Reactive Power Compensation Analysis Report

FOR

Globally Leading Tool Manufacturing Company

By

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Objective and the details of the equipment

Audit objectives:

Carry out Detailed Reactive Power Compensation / harmonic level study of facility and recommend modifications in the same so as to achieve full 3.5% incentive from MSEDCL as per new MSEDCL policy applicable since Sept 2018.

Details of Equipment Used:

No	Name of the equipment	SR. No., Model	Make	Use
1	Power Analyzer	1645 (CA 8335)	Chauvin Arnoux	Electrical Parameter Measurement

Audit team

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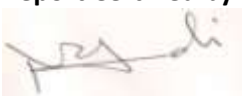
Mr. Prasad Paraskar
Mr. Kunal Bhangale

XXXXAAA : Mr. aaaabb

Certification:
Report Certified by:



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Chartered engineer

Executive Summary:

1) As per new MSEDCL policy power factor incentive will be available @ 3.5% of energy charges only if the consumer keeps “RKVAH Lead” and “RKVAH Lag” figures to their minimum values and also maintain “RKVAH Lag” > / = “RKVAH Lead”. This was suddenly implemented from Sept 2018. Before this leading power factors were considered as unity and full incentive was available.

2) It is observed that electrical maintenance team led by Mr. Kazi has taken all the required efforts to maintain the level of reactive power compensation to possible optimum level (By continuous monitoring and manual adjustments) since Oct 2018 to get 2.5% incentive in bills since then. It is not possible to go further up to 3.5% with existing APFC arrangements with 10 transformers.

3) The current harmonic levels at 22KV HT PCC are well within acceptable limits as per MSEDCL supply code 2005. We have included necessary compliance calculations in this report – assuming MSEDCL fault level is around 500MVASC.

4) Few transformers at present are equipped with fixed capacitors, few are with APFC / RTPFC. Few steps are not working in some panels while capacitors in few steps are not delivering full KVAR due to aging.

5) We have done electrical system simulation using ETAP and have included load flow analysis to know exact KVAR requirement for each transformer and also to analyse existing situation. Detail ETAP reports are included.

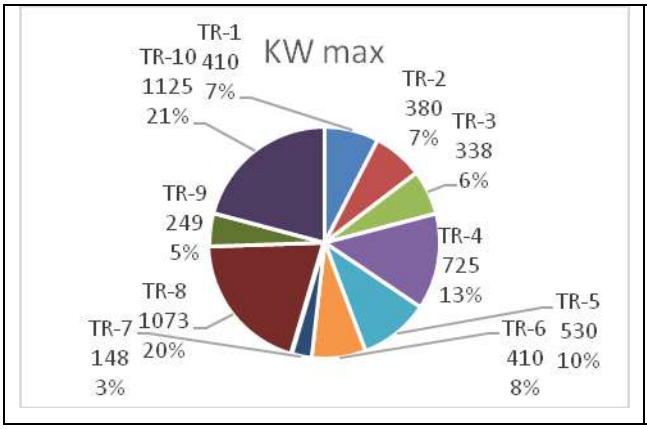
6) Our recommendations are given in two options on page 13 –
   a) Repair / Retrofit existing APFC panels and add top up RTPFC panels for all the transformers ---- OR ----
   b) Replace all the panels with new state of the art RTPFC panels.
   c) In both above options a and b, arrange HT CT/PT feedback where ever possible so that each transformer will draw power at almost unity PF in real time.
   d) In both the options APFC Controllers / Transformer secondary panel meters / HT incomer meter should communicate to EMS / cloud and send information regarding “RKVAH Lead”, “RKVAH Lag”, KWH and billing power factor in real time and generate appropriate alarms on SMS if there are problems at any location. Such a system will prepare the plant for KVAH billing also help in optimizing present as well as KVAH billing which is expected to start since 1st April 2020.

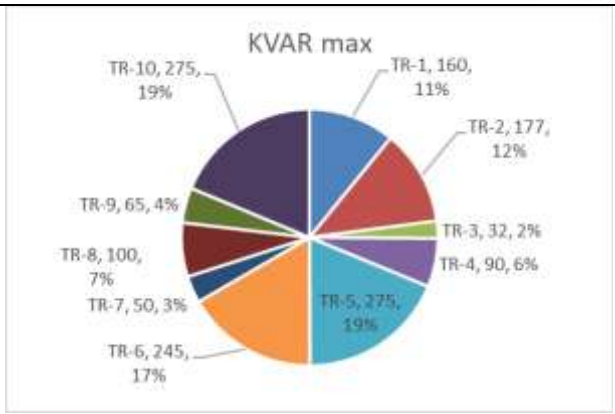
Description of Electrical infrastructure:

Globally Leading Tool Manufacturing Company is a HT consumer receiving 22KV supply from MSEDCL with a sanctioned contract demand of 7500 KVA. Further plant wise distribution is arranged through various transformer as follows. The table also gives available APFC panels on LT side of each transformer. Few Active filters are also available at site and are disconnected.

ID	Rating KVA	Location	% Z	APFC Capacity	APFC Type	Steps
TR 1	1500		5.30%	440 KVAR (Not working)	RTPFC	200 KVAR Fixed
TR 2	1500		5.10%	450 KVAR (250 working)	APFC	50x 7 + 25 x 5
TR 3	1600		6.23%	NO APFC	-	
TR 4	1500		5.04%	NO APFC	-	
TR 5	1000		5.07%	600 KVAR (370 working)	APFC	100 x 3 + 75 x 2 + 50 x 2 + 25 x 2
TR 6	1000	PE Building	5.88%	165 KVAR/525V	Detuned APFC	Steps not known Panel supplies 120 KVAR
TR 7	990	R and D		300 KVAR	APFC	50 x 2 + 25 x 6+ 12.5 x 4
TR 8	2000	Taps Building	7.91%	700 KVAR	APFC	Steps could not be studied.
TR 9	2000	Taps Building	7.14%	600 KVAR/525V (300KVAR OFF)	RTPFC	
TR 10	2000	PE Building	7.24%	600 KVAR	APFC	100 x 3+75 x 2+ 50 x 2+25 x 2 Panel supplies 346 KVAR

Average demand at present is 5660 KVA while KWH consumption per month is 2800000. At present 22 KV side billing power factor results into 2.5% incentive and requires lot of manual intervention and monitoring. KW and KVAR requirement pie chart per transformer is as follows.





The Pie charting as above is done based on the measurements carried out.

- Tr4(13%), Tr5 (10%), Tr6 (8%), TR8 (20%) , Tr10 (21%), and form 72% of KW load.
- Tr1 (11%), Tr2 (12%), Tr5 (19%), Tr6 (17%),Tr10 (19%), form 78% of total KVAR requirement.
- Thus Tr1,2,4,5,6,8,10 are major transformers which need maximum correction.

Strategy suggested for modifications in reactive power compensation:

- Transformers as above should be compensated with just adequate / fast acting RTPFC panels, so that reactive power requirement will be negligibly small in real time.

- The APFC / RTPFC panels for these transformers should have GOOD STEP RESOLUTION and should be equipped with INTELLIGENT CONTROLLERS so that just adequate steps would be selected fast and to do so panels will offer maximum number of ELECTRICAL STEPS.

  Following table shows one such example with a 12-step intelligent controller and proper step resolution.

Sr	Steps / QTY	Total Capacity KVAR
Total panel capacity 805 KVAR		
1	100 KVAR x 5	500
2	75KVAr x 3	225
3	50KVAR x 1	50
4	12.5 KVAR x 2	25
5	5 KVAr x 1	5

- Possible electrical steps: 5,12.5, 17.5, 25, 30, 50, 55, 62.5, 67.5, 75, 80, 87.5,92.5, 100, 105, 112.5 ---------- this offers required resolution for fine control. If these steps are switched using thyristors, the correction can be offered very fast.

- As far as possible use existing contactor based panels with increased step resolution and retrofit them with intelligent controllers to compensate about 75 to 80% of total KVAR requirement.

- Provide RTPFC panel with suitable fine steps for balance 20 to 25% requirement, Use HT Side current and voltage feedback whenever possible for PF correction so that transformer impedance can also be compensated.

- Fine tune after retrofitting all APFC panels to get optimized power factor at billing level.

Summary of available reactive power compensation:

Transformer	Rating (KVA)	Max KW	Max KVAR	% V_{thd}	% I_{thd}	Installed Capacitor		KVAR supplied
						Type	Rating (KVAR)	
TR-1	1500	410	32	3.7	47	Fixed	200	200
TR-2	1500	380	47	2.3	22.5	APFC	450	300
TR-3	1600	338	32	1.5	12.2	No APFC	-	-
TR-4	1500	725	96	1.3	5.9	No APFC	-	-
TR-5	1000	530	20	2.1	7	APFC	600	370
TR-6	1000	410	245	1.1	6.3	Detuned APFC	165	120
TR-7	990	148	90	1.7	38.5	APFC	300	142
TR-8	2000	1073	176.5	1.9	4.8	APFC	700	Cannot be
TR-9	2000	249	66	1.2	14.1	RTPFC	600	turned OFF
TR-10	2000	1125	77	4.3	15.9	APFC	600	346

Current harmonic compliance at 22KV interface with MSEDCL (As per IEEE 519 1992 and MSEDCL supply code 2005):

Assuming MSEDCL side fault level to be 500 MVAC (50 MVA transformer feeding 22 KV to XXXXAAA, and the maximum line current recorded as per table on next page (Derived from 24 hours recording of PQ data at 22KV) to be 143. 4 – say 145 Amps.
ISC/IL = MVAsc / Max MVA = 500 / (1.732 x 0.022 x 145) = 90.49.
As per compliance limit table (Given on next pages), the TDD (Total demand distortion) compliance limit for XXXXAAA is 12%. XXXXAAA should keep target of 8% at a lower slab.
At present calculated TDD is 4.5% - which is well within limit.

The same will remain in limit if total reactive power is compensated with just adequate detuned filters.

TDD Calculation for XXXXAAA.

Analysis of Current harmonic distortion				Recorded % VTHD at IF Max	
TimeStamp of IF Max		Current Amps	% Distortion		Volts
20-Nov-18	IFmax in B	143.4			
9:41:30 AM	Ih2	0.1434	0.1	Vh2	0
	Ih3	0.4302	0.3	Vh3	4.7
	Ih4	0.1434	0.1	Vh4	0
	Ih5	5.8794	4.1	Vh5	1.2
	Ih6	0	0	Vh6	0
	Ih7	1.434	1	Vh7	1.6
	Ih8	0	0	Vh8	0.1
	Ih9	0	0	Vh9	0.5
	Ih10	0	0	Vh10	0
	Ih11	0.4302	0.3	Vh11	0.8
	Ih12	0	0	Vh12	0
	Ih13	0.1434	0.1	Vh13	0.7
	Ih14	0	0	Vh14	0
	Ih15	0	0	Vh15	0.3
	Ih16	0	0	Vh16	0
	Ih17	0.1434	0.1	Vh17	0.3
	Ih18	0	0	Vh18	0.1
	Ih19	0	0	Vh19	0.2
	Ih20	0	0	Vh20	0
	Ih21	0	0	Vh21	0.2
	Ih22	0	0	Vh22	0
	Ih23	0.1434	0.1	Vh23	0.2
	Ih24	0	0	Vh24	0
	Ih25	0	0	Vh25	0.2
	Ih26	0	0	Vh26	0
	Ih27	0	0	Vh27	0.1
	Ih28	0	0	Vh28	0
	Ih29	0	0	Vh29	0
	Ih30	0	0	Vh30	0
	Ih31	0	0	Vh31	0.1
	Ih32	0	0	Vh32	0
	Ih33	0	0	Vh33	0.1
	Ih34	0	0	Vh34	0
	Ih35	0	0	Vh35	0.2
	Ih36	0	0	Vh36	0
	Ih37	0	0	Vh37	0.1
	Ih38	0	0	Vh38	0
	Ih39	0	0	Vh39	0
	Ih40	0	0	Vh40	0
	Ih41	0	0	Vh41	0
	Ih42	0	0	Vh42	0
	Ih43	0	0	Vh43	0
	Ih44	0	0	Vh44	0
	Ih45	0	0	Vh45	0
	Ih46	0	0	Vh46	0
	Ih47	0	0	Vh47	0
	Ih48	0	0	Vh48	0
	Ih49	0	0	Vh49	0
	Ih50	0	0	Vh50	0
	Sum of sq(A)	37.09666224			
	Sqrt(A)	6.090702935			
	TDD	4.247352116			

Table 2—Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
<20[c]	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

[a]Even harmonics are limited to 25% of the odd harmonic limits above.

[b]Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c]All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L

where

I_{sc} = maximum short-circuit current at PCC

I_L = maximum demand load current (fundamental frequency component) at the PCC under normal load operating conditions

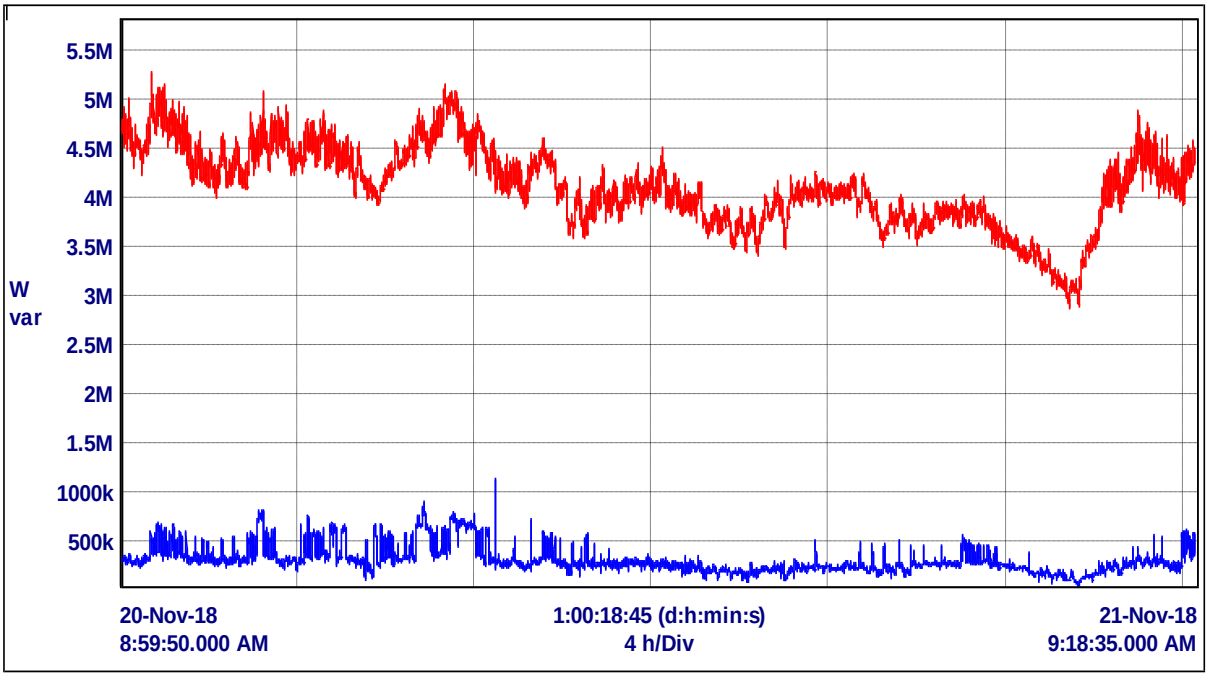
Voltage Distortion Limits

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.

22 KV Main Incomer:

1. The maximum demand for XXXXAAA recorded by MSEDCL is **5696KVA** in the month of October 2018.
2. The maximum recorded load of the facility is **5100KW** and when APFC is ON, the average reactive power requirement recorded is 500KVAR .



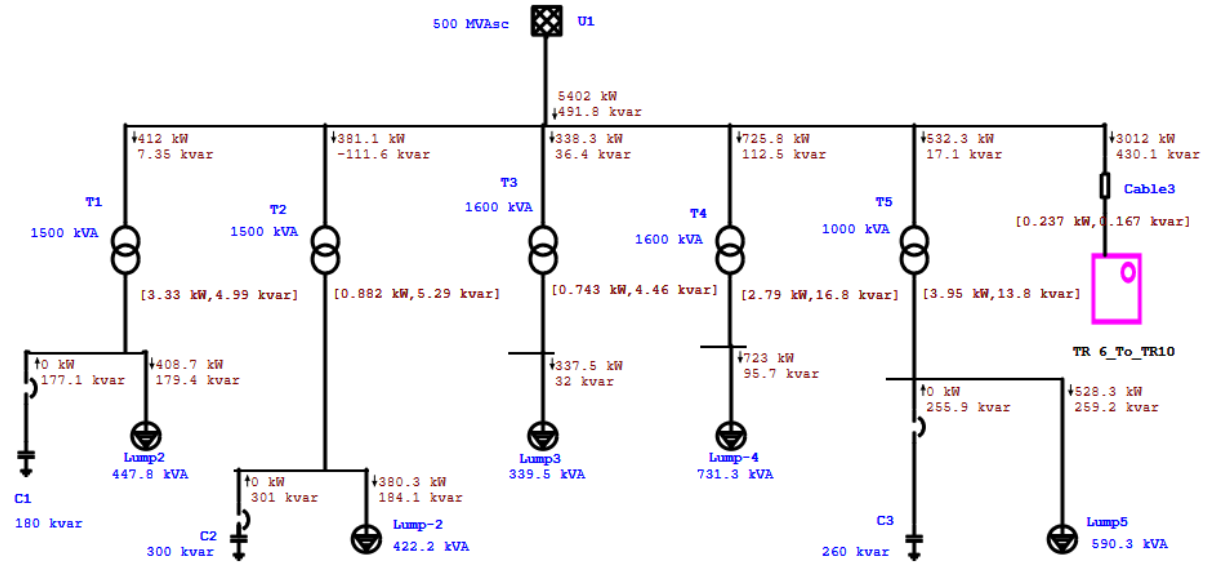
As per recent MSEDCL policy, Power factor is now calculated as per new formula and related incentive will be available only if **RKVAH Lag >/= RVAH Lead**. The new formula is as follows.

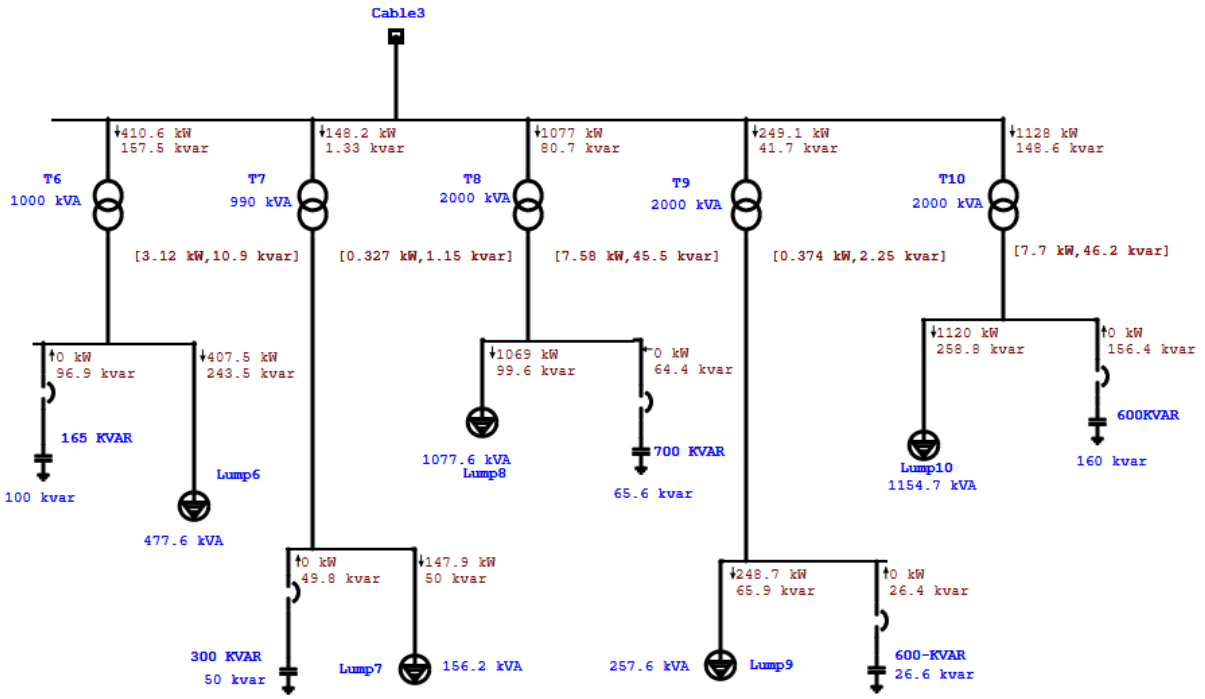
$$PF = \frac{KWH}{\sqrt{(KWH)^2 + (RKVAH\ Lag + RKVAH\ Lead)^2}}$$

This means in view of achieving unity PF, RKVAH Lag and RKVAH Lead figures should be as minimum as possible at the end of billing cycle. This calls for close control over both these values and the same is possible only through sensitive and fast acting APFC panels with some intelligent control. This type of compensation will avoid involvement of manpower for close monitoring.

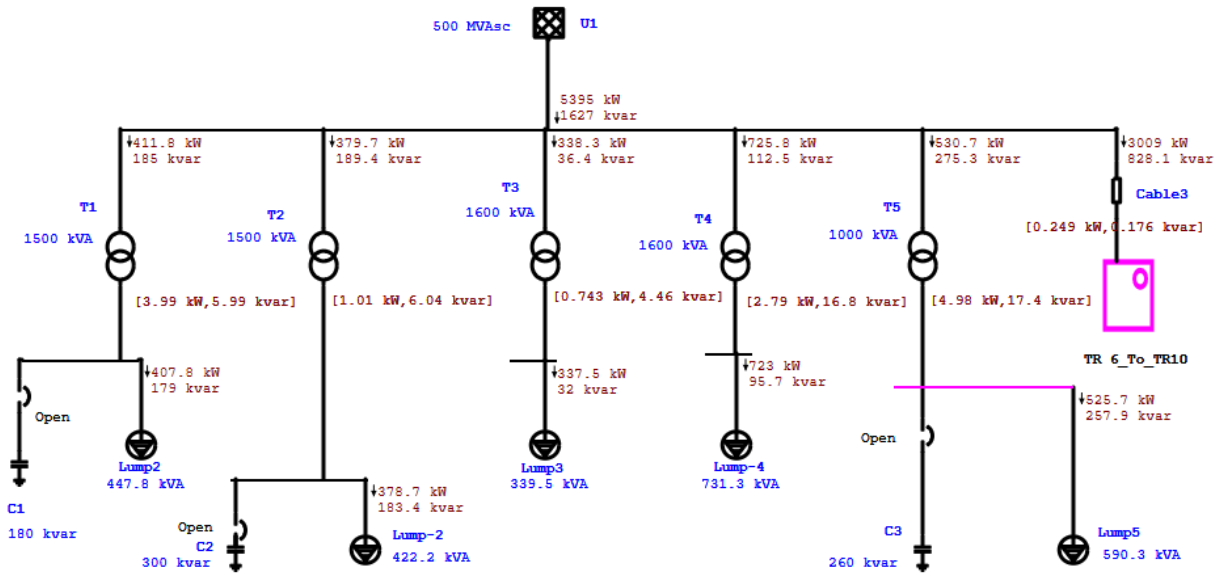
The average value of such 3.5% incentive would be around Rs.750000 per month for XXXXAAA. Further 1% incentive would be around Rs. 225000 per month. There is a possibility of loosing this 1% if close control is not monitored. This type of sensitive reactive power control will avoid harmonic resonance at transformer secondaries and will also help in minimizing electricity bills when MSEDCL starts KVAH billing.

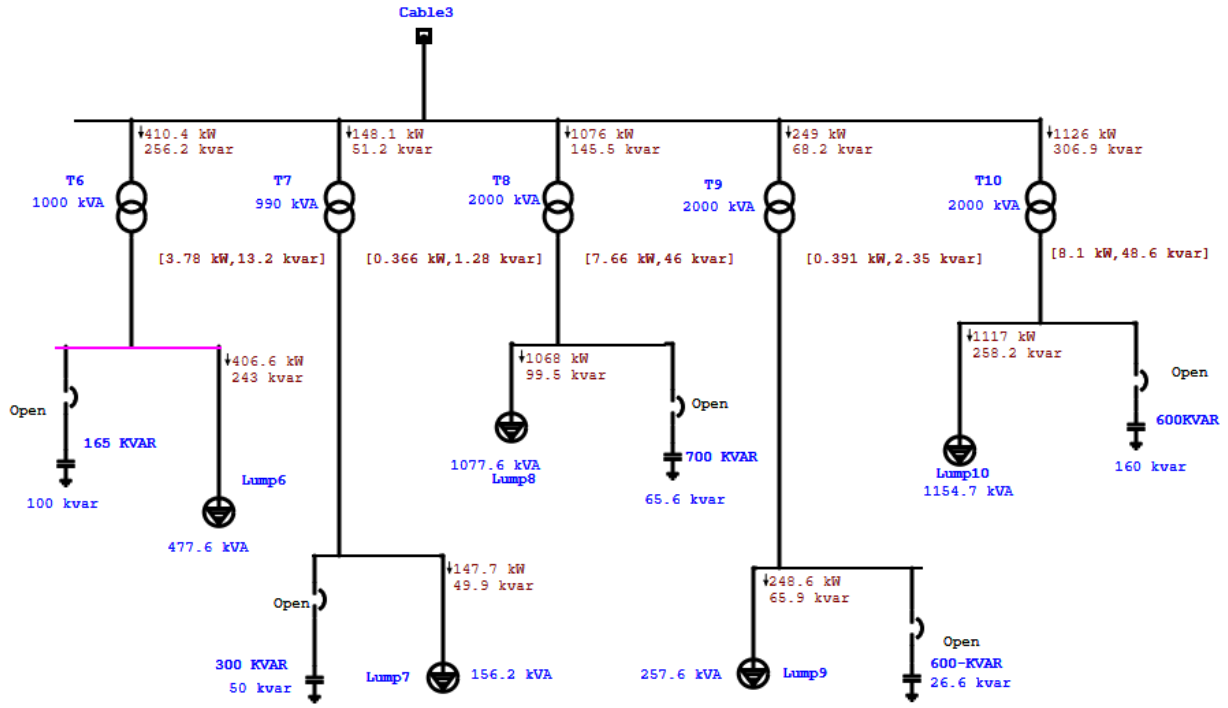
ETAP Simulation with existing normal running reactive power correction. (Adjusted manually by maintenance team frequently)





ETAP Simulation with existing normal running reactive power correction. (With all capacitors OFF)





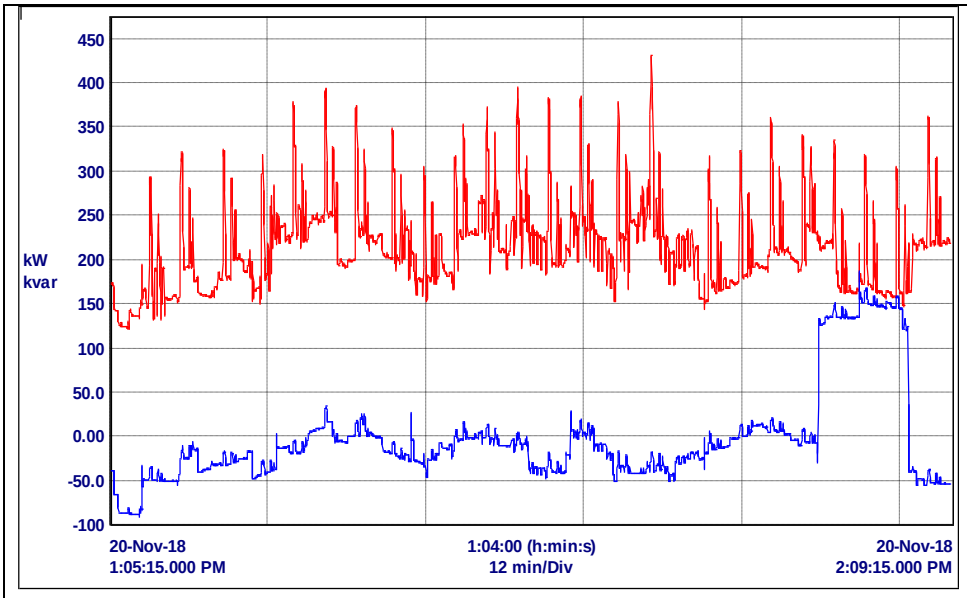
Load Flow through transformers - Present situation							
ID	Type	Voltge ratio	Tr KVA	kW Flow	kvar Flow	%Loading	kW Losses
T1	Transf. 2W	22 / 0.433 kV	1500 kVA	412	7.35	27.5	3.33
T2	Transf. 2W	22 / 0.433 kV	1500 kVA	380.3	-116.9	26.5	0.882
T3	Transf. 2W	22 / 0.433 kV	1600 kVA	338.3	36.42	21.3	0.743
T4	Transf. 2W	22 / 0.433 kV	1600 kVA	725.8	112.5	45.9	2.79
T5	Transf. 2W	22 / 0.433 kV	1000 kVA	532.3	17.11	53.3	3.95
T6	Transf. 2W	22 / 0.433 kV	1000 kVA	410.6	157.5	44	3.12
T7	Transf. 2W	22 / 0.433 kV	990 kVA	148.2	1.33	15	0.327
T8	Transf. 2W	22 / 0.433 kV	2000 kVA	1076.6	80.73	54	7.58
T9	Transf. 2W	22 / 0.433 kV	2000 kVA	249.1	41.73	12.6	0.374
T10	Transf. 2W	22 / 0.433 kV	2000 kVA	1127.6	148.6	56.9	7.7
				5400.8	**486.37**		**30.796**

Load Flow through transformers - All Capacitors OFF							
ID	Type	Rating 1	Rating 2	kW Flow	kvar Flow	% Loading	kW Losses
T1	Transf. 2W	22 / 0.433 kV	1500 kVA	411.8	185	30.1	3.99
T2	Transf. 2W	22 / 0.433 kV	1500 kVA	379.7	189.4	28.3	1.01
T3	Transf. 2W	22 / 0.433 kV	1600 kVA	338.3	36.42	21.3	0.743
T4	Transf. 2W	22 / 0.433 kV	1600 kVA	725.8	112.5	45.9	2.79
T5	Transf. 2W	22 / 0.433 kV	1000 kVA	530.7	275.3	59.8	4.98
T6	Transf. 2W	22 / 0.433 kV	1000 kVA	410.4	256.2	48.4	3.78
T7	Transf. 2W	22 / 0.433 kV	990 kVA	148.1	51.18	15.8	0.366
T8	Transf. 2W	22 / 0.433 kV	2000 kVA	1075.6	145.5	54.3	7.66
T9	Transf. 2W	22 / 0.433 kV	2000 kVA	249	68.24	12.9	0.391
T10	Transf. 2W	22 / 0.433 kV	2000 kVA	1125.5	306.9	58.3	8.1
				5394.9	**1626.64**		**33.81**

ID	Rating KVA	% Z	APFC Capacity	APFC Type	Retrofit existing and ADD New RTPFC KVAR @ 525V	Replace existing and ADD New RTPFC KVAR @ 525V
T1	1500	5.30%	440 KVAR	RTPFC	325	325
T2	1500	5.10%	450 KVAR	APFC	150	325
T3	1600	6.23%	NO APFC	-	150	150
T4	1500	5.04%	NO APFC	-	200	200
T5	1000	5.07%	600 KVAR	APFC	100	450
T6	1000	5.88%	165 KVAR	Detuned APFC	300	450
T7	990		300 KVAR	APFC	150	150
T8	2000	7.91%	700 KVAR	APFC	100	250
T9	2000	7.14%	600 KVAR	RTPFC	100	150

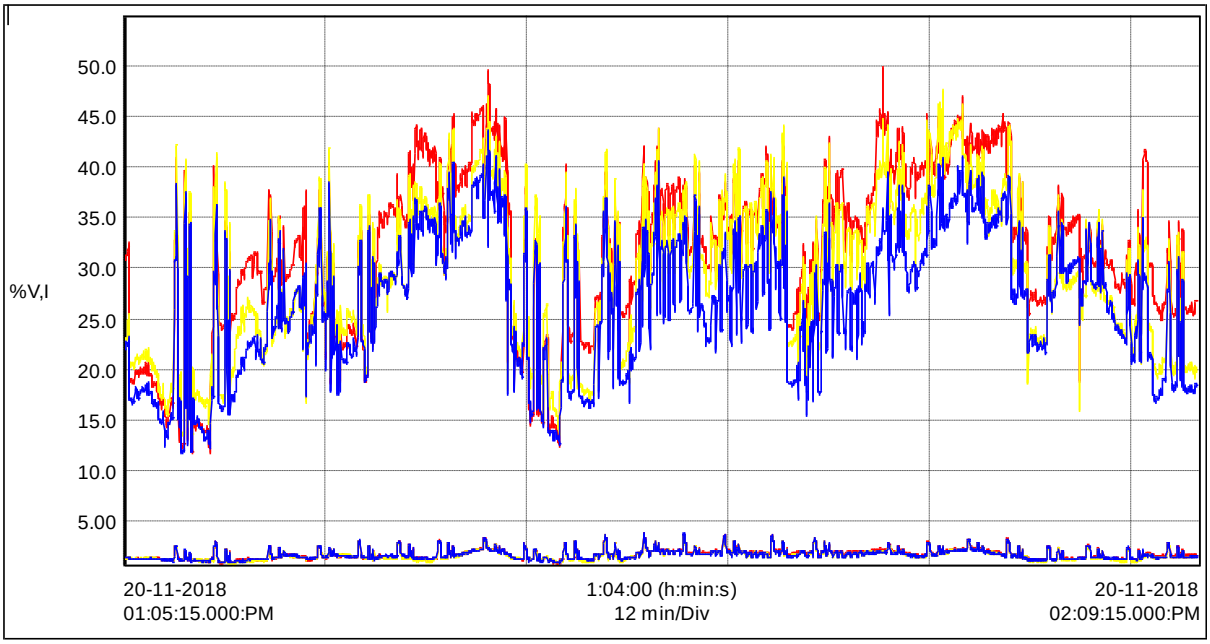
T10	2000	7.24%	600 KVAR	APFC	250	500
				Total	1825	2950

Transformer -1:

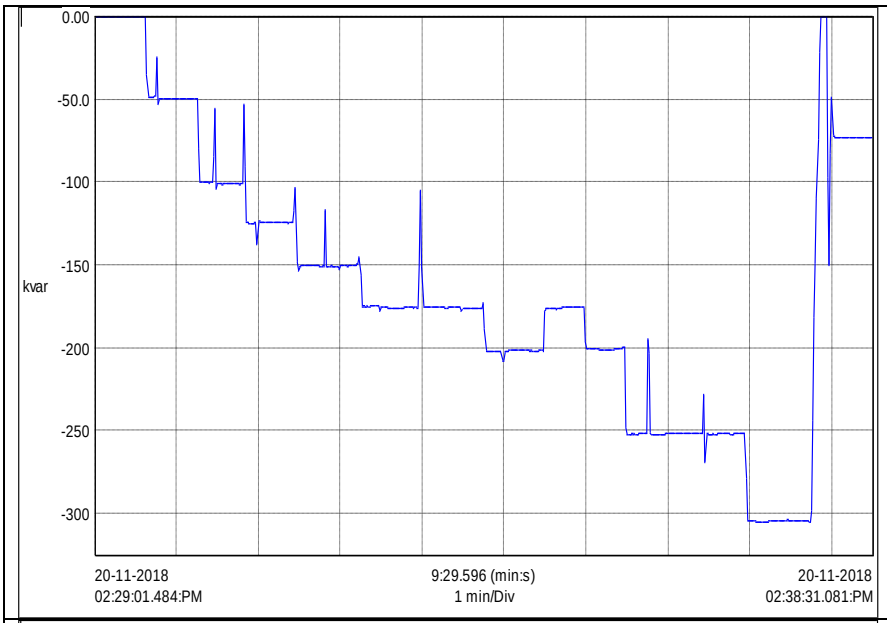


There is fixed 200 KVAR capacitor installed with 440 KVAR RTPFC which is in out of service condition

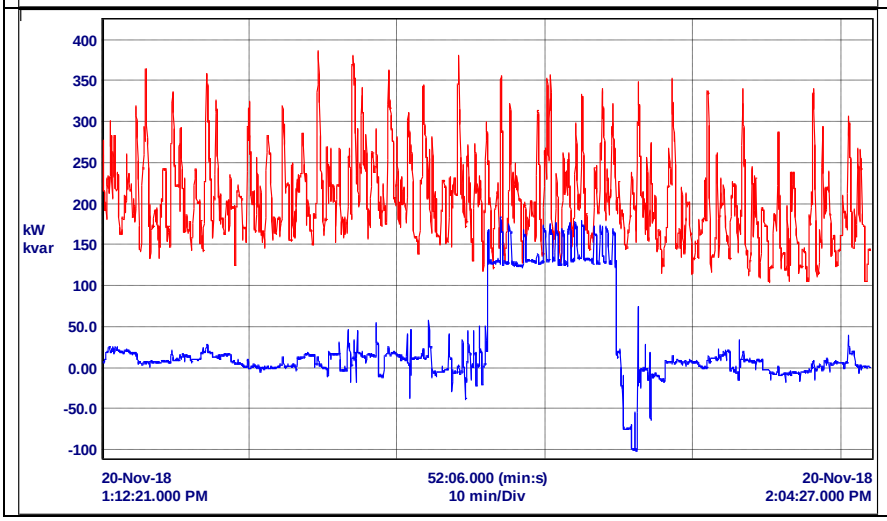
Normally entire 180 KVAR requirements is compensated by correction.



Transformer 2

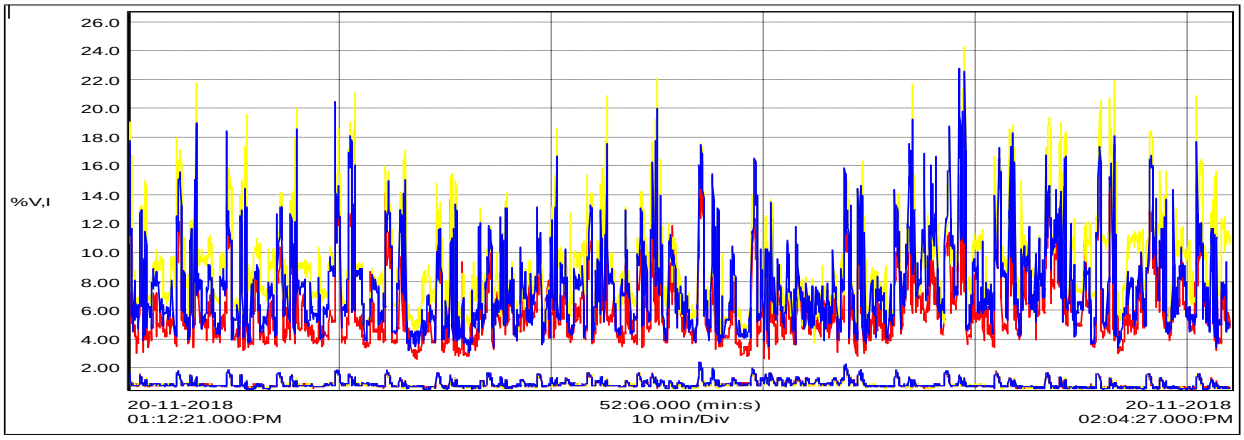


Transformer 2		
APFC Step	Rating (KVAR)	Available KVAR
1	50	50
2	50	50
3	25	25
4	25	25
5	25	25
6	25	-
7	25	25
8	50	50
9	50	50
10	50	-
11	50	-
12	50	-
Total		250

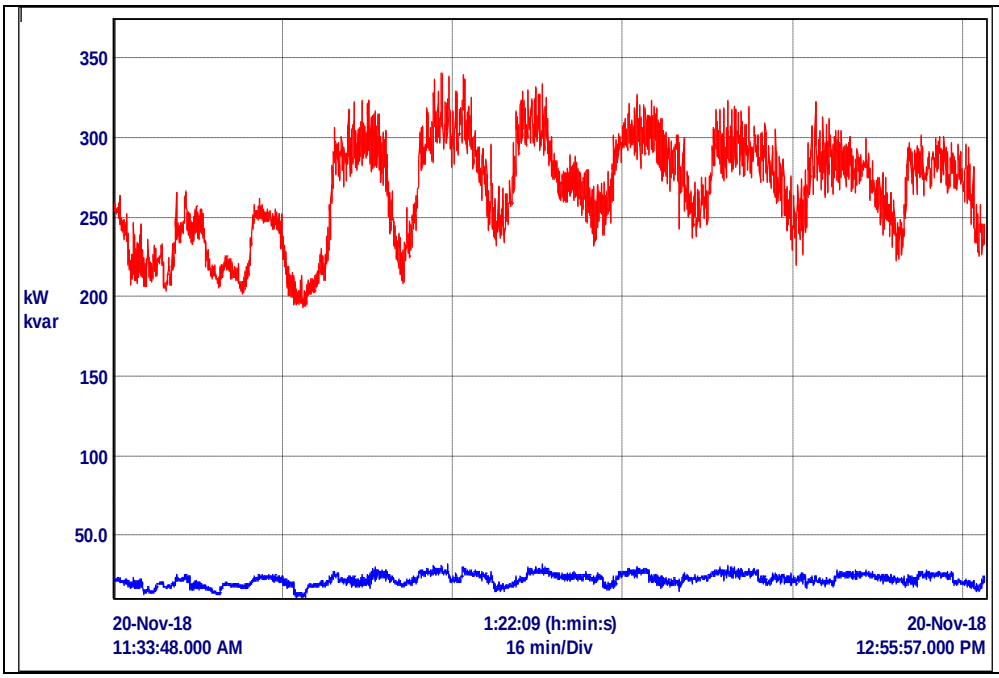


The APFC Panel offers 250 KVAR.

Normally entire 200 KVAR requirement is compensated by above panel.



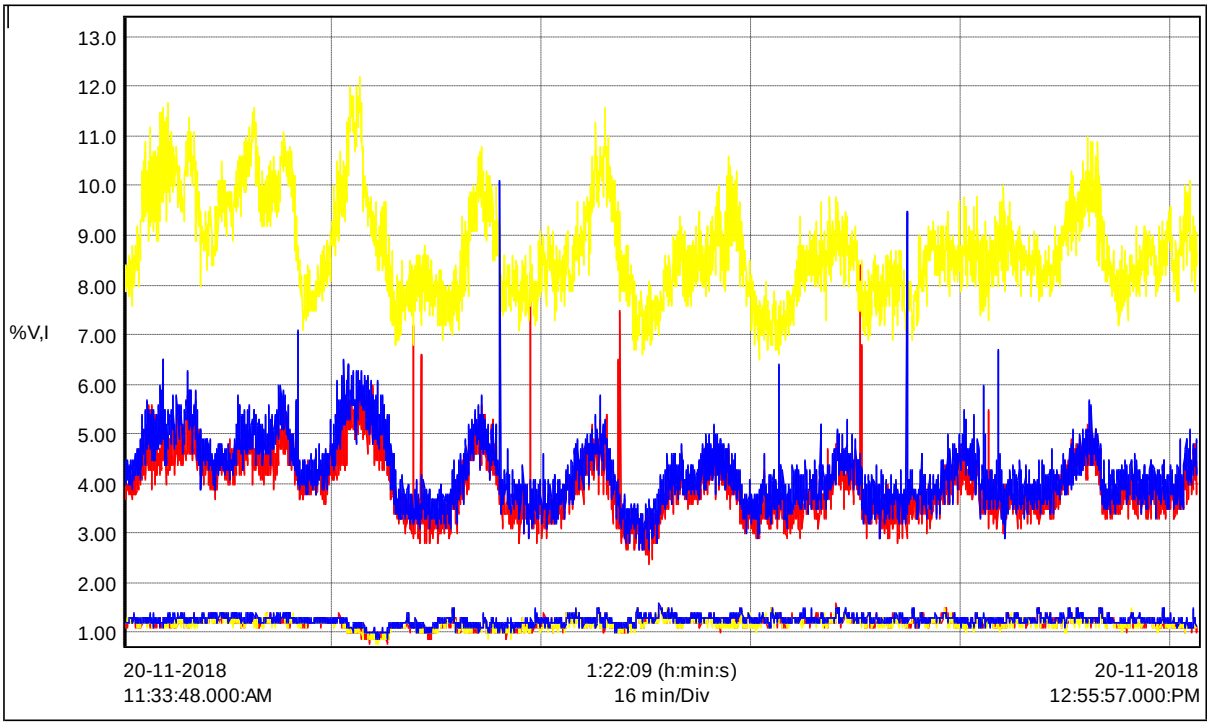
Transformer 3



APFC panel not provided.

The maximum KVAR requirement recorded is 35 KVAR.

The Current harmonic distortion observed is 12%.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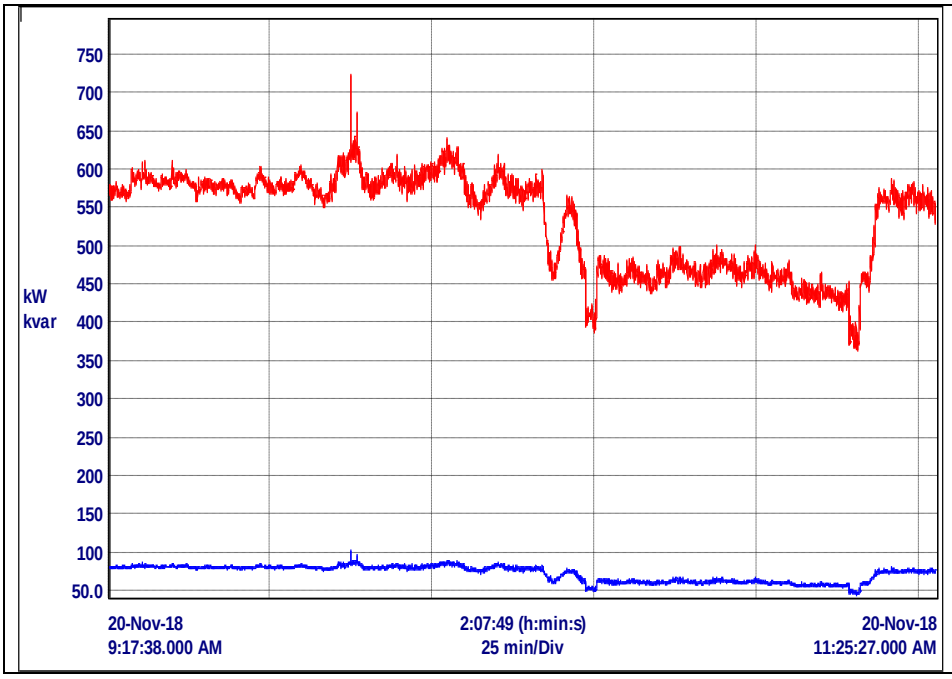
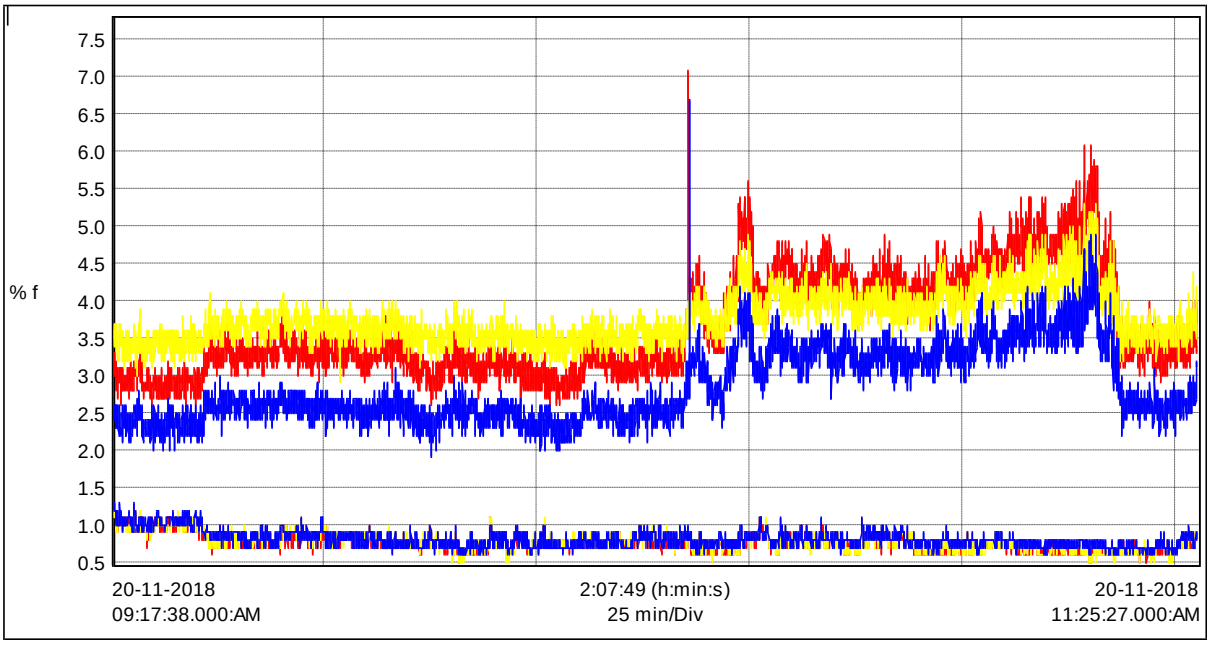
Transformer 4



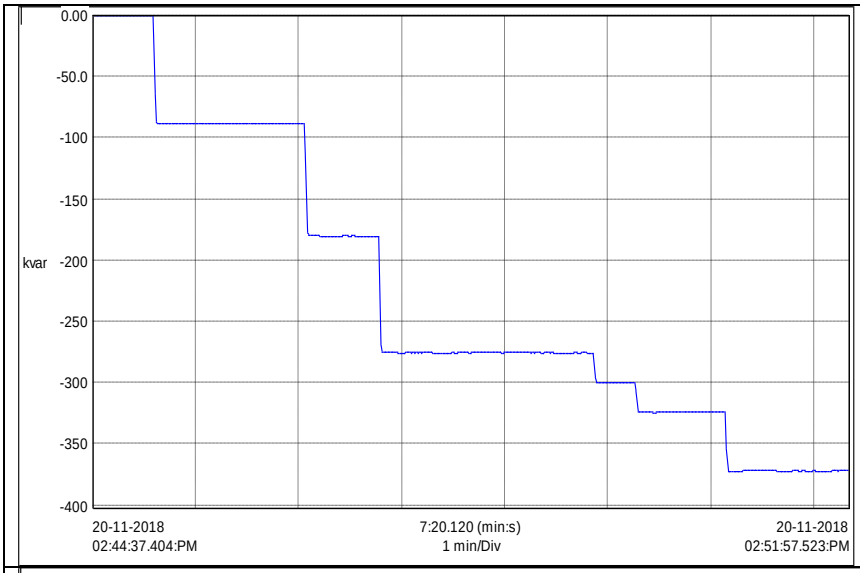
APFC Panel not provided

The maximum KVAR requirement observed at
TR-4 is 96 KVAR.

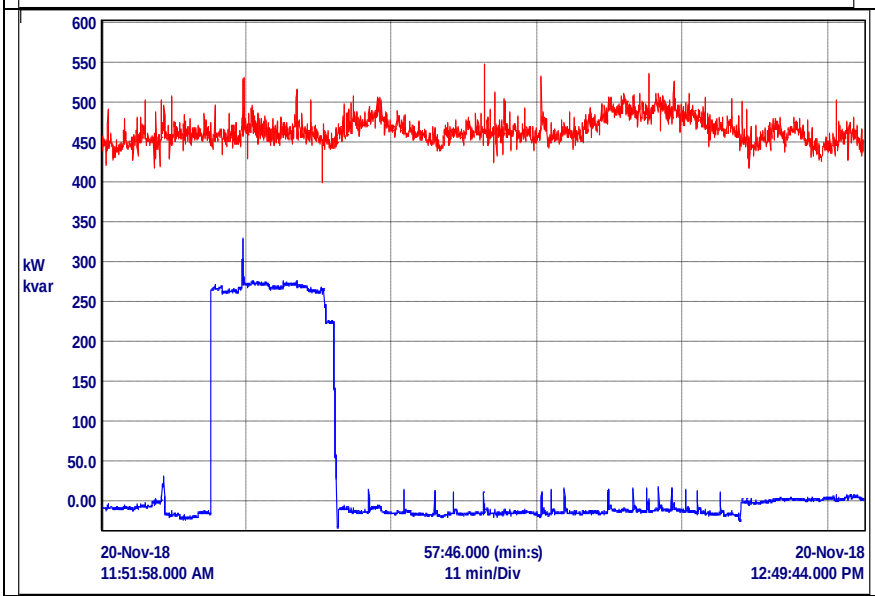
% VTHD = 1.3%
%ITHD = 5.9%



Transformer -5



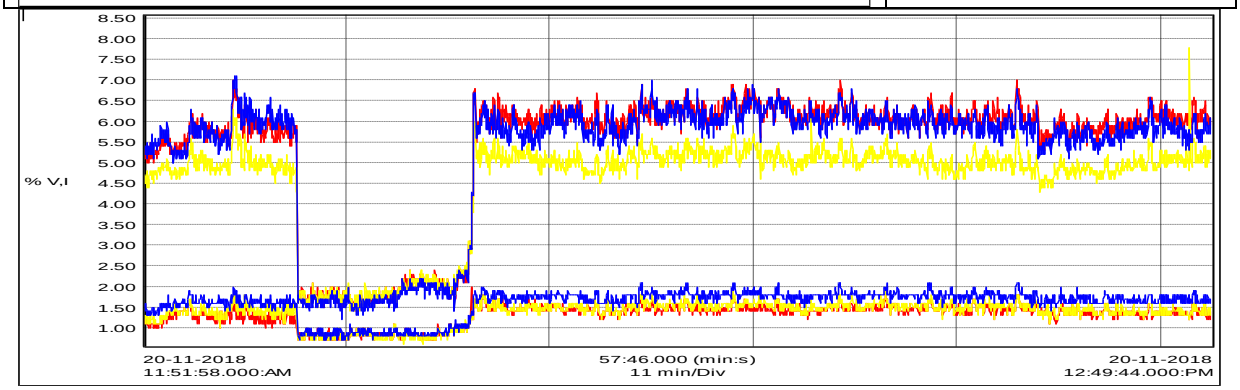
Transformer 5		
APFC Step	Rating (KVAR)	KVAR
1	100	88
2	100	93
3	100	96
4	75	-
5	75	-
6	25	23
7	25	24
8	50	46
9	50 (OFF)	-
Total		370



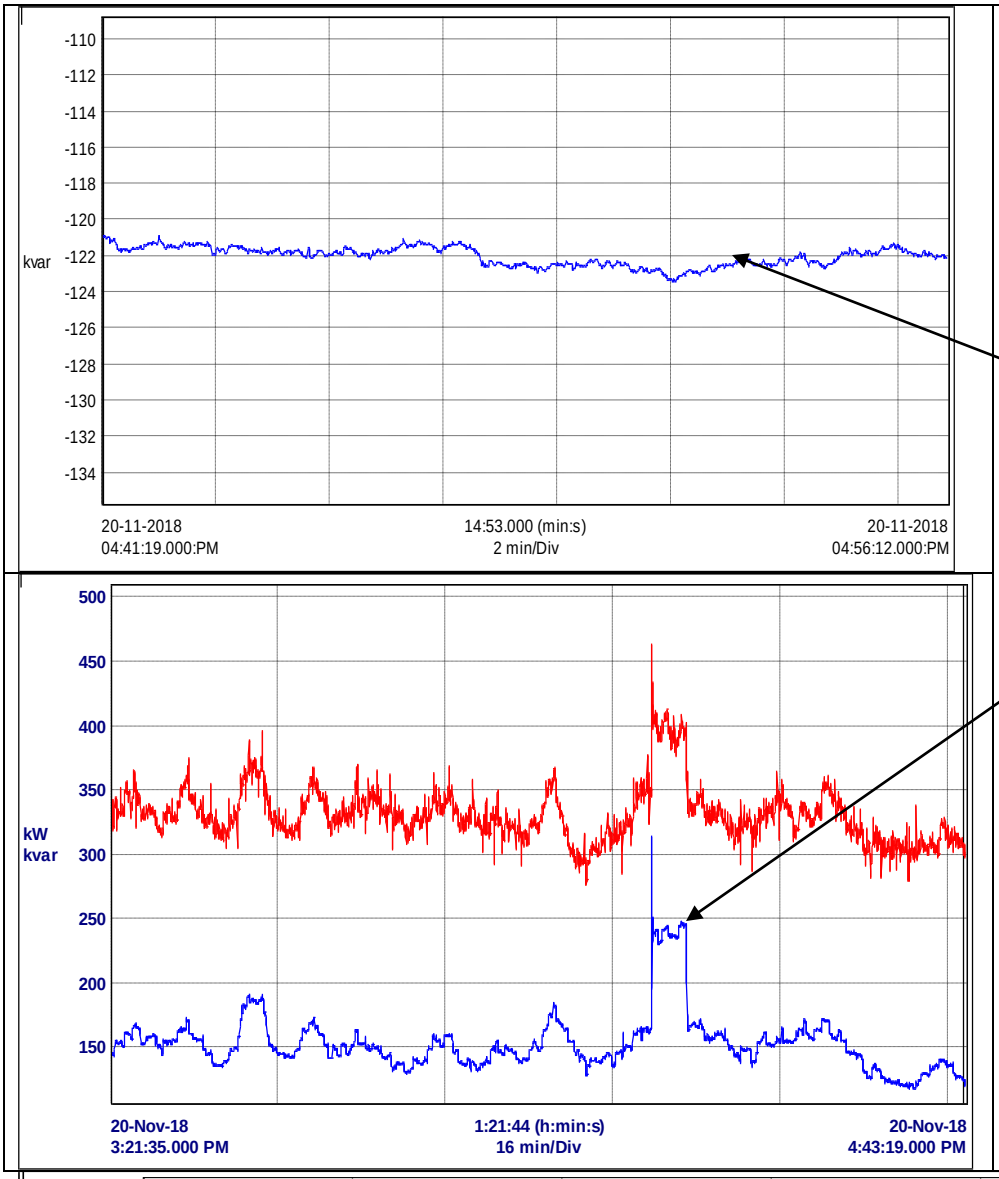
The APFC Panel offers 370 KVAR.

Normally entire 270KVAR requirement is compensated by above panel.(100KVAR Spare)

% VTHD = 2%
%ITHD = 7%
Resonance is present.



Transformer – 6:



This transformer has 165KVAR APFC panel

It is observed that the reactive power supplied by 165KVAR detuned APFC panel is only **120KVAR**

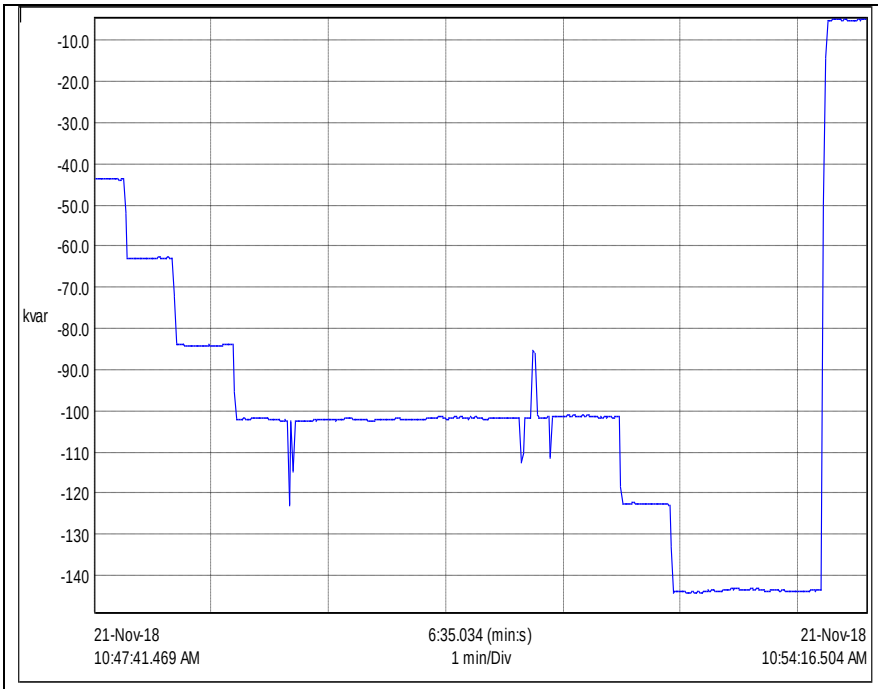
The actual KVAR requirement is 250KVAR

Still there is a requirement of around **150KVAR** more

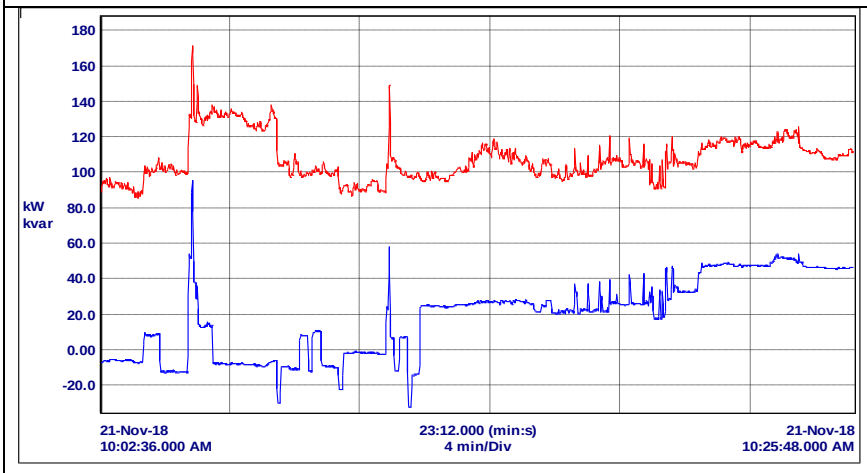
Existing panel is not providing full Reactive power compensation.

%VTHD = 1%
% ITHD = 6%

Transformer 7:



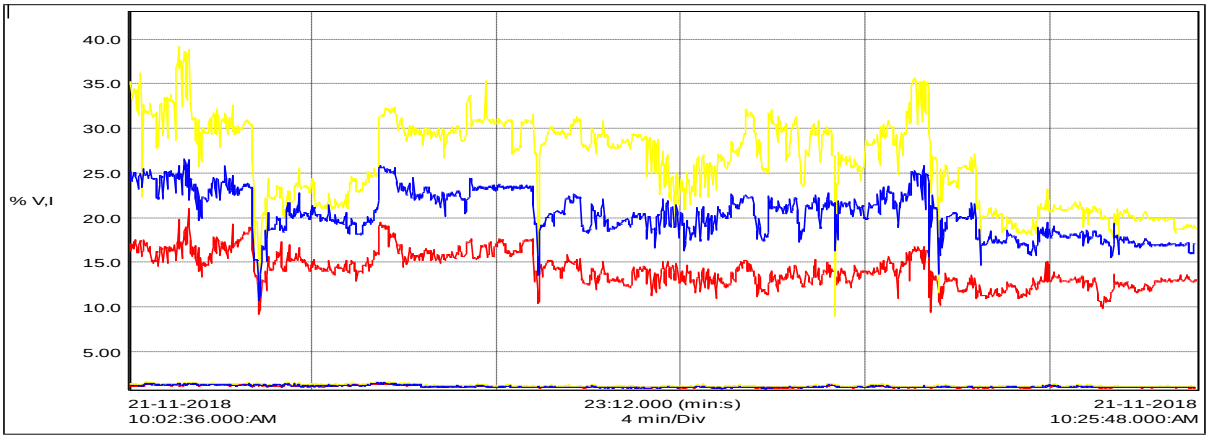
Transformer 7		
APFC Step	Rating (KVAR)	KVAR
1	25	19
2	25	22
3	25	19
4	25	21
5	50	-
6	50 (OFF)	-
7	12.5 (OFF)	-
8	12.5 (OFF)	-
9	12.5	-
10	12.5	40
11	25	
12	25	21
Total		142



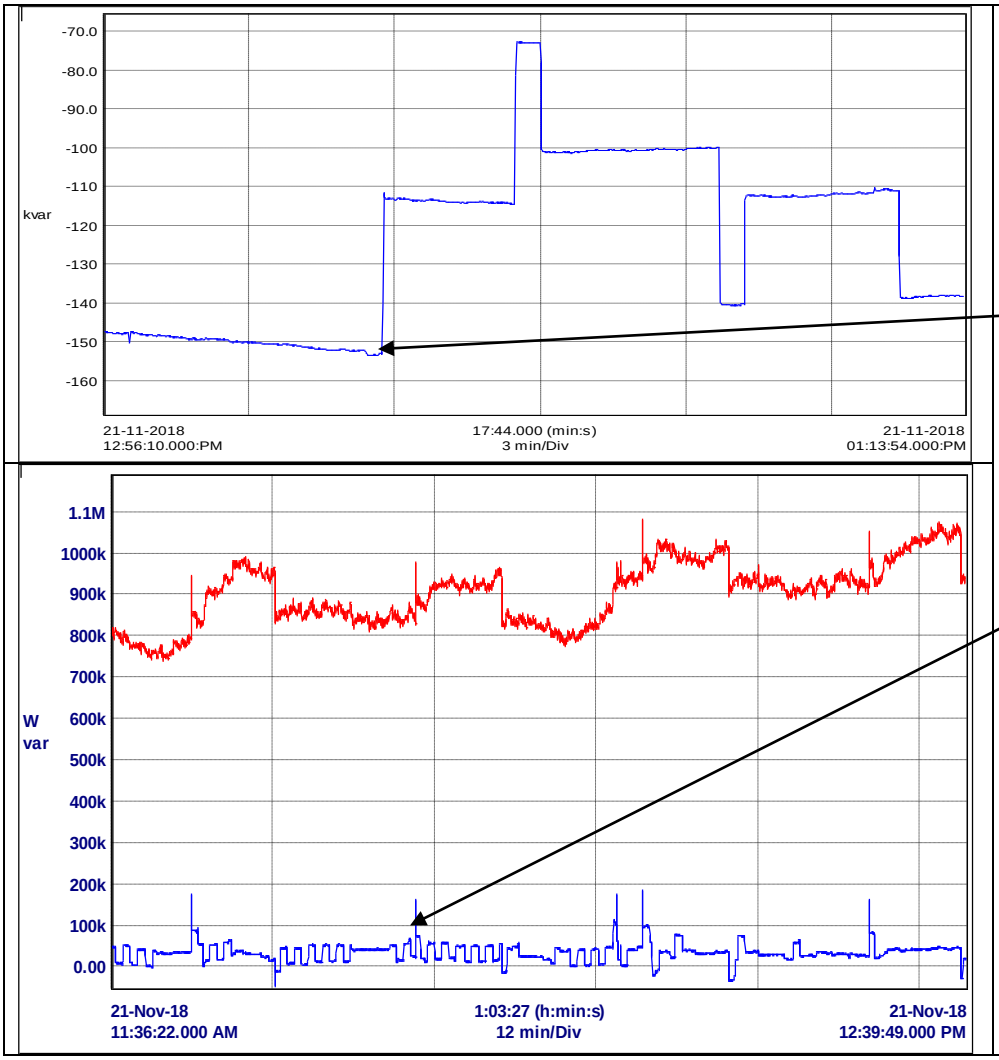
The APFC Panel of 300 KVAR offers 150 KVAR.

Normally entire KVAR requirement is compensated by above panel.

% VTHD = 1.7%
%ITHD = 35 %


% V,I
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.00
21-11-2018
10:02:36.000:AM
23:12.000 (min:s)
4 min/Div
21-11-2018
10:25:48.000:AM

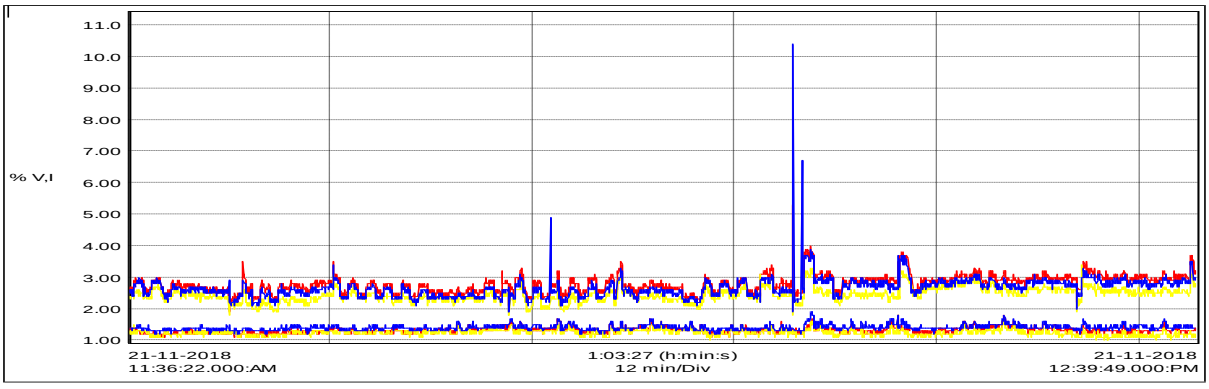
Transformer 8:



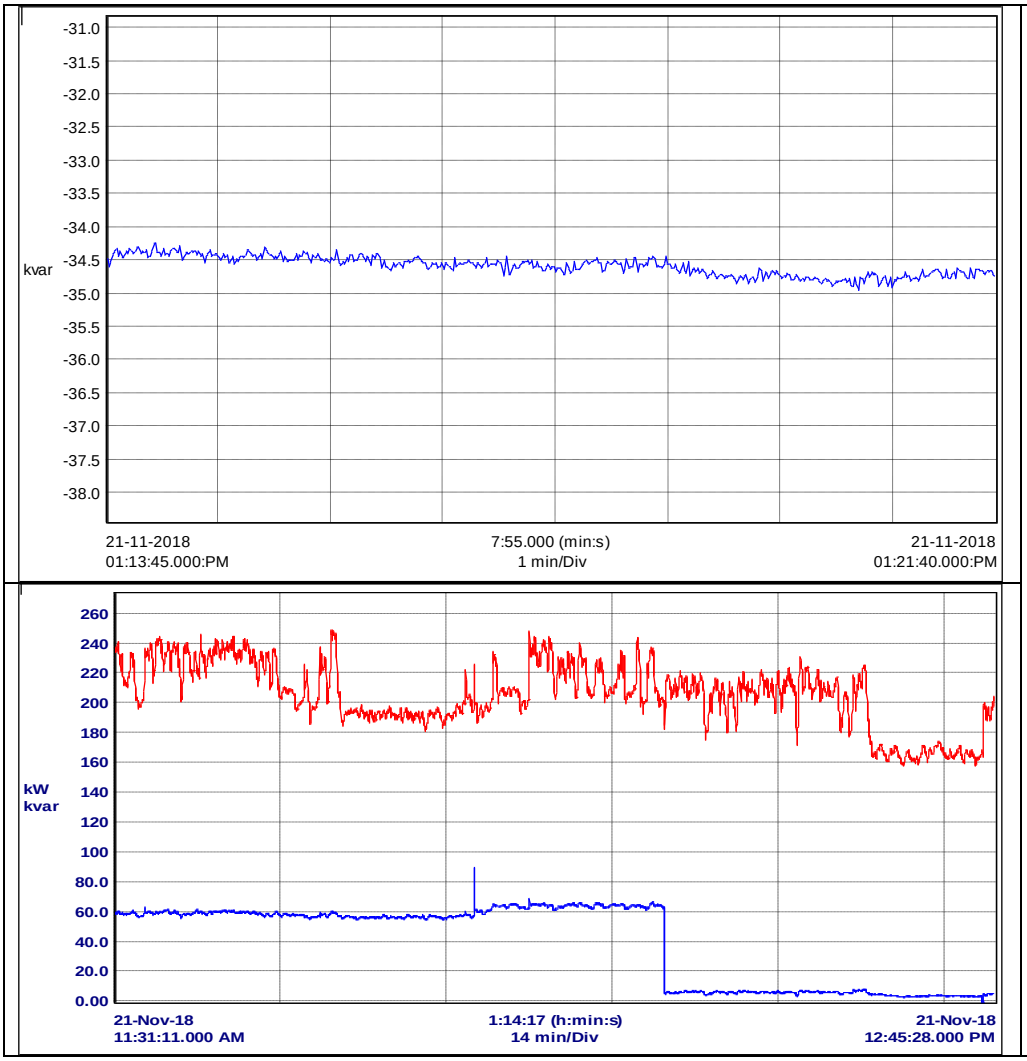
It IS observed that the reactive power supplied by 165KVAR detuned APFC panel is only **150KVAR** in "Automatic mode"

The maximum KVAR requirement recorded is **100KVAR**

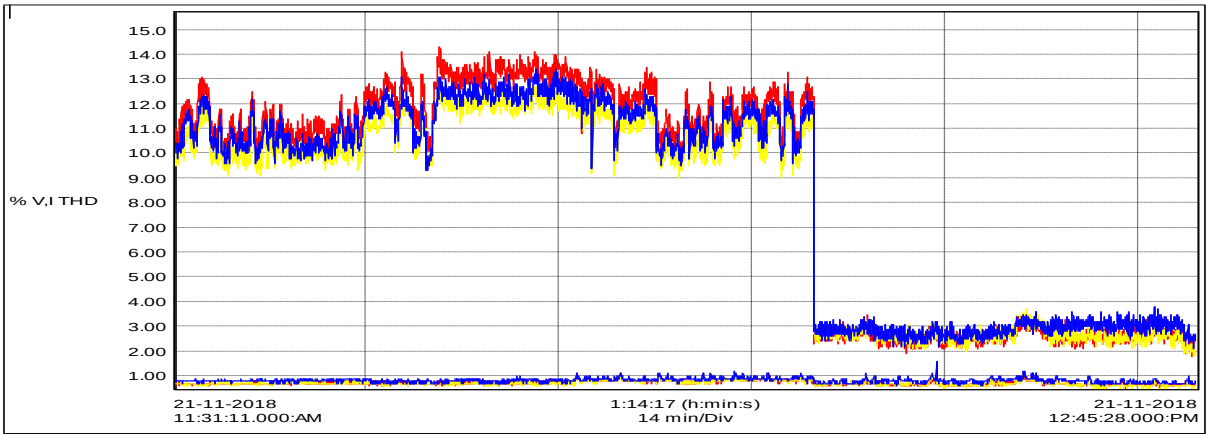
%VTHD = 1.9%
%ITHD = 4%



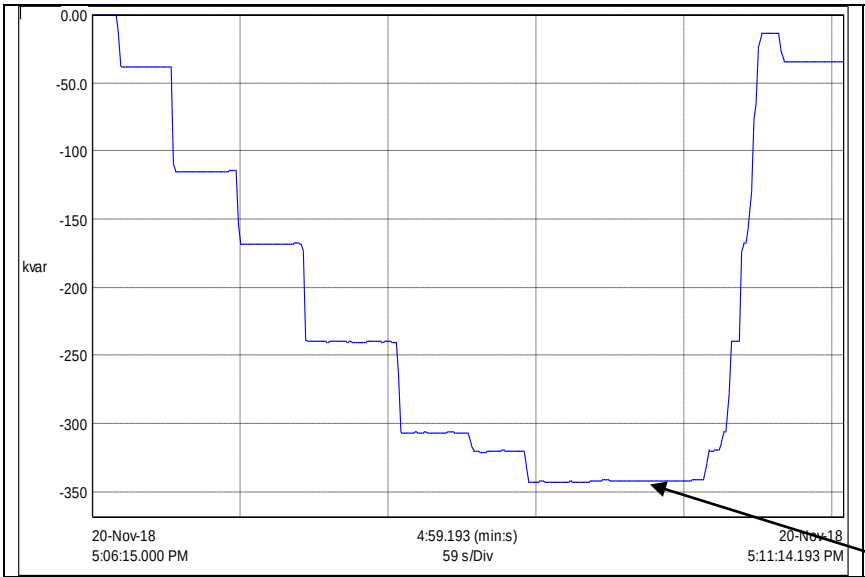
Transformer – 9



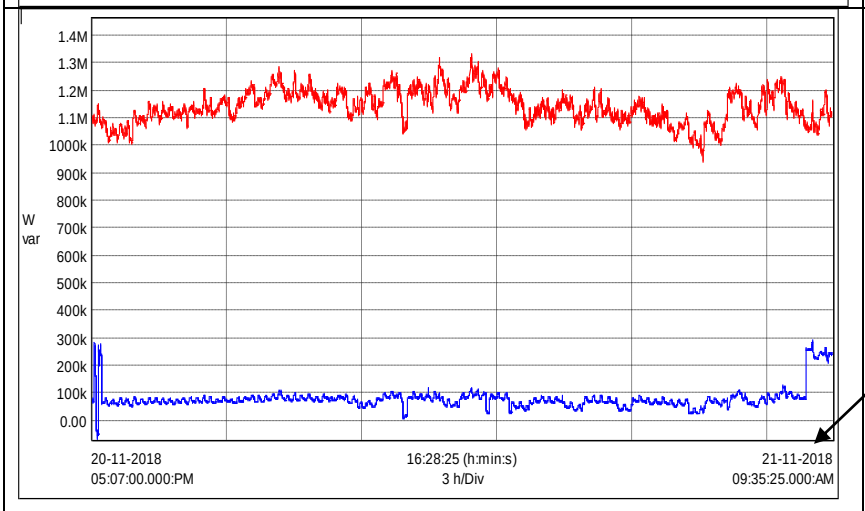
%VTHD= 0.8%
%ITHD = 8.4



Transformer 10



Transformer 10		
Step	Rating (KVAR)	KVAR
1	100	76
2	100	73
3	100	69
4	75	53
5	75	39
6	50 (OFF)	-
7	50 (OFF)	-
8	25	12
9	25	24
Total		346

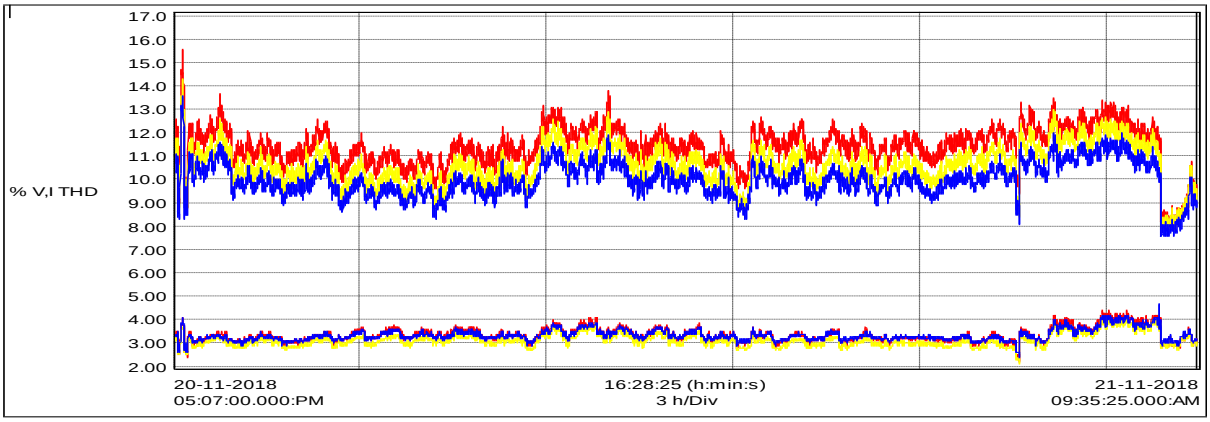


The APFC Panel of 600 KVAR offers 346 KVAR.

The load requirement is 260 KVAR. The panel corrects only 160 out of this.

The APFC function is not operating properly.

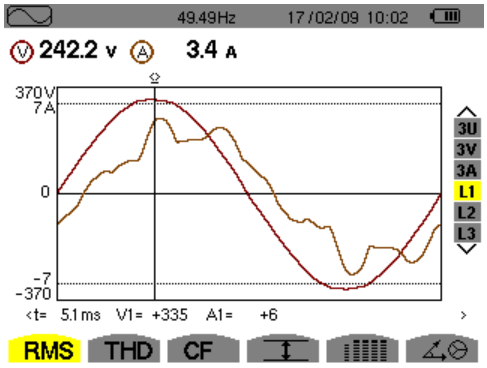
% VTHD = 4%
%ITHD = 13%



A note on Power factor, current and voltage harmonic distortion

1. Power factor is characteristics of load and varies from -1 - 0 +1. Resistive loads like bulbs, heaters etc take current at unity power factor (i.e.1).Other loads like electric motors, computers, UPS systems, tube lights etc take current at power factors which are less than 1.
2. Electrical Power = $V \times I \times Cos\phi(PowerFactor)$
3. One can take 100 watts of electrical power at 100 volts by taking 1 Amp current, if power factor is 1, while if power factor is 0.5, then the current required will be 2 Amps for delivering same power of 100 watts.
4. One unit of electricity = 1Kilowatt x 1 Hr. If we use 1 KW for 1 hour then the utility meter advances by 1 unit.
5. It is clear from above that if power factor is low, utility company (Like MSEDCL) has to supply us more current while delivering same power but gets same revenue from us.
6. Infrastructure investment done by utility company is more for delivering more current, so for these commercial reasons, they insist on better power factor and offer incentives.

Non linear loads like computer power supplies, VFDs, UPS systems, electrical arc furnaces, Plating rectifiers, and Battery chargers take non sinusoidal current while sinusoidal voltage is applied to them. This is shown in waveforms bellow.



Mathematically it can be proved that these non sinusoidal currents are made up of sinusoidal currents having frequencies which are integral multiples of fundamental frequency i.e. 50 Hz. These (3^{rd} =150Hz, 5^{th} = 250Hz, 7^{th} = 350Hz etc) currents cause overheating of transformers, cables, switchgears etc due to

increased losses requiring their derating for normal operation. Excessive current harmonics cause voltage harmonics distorting the voltage waveform. This can further cause harmonic currents in linear loads. This causes increased losses, vibrations in electrical motors, malfunctioning of electronic controls due to generated electromagnetic noise, Unwanted erratic tripping of circuit breakers due to overheating etc.

In electrical distribution networks, having presence of harmonic currents, if only capacitors are added to improve system power factor, there is a possibility of amplification of these harmonics due to resonance created by transformer inductance and these capacitors. This should be avoided by using detuned L – C filters or harmonic filters in place of capacitors. Utility companies also make it mandatory for consumer to control harmonics generated by his load as it improves their revenue potential by avoiding derating. Active filters also could be another solution to suppress harmonics. These are specially designed power electronic circuits, which take anti phase current from source which is equal and opposite of non linear component of load current. These filters are very costly and as such are not very popular as yet.