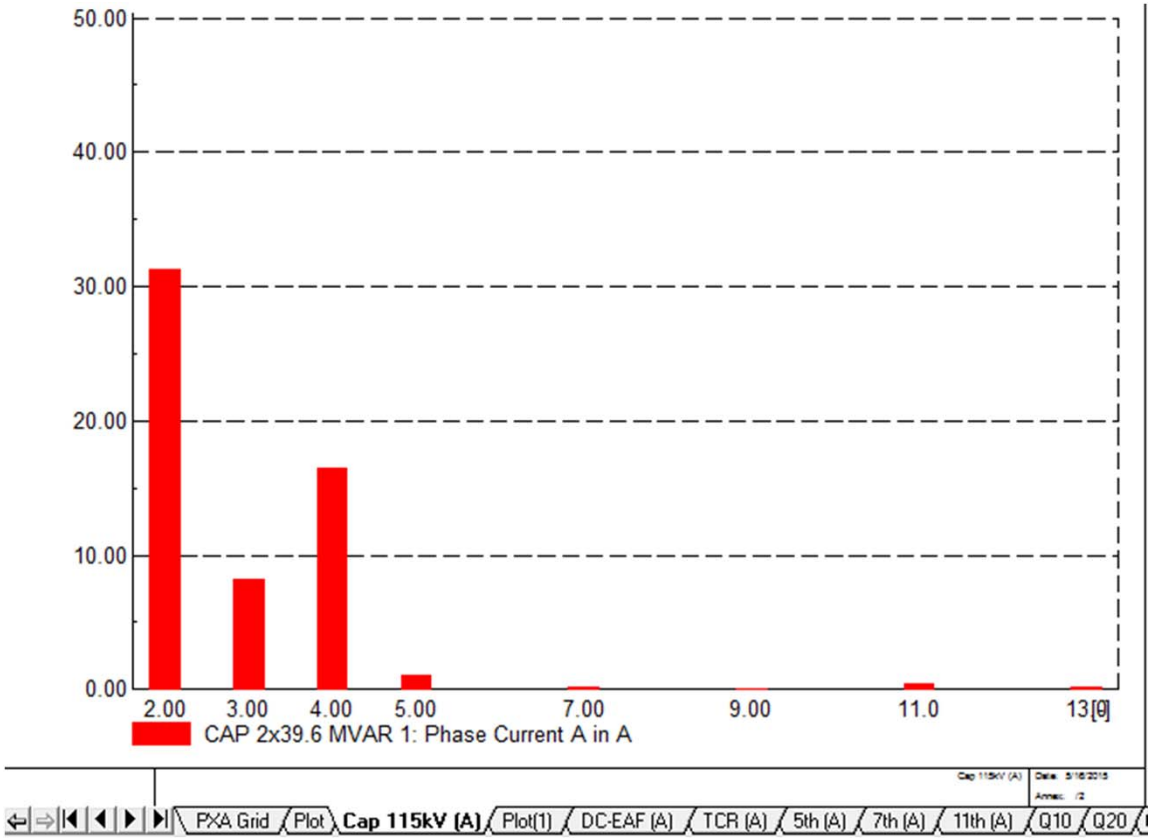


(c) Q2
5th, 7th, 11th order





Harmonic current in Cap Bank



This is a result simulated spectrum harmonic current at 115 kV cap bank.

Irms = 160 A -> I1 = 155 A

Ih2 = 32 A -> 20.6%
Ih3 = 9 A -> 5.8%
Ih4 = 17 A -> 10.9%

Conclusion

- Implemented 115 kV Cap bank at PXA substation for under voltage problem.
- Cap bank purpose to detuned harmonic filter with 6% reactor for prevent an inrush current & resonance problem.
- Cap bank has affected to SVC of customer.
- 1st Solution: To Adjust a set point of OLTC (Feb 2013)
- 2nd Solution : To Modify a SVC unit (June 2015)
- Cap bank has damaged (Short Circuit, March 2015)
- This year, PEA have a plan to investigate that problem and find some method for prevention a problem like this.
- 3rd Solution : Soon….

Q&A