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Reduction of Harmonis by Detuning of Capacitors

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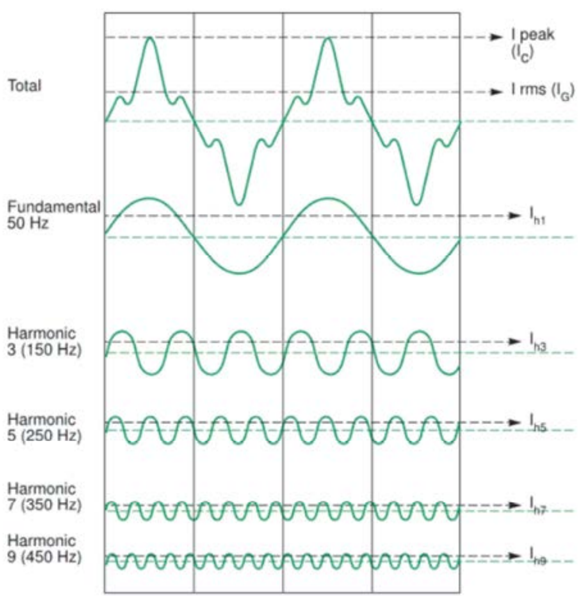
Abstract: The existing real time harmonics level at various types of loads were studied, Characterized, Harmonics level of a new type load is is measured on real time, analyzed and suggestions furnished for reduction of the Harmonics current. The method of Detuning of Capacitors is proposed for reducing the harmonics level.

Key words: Index Terms · Harmonics · Detuned capacitors · Reactors

INTRODUCTION

Harmonics are unwanted currents that are multiples of the fundamental line frequency (50 or 60 Hz). Harmonic currents can overload wiring and transformers, creating heat and, in extreme cases, fire.



Nonlinear loads cause harmonics to flow in the power lines. In information technology power systems, many desktop personal computers present a nonlinear load to the AC supply. This is because they have a power supply design known as a "capacitor input switch mode power supply.

Ideally, voltage and current waveforms are perfect sinusoids.

However, due to the increased popularity of electronic and other non-linear loads, these waveforms get distorted. This deviation from a perfect sine wave can be represented by harmonics-sinusoidal components having a frequency that is an integral multiple of the fundamental frequency. Thus, a pure voltage or current sine wave has no distortion and no harmonics and a non-sinusoidal wave has distortion and harmonics.

Harmonics are created from equipment's containing electronics that control other apparatus, e.g. variable speed drives, soft starters, static compensators, rectifiers and arc furnaces, etc.

Standards of Harmonics: The Central Electricity Authority of India has sought compliance of the IEE standards of harmonics as follows:

- Total Voltage Harmonic Distortion should not exceed: 5% (V-THD)
- Any individual Voltage Harmonic Distortion Should not exceed: 3% (V-Ind)
- Total Current Harmonic Distortion should not exceed: 8% (I-THD)

Existing System: The real time harmonics level existing in various nature of loads such as Corporate Offices, Commercial Shops, Textile industries, Foundries/Castings, Printing press, Hotels, Hospitals and Theatres were studied. It was noticed that the %THD in Textile industries, Hospitals and theatres are within the standards. Whereas, the %THD existing in Corporate offices, Commercial shops, Foundries, Printing presses

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and Hotels are high than the standards. Thus loads such as lavish lightings and Personal computers increase the %THD level in utilization. It was proposed to study the existing harmonics level in real time in an educational institution. The existing harmonics level at Karpagam University, Coimbatore was measured in real time on

Power Distribution Details: The Power distribution details of Karpagam University are as follows.

Customer Details	M/s. KARPAGAM UNIVERSITY -- COIMBATORE
No. of Service Connection	One
Service Connection Number	HT S.C.no - 569
Transformer Make	KIRLOSKAR
Capacity (KVA)	800
Quota Demand (KVA)	500
Reached Demand (KVA)	362.8
Percentage of Impedance (%)	4.75
HT Voltage (KV)	22
LT Voltage (V)	433
HT Current (A)	20.99
LT Current (A)	1066.7

Service Connection Details: The Karpagam Academy of Higher Education has availed HT Service connection in 22KV system through the 22 KV Ganeshapuram Feeder fed from 110/22KV Kurichi Sub-station.

The HT Service connection number is 569.

Sanctioned Demand: The Sanctioned demand of HT SC No.569 is 500KVA.

Maximum Recorded Demand: The HT meter readings are recorded once in a month (i.e. on 27th of every month) by the Electricity department for calculation of Current Consumption and demand charges.

The maximum demand was reached during August 2015 and it is 362.8KVA.

Transformer Details: At the Consumer side, a 800KVA/22KV/433V Step down transformer is provided for stepping down of the voltage.

Capacitor Details: The following Capacitors are connected at Karpagam Academy of Higher Education.

25 kvar : 5 nos.
12.5 kvar : 1 no.
6.5 kvar : 2 nos.

Feeder Details: At the secondary of the transformer is the LT bus bar. There are several feeders connected to the transformer secondary side, for various blocks which are electrically separated.

The following are the seven various LT feeders available at Karpagam

Academy of Higher education.

- MLSB-1
- A Block
- B-Block lighting load
- D-Block
- Commercial
- A2 Block
- B-Block power load

Power Quality Analyzer: The equipment used for measuring existing harmonics level at Karpagam Academy of Higher Education is Fluke 434 series II. The Serial number is 27783408.

The Analyzer offers an extensive and powerful set of measurements to check power distribution systems. Some give a general impression of power system performance. Others are used to investigate specific details [1].

The analyzer measures and records harmonics and inter-harmonics up to the 50th order. Related data such as DC components, THD (Total Harmonic Distortion) and K-factor are measured.

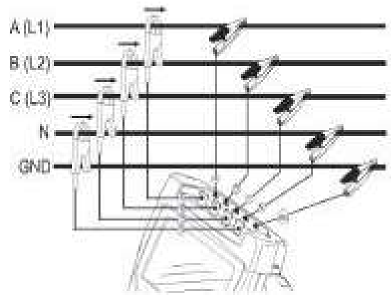
Readings can be given as a percentage of the fundamental, or as a percentage of all harmonics combined (rms value). Results may be viewed in a Bar Graph display, a Meter screen, or a Trend display.

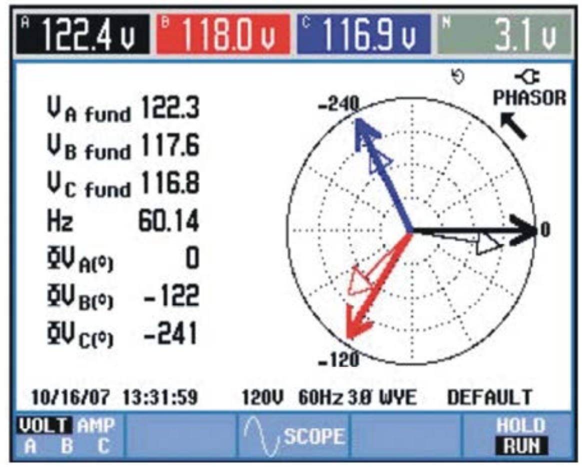
Connections: The current clamps are first put around the conductors of phase A (L1), B (L2), C (L3) and N(eutral). The clamps are marked with an arrow indicating the correct signal polarity.

The voltage connections are made next, starting with Ground and then in succession N, A (L1), B (L2) and C (L3). For correct measuring results, always connect the Ground input.

For single phase measurements, use current input A (L1) and the voltage inputs Ground, N (neutral) and phase A (L1).

A (L1) is the reference phase for all measurements.





Before making measurements, the Analyzer is set-up for the line Voltage, frequency and wiring configuration of the power system.

Scope Waveform and Phasor display are useful to check if voltage leads and current clamps are connected correctly. In the vector diagram the phase voltages and currents A(L1), B (L2) and C (L3) should appear in sequence when observing them in clockwise direction.

Voltage and frequency should be close to the nominal values [for example 120 V, 230V, 480 V, 60 Hz, or 50 Hz.].

The voltages and currents in the Meter screen can be used to check if power applied to a 3-phase induction motor is in balance.

Voltage unbalance causes high unbalanced currents in stator windings resulting in overheating and reduced motor life. Each of the phase voltages should not differ more than 1 % from the average of the three.

Current unbalance should not exceed 10 %. In case of too high unbalance, use other measuring modes to further analyze the power system.

Measurement of Harmonics

Harmonics Data

											V(H)%							I(H)%					
Loading Condition	KW	KVA	KVAr	PF	V	A	V-Unb %	I-Unb %	V-THD%	I-THD%	2	3	5	7	11	13	I(A)	2	3	5	7	11	13
800 KVA Transformer LT side																							
800 KVA Tr- LT side with Capacitor	362.6	366	38.6	0.99	392.50	538.33	0.51	1.54	3.7	9.8	0.04	0.55	2.95	1.55	0.66	0.97	538.33	0.33	4.56	6.30	4.21	1.51	2.14
800 KVA Tr- LT side with Capacitor	353.9	356.8	30.1	0.99	393.17	523.6	0.55	2.6	3.8	10.41	0.05	0.56	3.09	1.51	0.78	1.06	523.6	0.37	4.80	6.65	4.14	2.34	2.94
800 KVA Tr- LT side without Capacitor	349.4	360.4	87.1	0.97	389.00	533.67	0.54	3.36	3.1	8.13	0.05	0.63	2.55	1.25	0.4	0.02	534	0.4	4.66	3.80	4.70	1.15	0.43
MLSB - 1	21	22	3.4	0.96	392.0	32.0	0.55	13.8	4.19	16.34	0.06	0.73	3.24	2.30	0.87	1.12	32.0	2.43	11.39	5.65	7.93	4.94	1.74
A Block	42.1	45.4	11.2	0.93	398.3	63.7	0.50	22.3	3.53	15.59	0.07	0.69	2.49	1.59	1.31	1.36	63.7	2.43	13.52	4.24	4.54	1.41	2.26
B Block Lighting	61.7	64.9	15.0	0.95	413.6	88.7	0.41	13.5	1.9	9.18	0.06	0.66	1.38	0.40	0.75	0.98	88.7	0.93	6.71	3.95	3.69	3.89	2.46
D Block	33.1	36.9	14.1	0.9	400.8	52.3	0.34	12.5	4.34	21.91	0.06	0.76	3.1	2.41	1.39	1.4	52.3	0.94	6.27	6.19	12.6	1.10	5.34
Commercial block	19.9	22	8.1	0.91	403.4	32.3	0.36	20.2	3.49	12.73	0.05	0.76	2.71	1.69	0.82	1.01	32.3	2.2	7.91	5.86	3.7	1.9	2.5
A 2 Block	41	42.1	7.9	0.98	409.6	59.3	0.38	1.0	1.93	13.84	0.05	0.7	1.3	0.72	0.27	0.75	59.3	4.15	10.78	5.5	5.5	4.51	2.65
B Block	106.8	111.2	28.8	0.96	405.5	157.3	0.48	7.4	4.98	8.22	0.05	0.83	3.88	2.40	1.52	1.41	157.3	0.86	5.44	3.94	5.68	2.00	11.43

Energy Data

	V(V)			I(A)			P(KW)			S(KVA)			Q(KVAr)			KWH	KVAH	KVARH	T-PF		
Description	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.	Max	Max	Max	Min	Max	Avrg.
800 KVA Tr- LT side with Capacitor	391.0	397.0	394.0	486.0	538.0	511.0	330	362.0	346.0	333	366.0	349.0	26	38	31.6	118	119	32.6	0.99	0.99	0.99
MLSB 1	390.3	400.8	393.9	27.7	32.0	29.9	18.7	21.7	19.9	19.2	22.2	20.51	2.7	3.8	3.25	10.1	10.4	1.65	0.96	0.98	0.97
A Block	397.4	406.5	401.4	47.3	63.7	55.9	31.7	42.1	37.0	33.7	45.4	39.8	8.7	12.2	10.73	20.3	21.9	5.90	0.92	0.94	0.93
B Block Lighting	404.8	413.9	408.7	85.7	88.7	87.0	58.9	61.7	60.0	61.7	64.9	62.95	13	15	13.83	31.3	32.8	7.22	0.95	0.95	0.95
D Block	395.5	409.6	402.1	46.3	52.3	49.5	29.2	33.1	30.9	32.7	36.9	34.71	13.1	15.3	14.15	31.4	35.3	14.38	0.88	0.9	0.89
Commercial Block	400.2	406.7	402.9	19.3	32.3	22.4	12.5	20.4	14.5	13.9	22.5	16.08	3.1	8.1	4.39	7.43	8.3	2.25	0.86	0.93	0.9
A 2 Block	407.9	412.4	409.4	42.0	59.3	52.4	29.0	41.0	36.1	30.1	42.1	37.46	4.4	9.6	7.38	18.8	19.5	3.82	0.95	0.98	0.96
B Block	403.2	411.5	405.4	130.7	157.3	145.6	89.2	106.8	98.9	92.6	111.2	102.9	21.3	29.3	25.45	50.9	53.0	13.09	0.95	0.96	0.96

A Crest Factor close to 2.0 indicates high distortion. CF = 2.0 can be found if you measure the current drawn by rectifiers that only conduct at the sine wave top.

Measurement Mode: Harmonics mode is used for measuring voltage and current harmonics and THD per phase. Trend mode is used to record harmonics over time.

Software: Power Log [2] is the software supplied with Fluke 435 and it is the dedicated software for data logging.

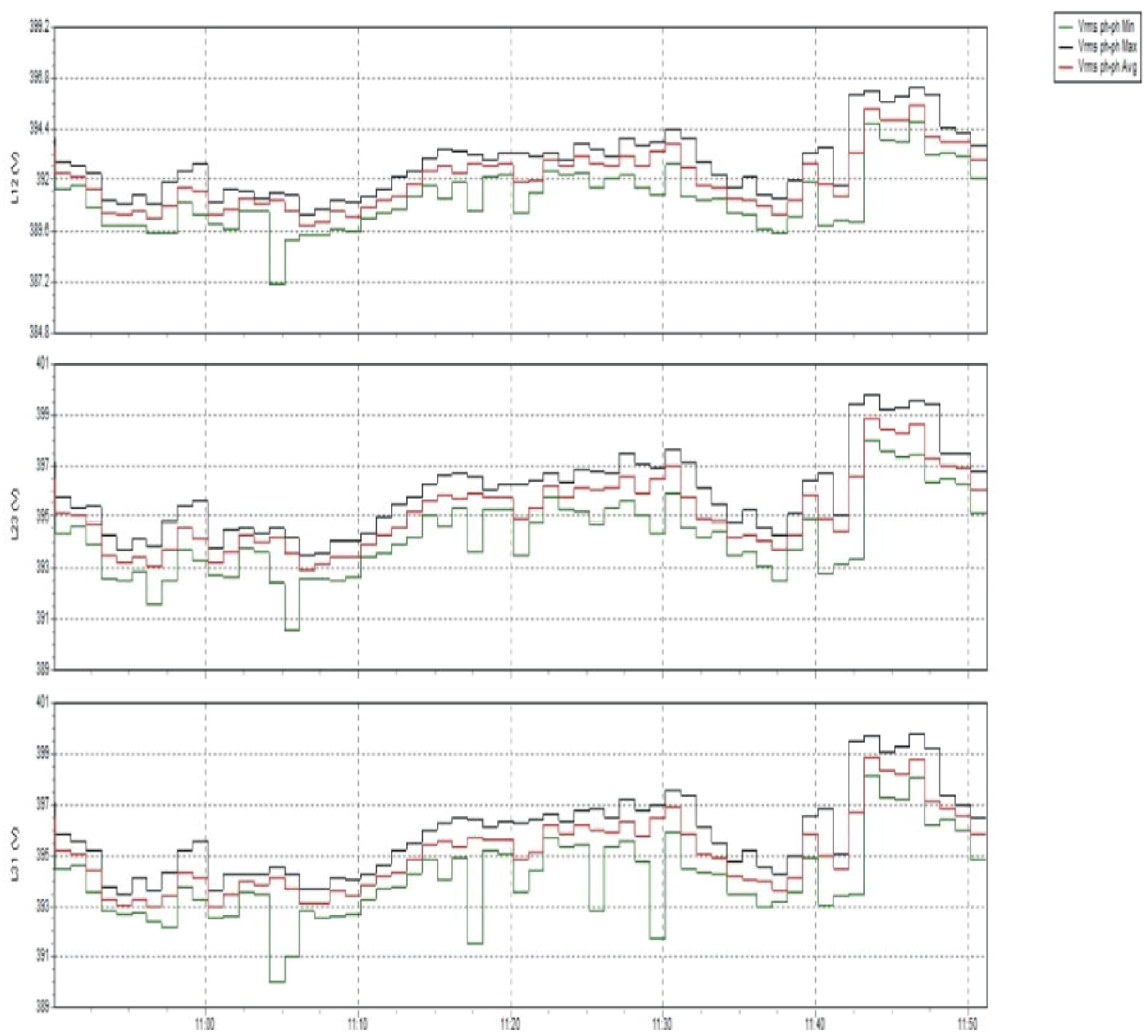
The interface connection is located at the right Analyzer side and attainable if the tilt stand is folded out.

Harmonics is measured at the following locations of Karpagam Academy of Higher Education, Coimbatore.

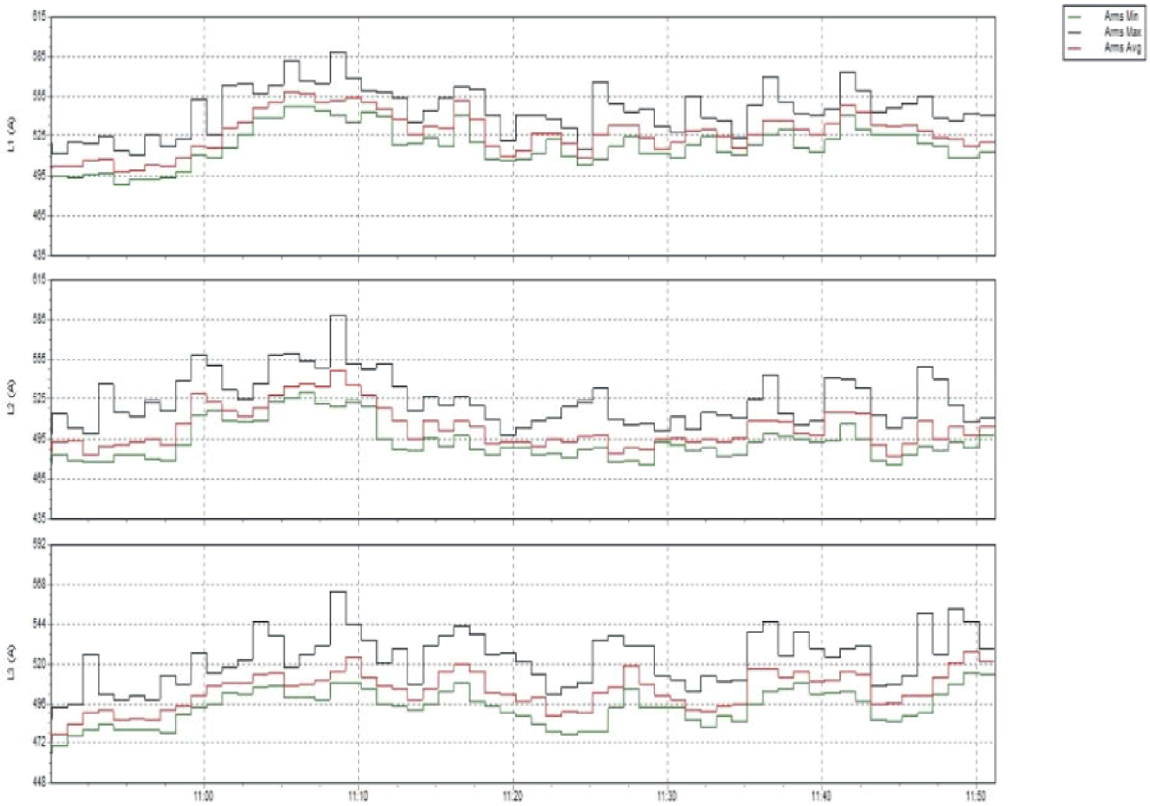
1) 800 KVA Transformer LT Side
2) 7 - Feeders
   - MLSB-1
   - A Block
   - B-Block lighting load
   - D-Block
   - Commercial
   - A2 Block
   - B-Block power load

Voltage profile, Current profile, Load profile, Frequency, V-THD%, I-THD%, Voltage individual harmonics, Current individual harmonics are measured using the Power quality analyzer.

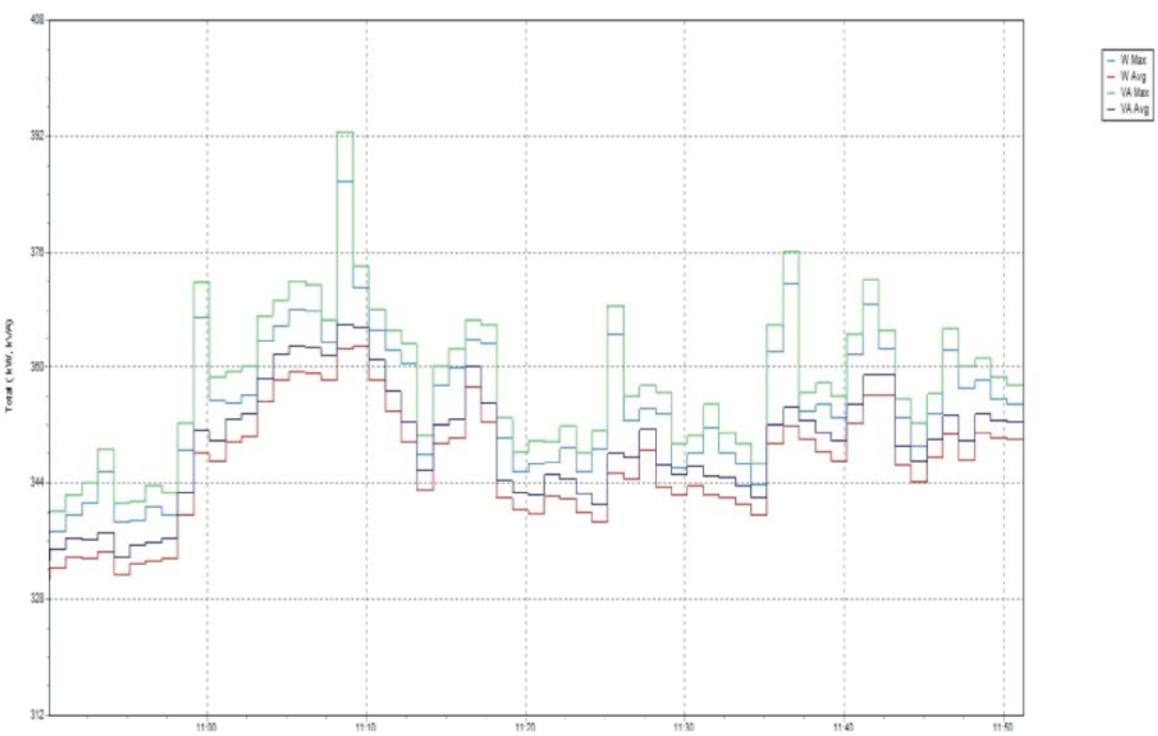
RESULTS



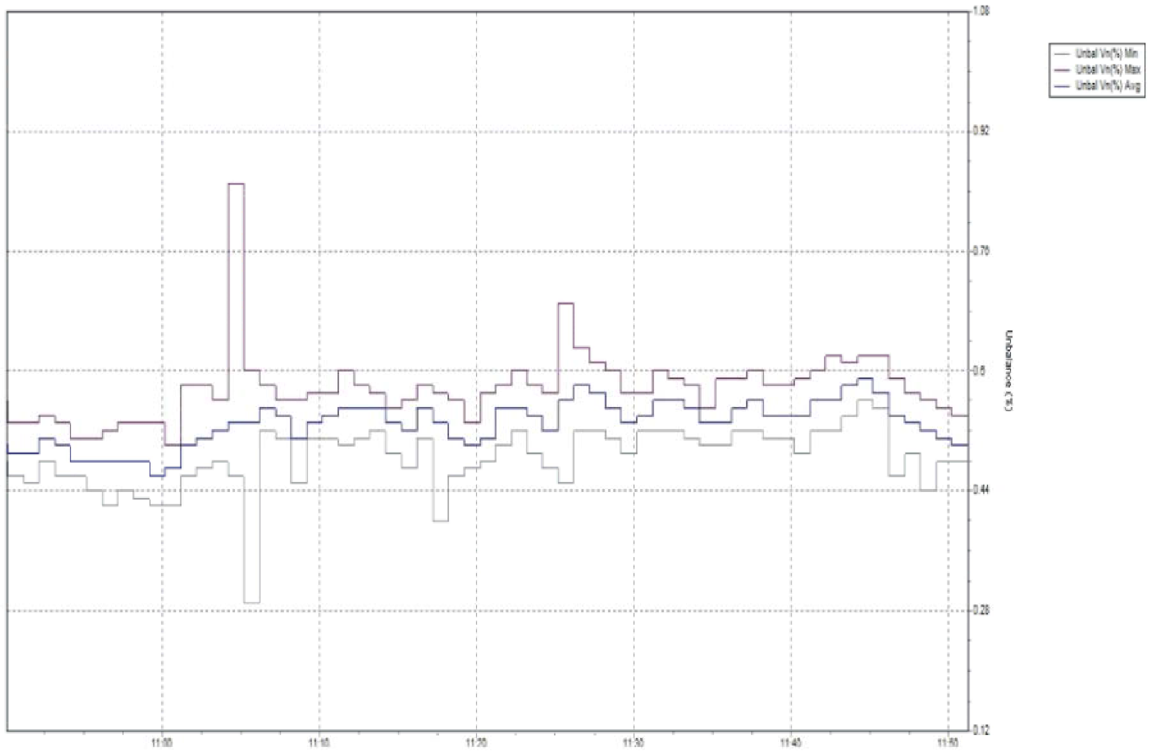
Voltage profile



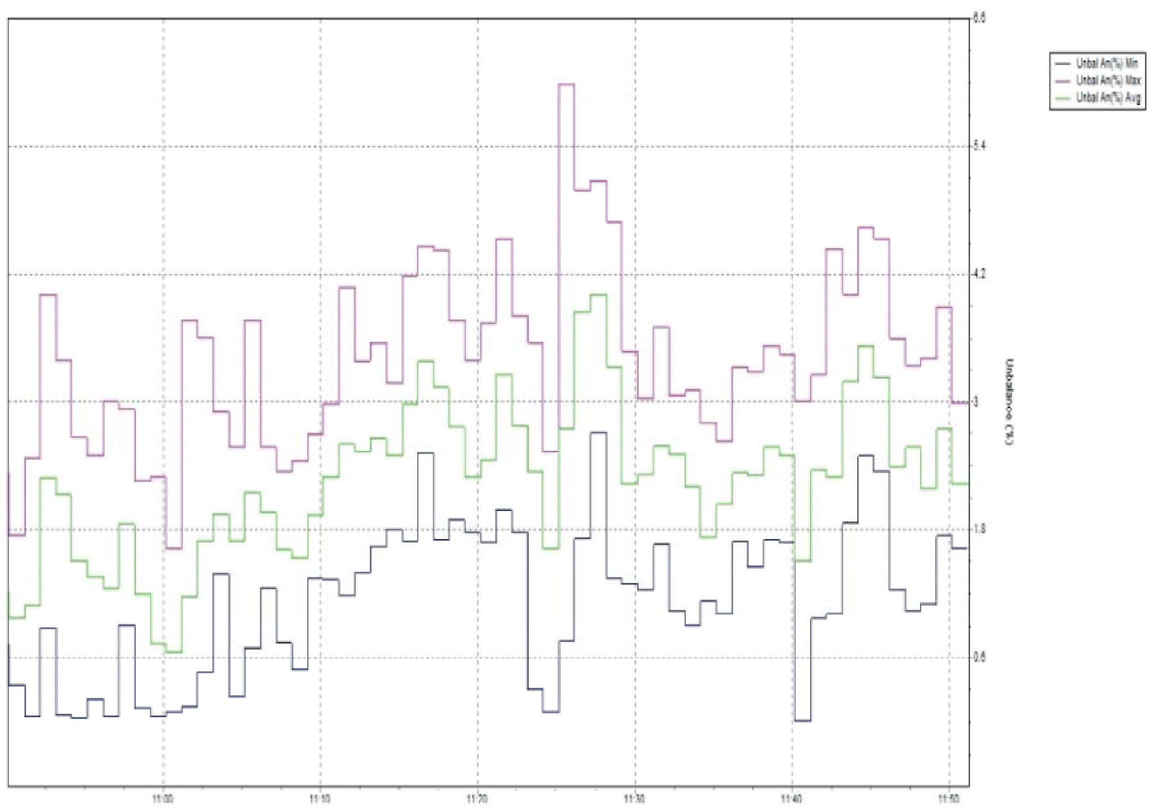
Current profile



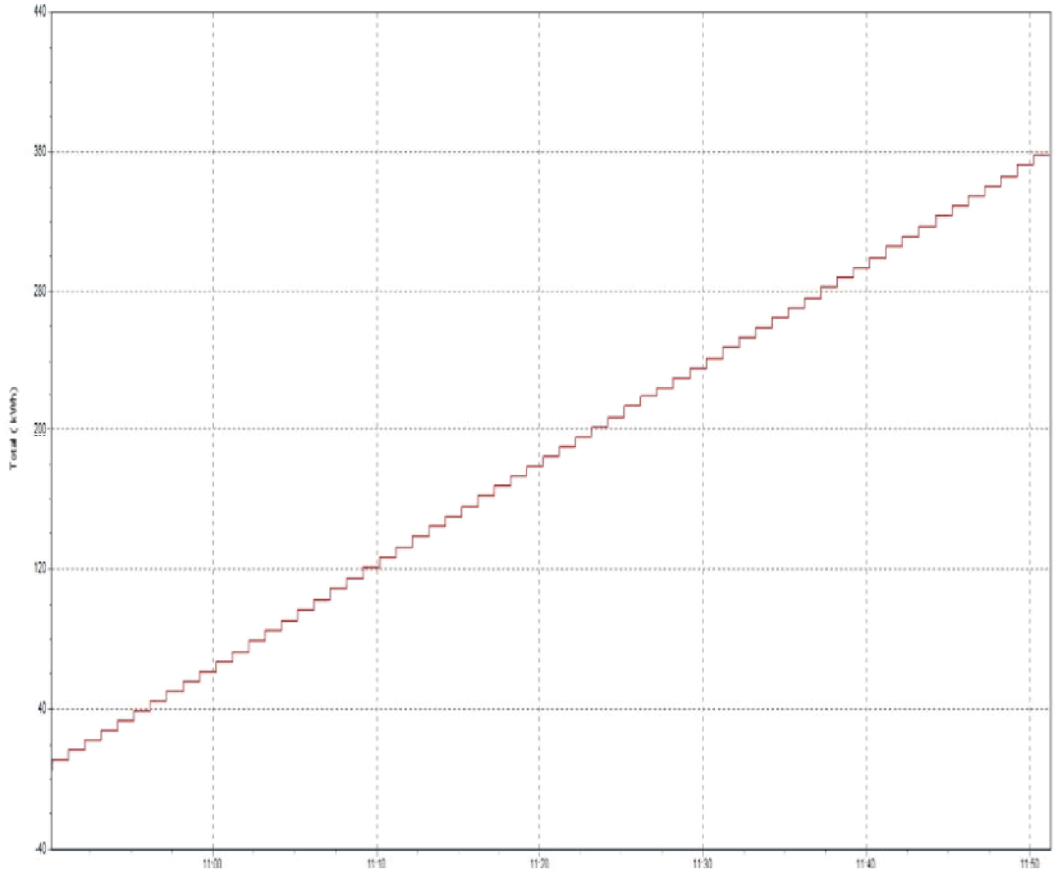
Load profile



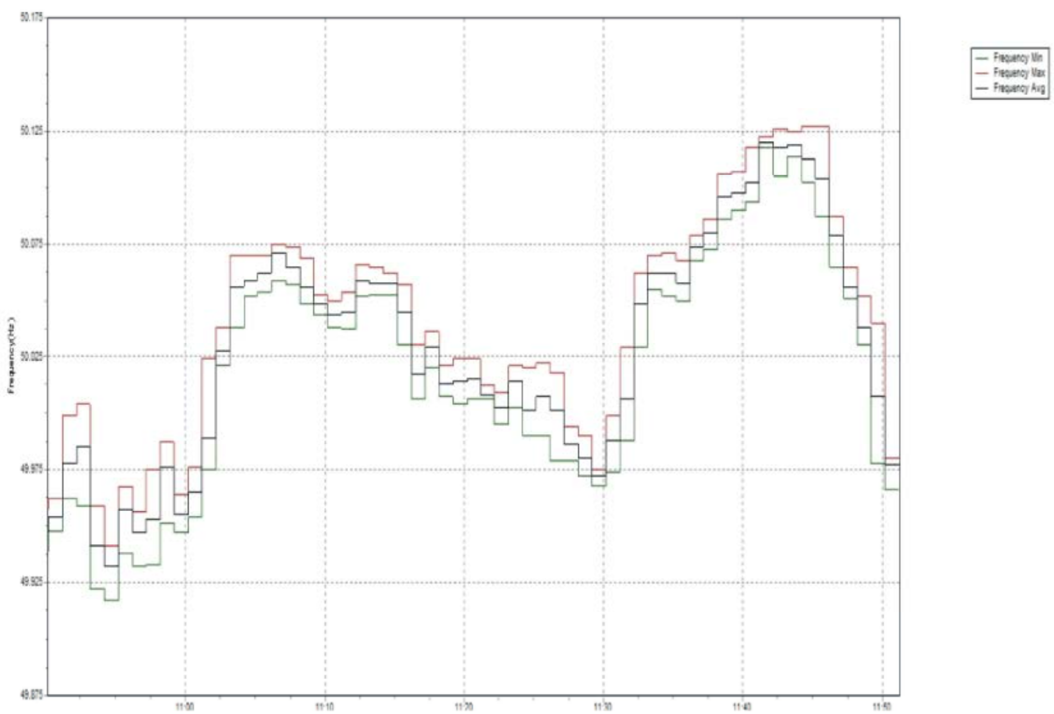
Voltage unbalance (V-unb %)



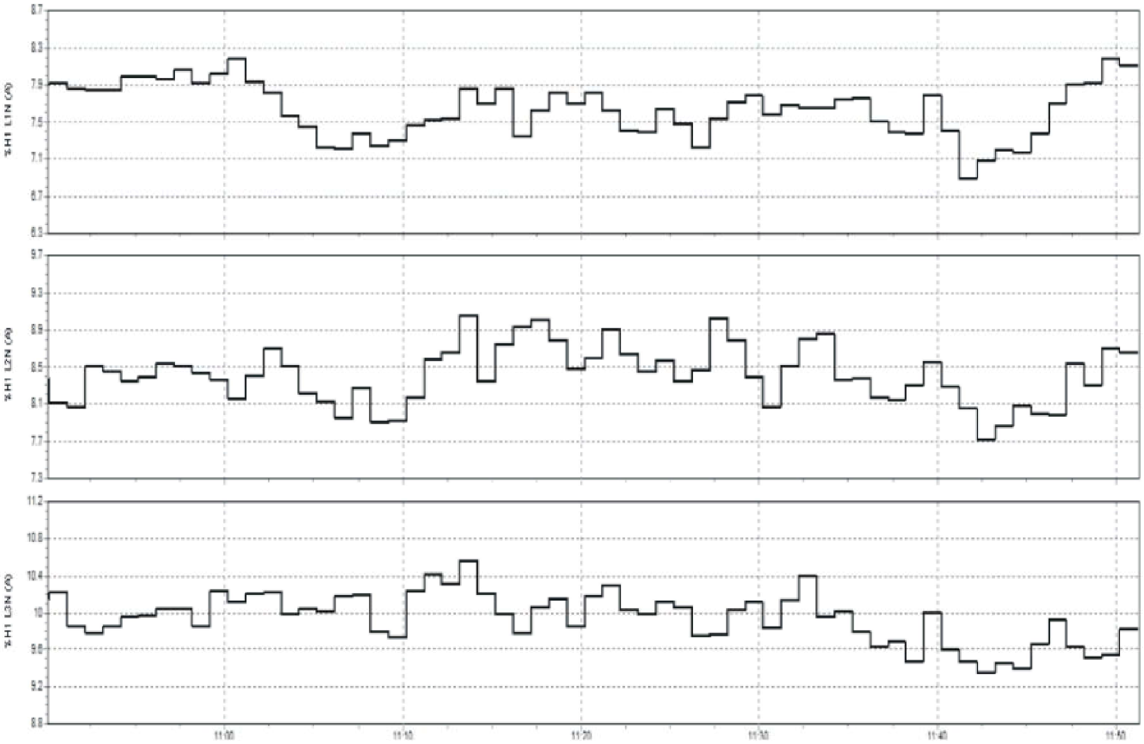
Current unbalance (I-unb %)



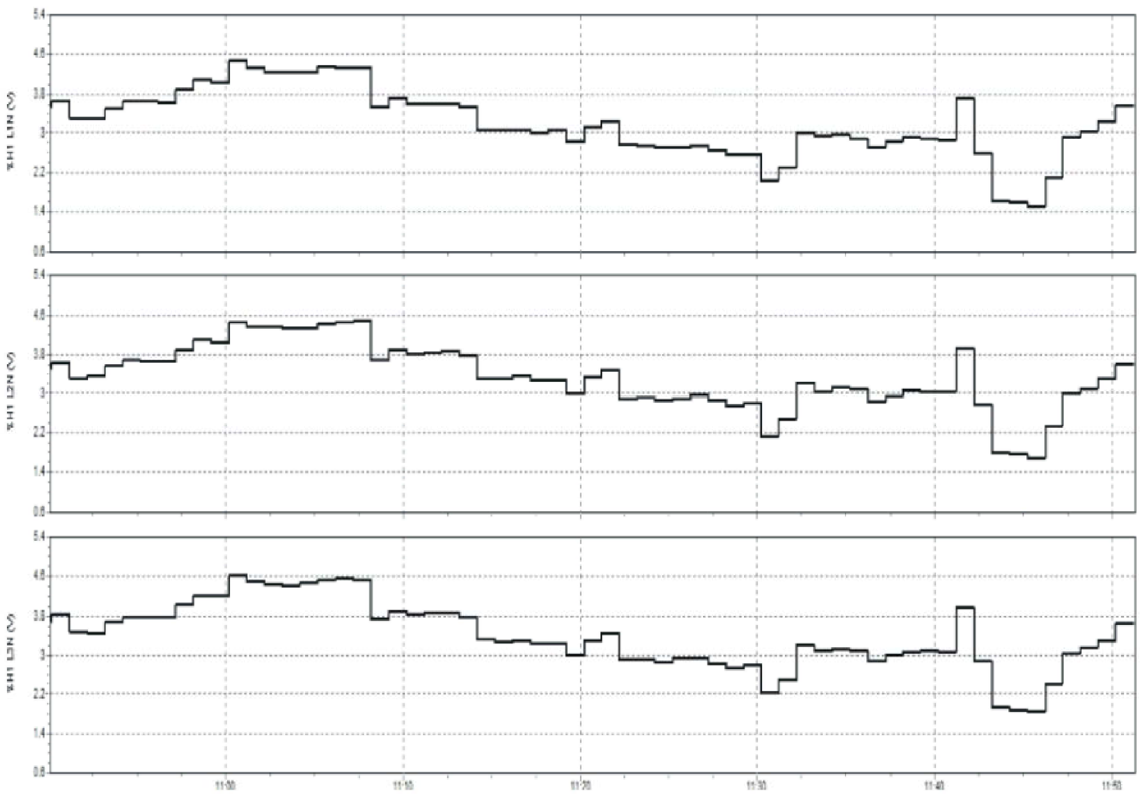
Active Energy(kwh)



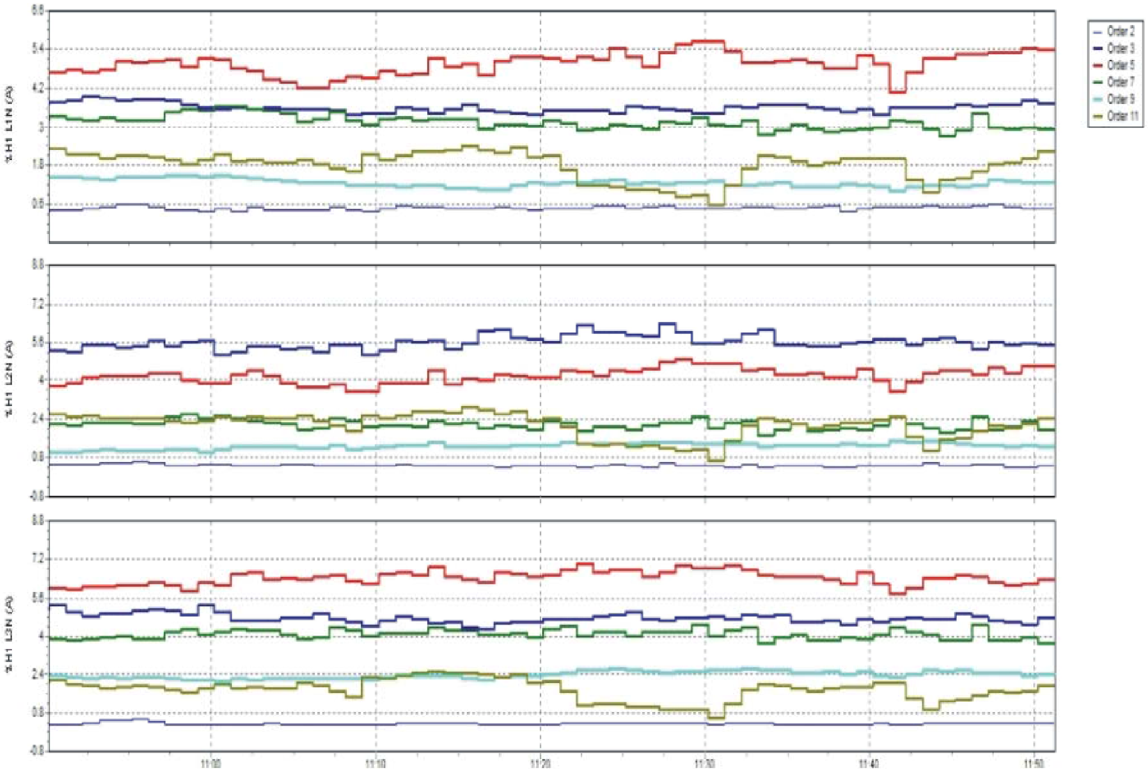
Frequency (HZ)



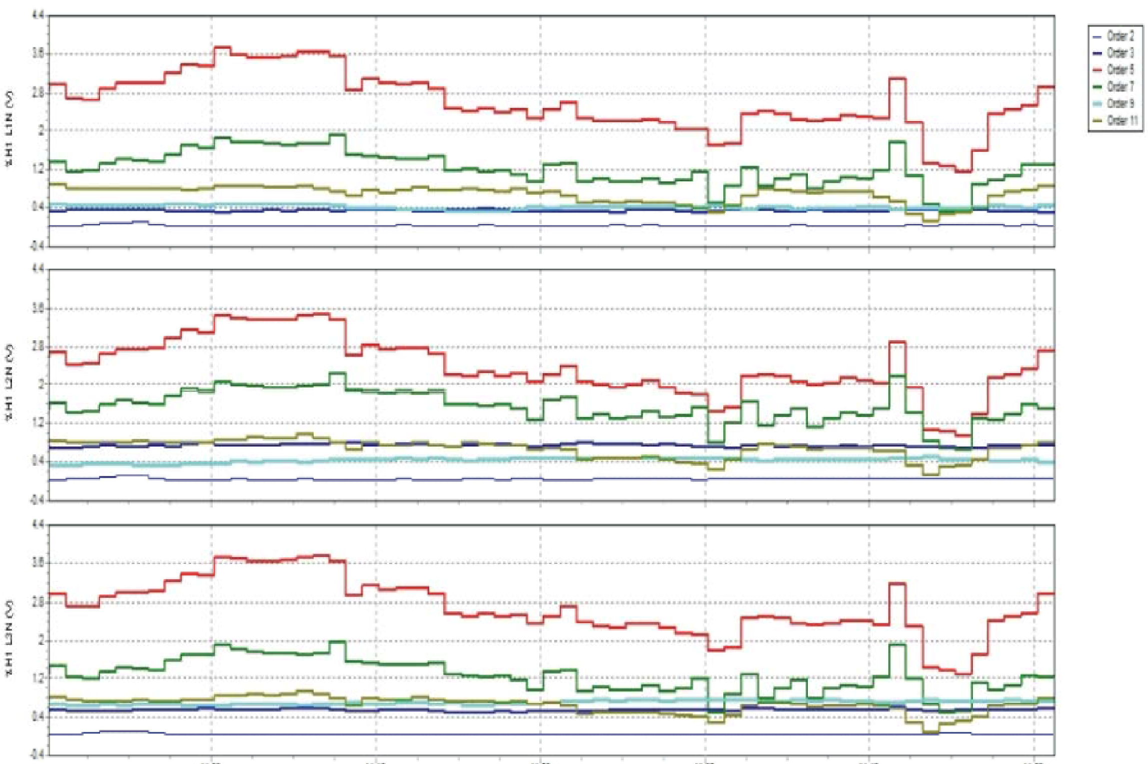
Total Current Harmonics (I-THD %)



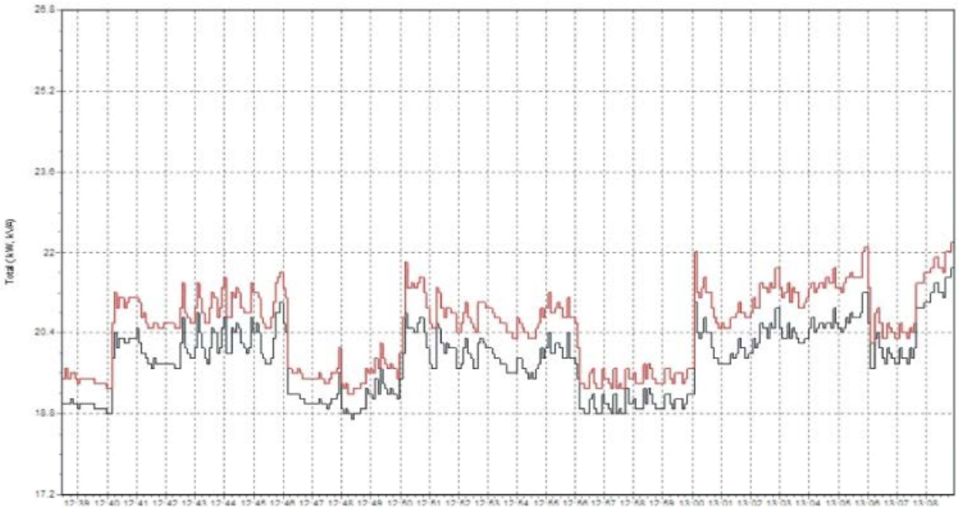
Total Voltage Harmonics (V-THD %)



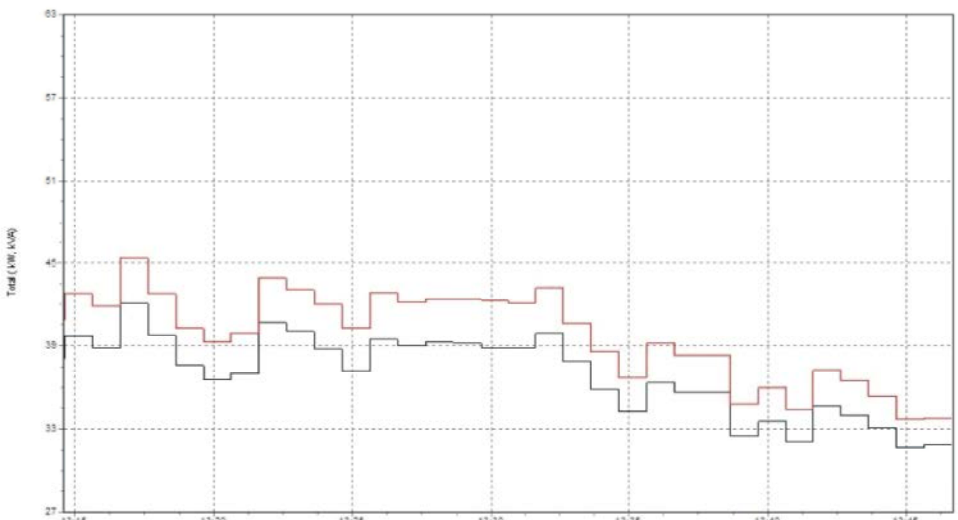
Current Individual Harmonics%



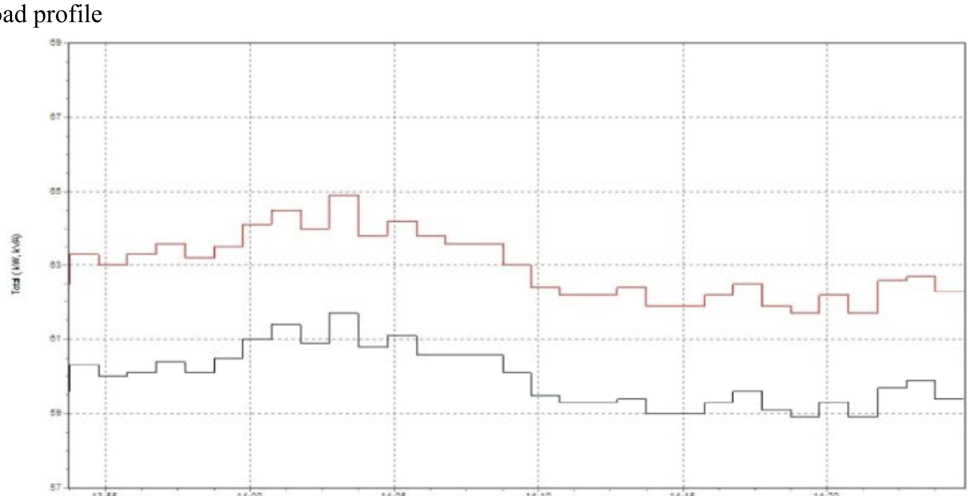
Voltage Individual Harmonics %



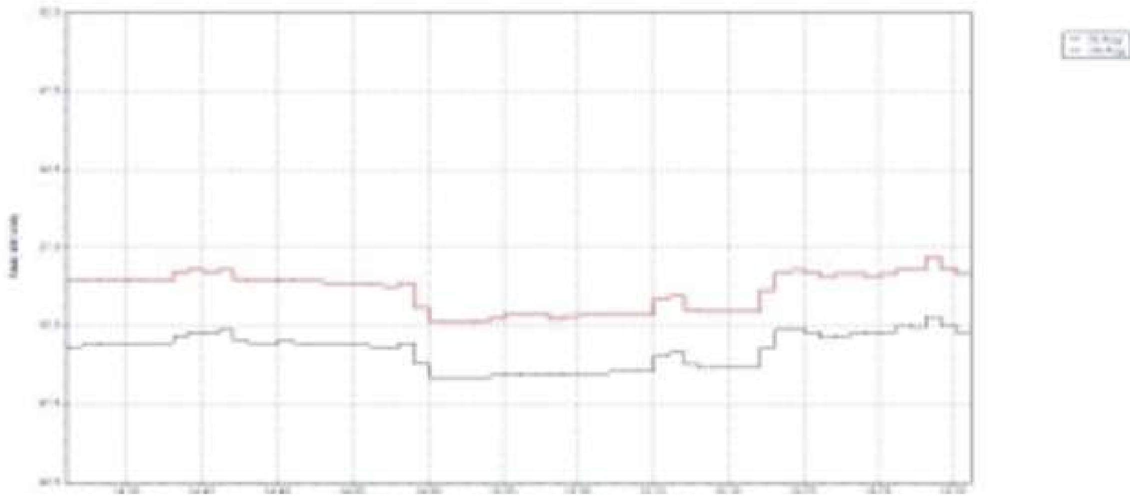
MLSB-1 Load Profile



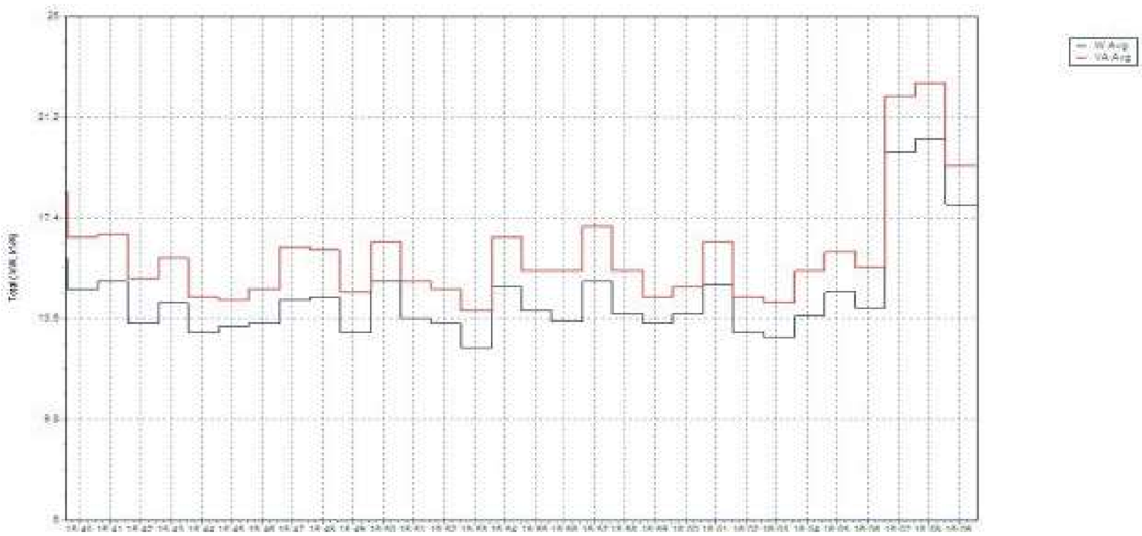
A-Block Load profile



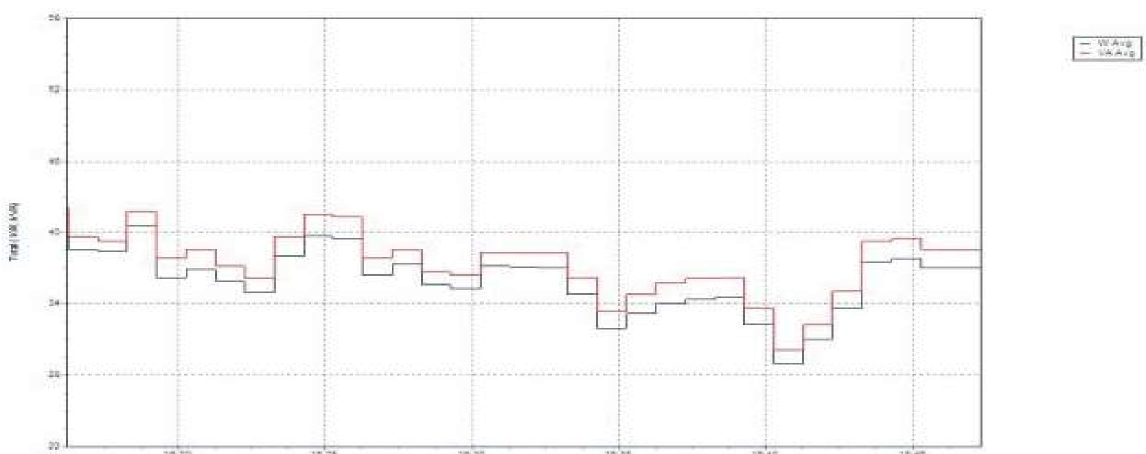
B-Block Lighting Load profile



D- Block Load Profile



Commercial Block Load profile



A2-Block Load Profile

B-Block Power Load Profile

Observations

Voltage Harmonics: From the measurement made above, it is concluded that the presence of Voltage Total Harmonics Distortion at the LT side is within the limits & the individual Voltage Harmonics at the LT side is not within the standards.

Description	TNERC norms	Existing value
Harmonics V-THD % (max)	5%	3.8%
Harmonics V-ind % (max)	3%	3.09%

Current Harmonics: The presence of Total Demand Distortion - Current (I-TDD) at LT side is not within the standards.

Description	TNERC norms	Existing value
Harmonics I-THD % (max)	8%	10.4%
Highest order harmonics		5th order

It is proposed to bring down the existing harmonics level I-THD% within the standards (i.e. within 8%).

Methods Used for Mitigation of Harmonics: There are a number of techniques existing in field for mitigation of harmonics., such as, [4].

- Passive techniques
- Introducing line reactors
- Detuned Capacitors
- Tuned harmonic filters
- High pulse rectification
- Active harmonic filters
- Hybrid filters

Proposed Method: We have proposed the technique of Detuning of capacitors for mitigation of harmonics at Karpagam University, Coimbatore.

Detuned Capacitors: The addition of detuning reactors to power factor correction capacitors causes the terminal voltage of the capacitors to rise in the presence of harmonics.

It is important to increase the voltage rating of the capacitors considerably. Capacitors designed for use with detuning reactors are typically rated at 525V or 565 volts for a 380/400 volt system. The KVAR rating of the capacitors must be based on the actual supply voltage and the continuous applied voltage rating must be much higher [8].

Detuning Reactors: The detuning reactors are designed to be used with special high voltage capacitors and are rated in KVAR where the KVAR rating is the KVAR of the capacitor that they are designed to be used with. You use a 25KVAR detuning reactor to detune a 25KVAR capacitor.

The series circuit of reactor and capacitor forms a resonant circuit. It is important that the resonant frequency of this tuned circuit is not near a harmonic frequency. This is why the detuning reactor must match the detuned capacitor. [8]

Avoiding Resonance: There are a number of ways to avoid resonance when installing capacitors.

In larger systems it may be possible to install them in a part of the system that will not result in a parallel resonance with the supply. Varying the kvar output rating of the capacitor bank will alter the resonant frequency.

With capacitor switching there will be a different resonant frequency for each step. Changing the number of switching steps may avoid resonance at each step of switching.

Over Coming Resonance: If resonance cannot be avoided, an alternative solution is required. A reactor must be connected in series with each capacitor such that the capacitor/ reactor combination is inductive at the critical frequencies but capacitive at the fundamental frequency. To achieve this, the capacitor and series connected reactor must have a tuning frequency be low the lowest critical order of harmonic, which is usually the 5th. This means the tuning frequency is in the range of 175 Hz to 270 Hz, although the actual frequency will depend upon the magnitude and order of the harmonic currents present.

The addition of a reactor in the capacitor circuit increases the fundamental voltage across the capacitor. [9].

Use of reactor is a simple and cost effective method to reduce the harmonics produced by nonlinear loads and is a better solution for harmonic reduction than an isolation transformer.

Reactors or inductors are usually applied to individual loads such as variable speed drives and available in a standard impedance ranges such as 2%, 3%, 5% and 7.5%.

When the current through a reactor changes, a voltage is induced across its terminals in the opposite direction of the applied voltage which consequently opposes the rate of change of current.

This induced voltage across the reactor terminals is represented by equation below.

$$e = L\,[di/dt]$$

where:

e = Induced voltage across the reactor terminals
L = Inductance of the reactor, in Henrys
di/dt = Rate of change of current through reactor in Ampere/Second

This characteristic of a reactor is useful in limiting the harmonic currents produced by electrical variable speed drives and other nonlinear loads.

In addition, the AC line reactor reduces the total harmonic voltage distortion (THDv) on its line side as compared to that at the terminals of the drive or other nonlinear load.

AC line reactor is used more commonly in the drive than the DC bus reactor and in addition to reducing harmonic currents, it also provides surge suppression for the drive input rectifier [5].

CONCLUSION

We, at Karpagam University, Coimbatore, had observed that Distributed and fixed Capacitors (150 KVAr) for power factor compensation are connected at feeder level.

This kind of arrangement will either

- Over Compensate during part load conditions. Or
- Under compensate if installed considering the low/ average load conditions.

Hence it is proposed to go for Centralized Automatic Power Factor compensation at MV Panel level.

From the recordings, the harmonic current present at the Incomer is about 36 A, Which is generated due to

- The Non Linear loads at Load level (flowing towards the capacitors and towards the transformer, flowing towards the other loads)
- The ripple current generated by the capacitors(flowing towards the loads)
- The amplification effect(resonance) caused by the collision of the above two currents, travelling in the same line in the opposite direction.

The above harmonic currents can be mitigated by Detuning the Capacitors.

By installing suitable reactors in series with the capacitors can reduce the effect of ripple currents & resonance with the harmonic current. This method requires 480 V AC or 525 V AC reactors.

Also, the existing “Distributed & Fixed” capacitors are proposed to be converted into “Centralized & Automatic” capacitors of 525 KVAr.

By this technique, the ITHD% is expected to be reduced upto 2% of the existing level.

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