Diagnosis and Mitigation of Ground Noise Pollution

Power Quality @ Variable Frequency Drives

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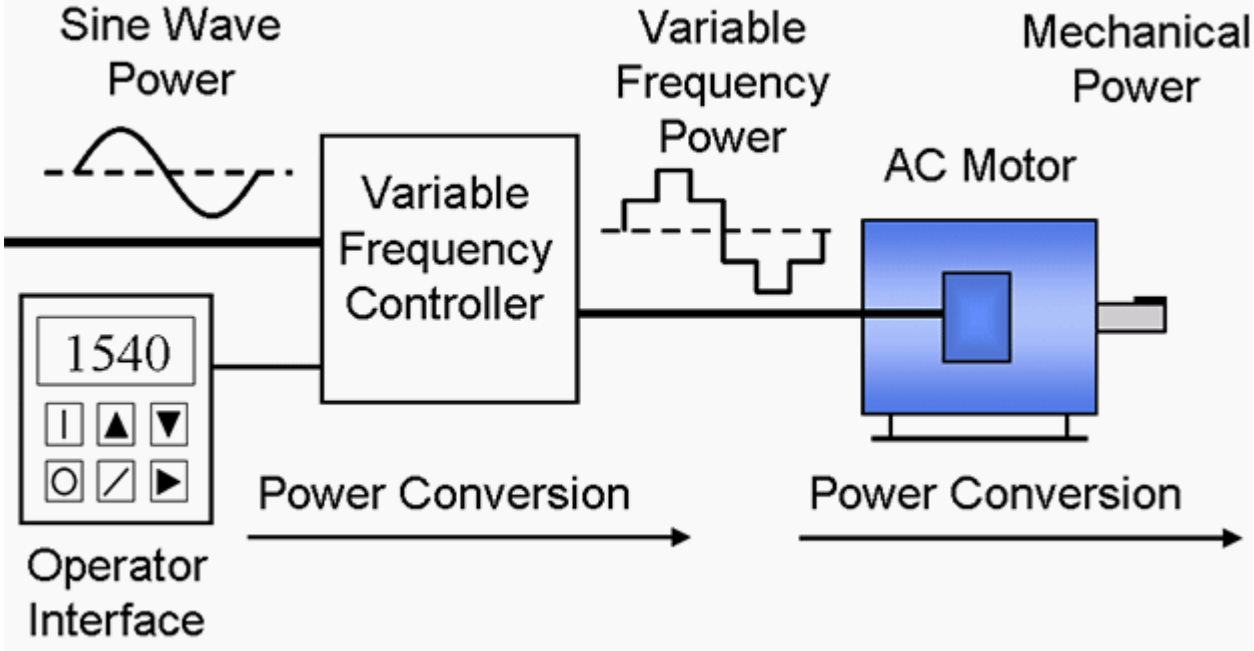
Outline

- VFD benefits and working principle at a glance.
- Introduction – Power Line Disturbances in VFD applications.
- About this Case Study: Paper Industry
- Client Pain, Events
- Observations & Findings in Root Cause Study
  - Power Quality Study
  - Earthing System Study
- Recommended Practices and Solutions.

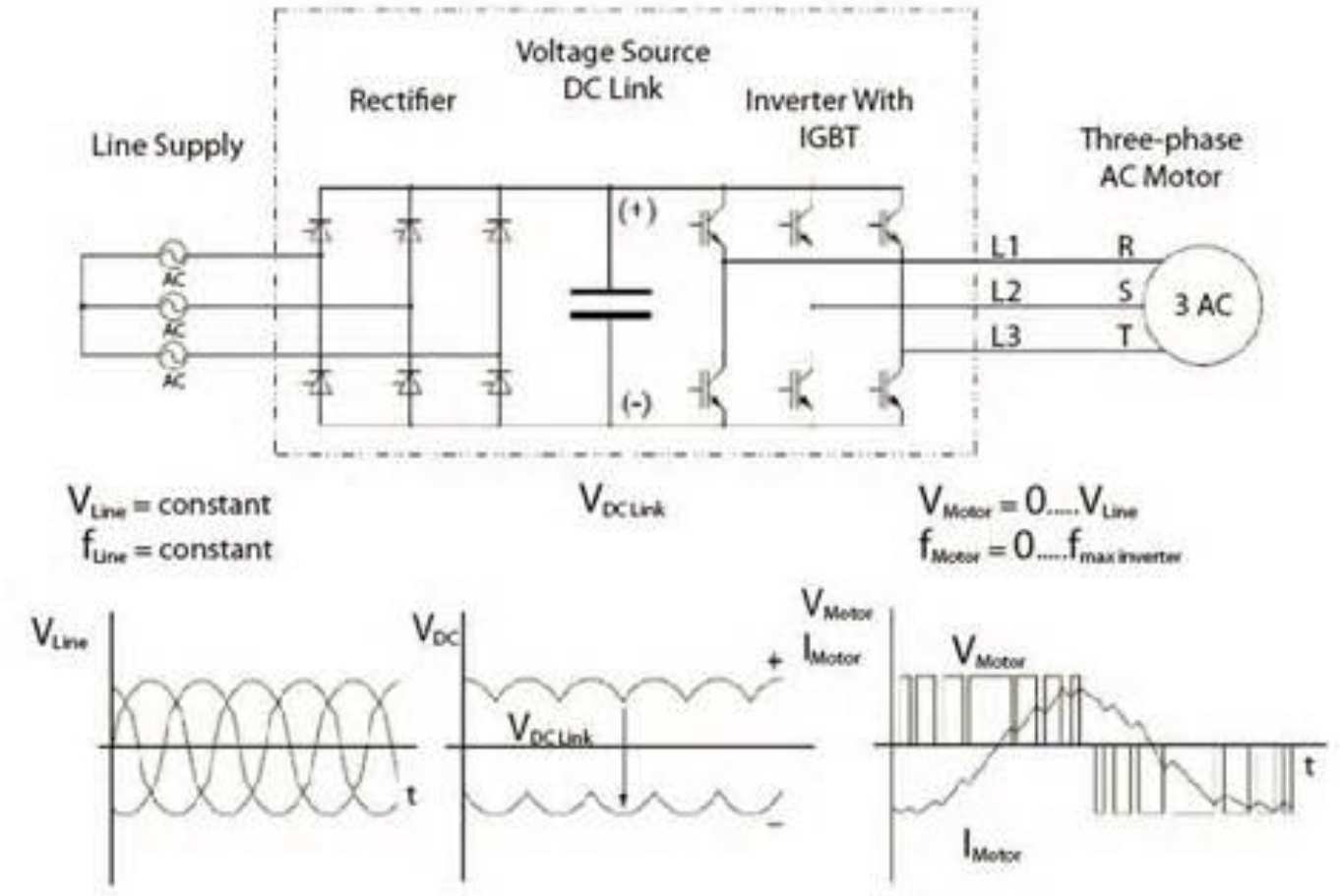
Benefits of VFD

- Saves Energy by controlling speed rather than flow.
- 20% speed reduction yields 50% energy savings.
- Eliminates the need of separate controllers in process control applications.

VFD: Working Principle



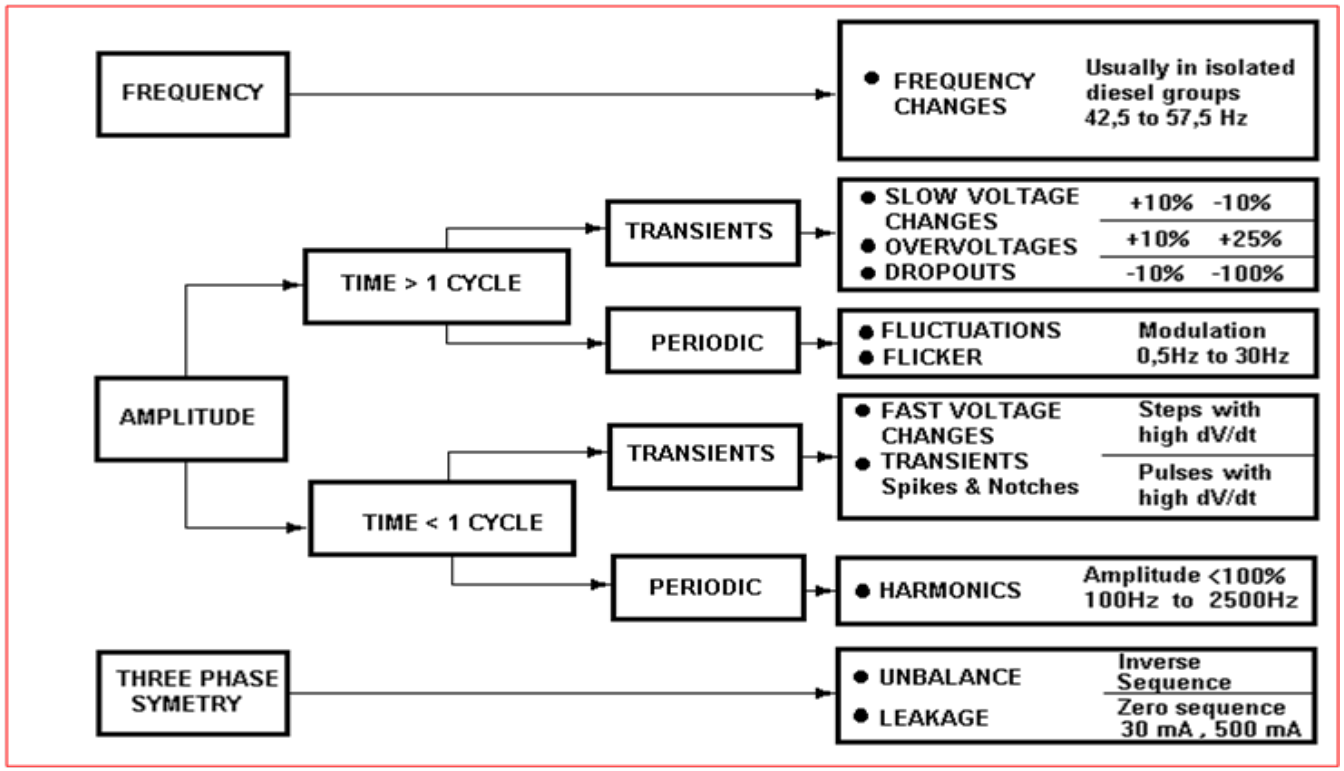
VFD: Working Principle – typical schematic



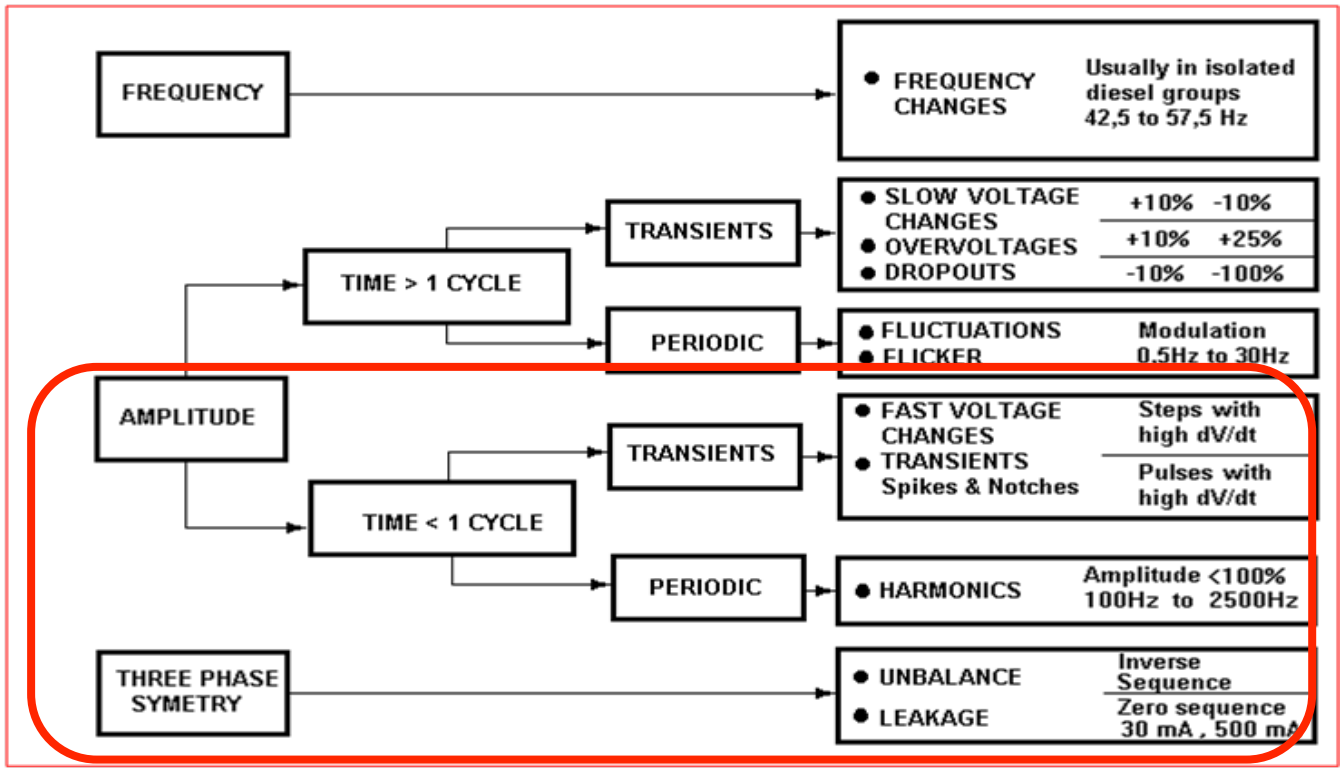
Power Line Disturbances in VFD applications

A Quick Look

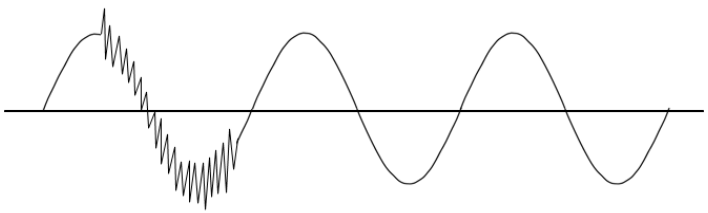
Power Line Disturbances – General Classification



Power Line Disturbances in VFD installations



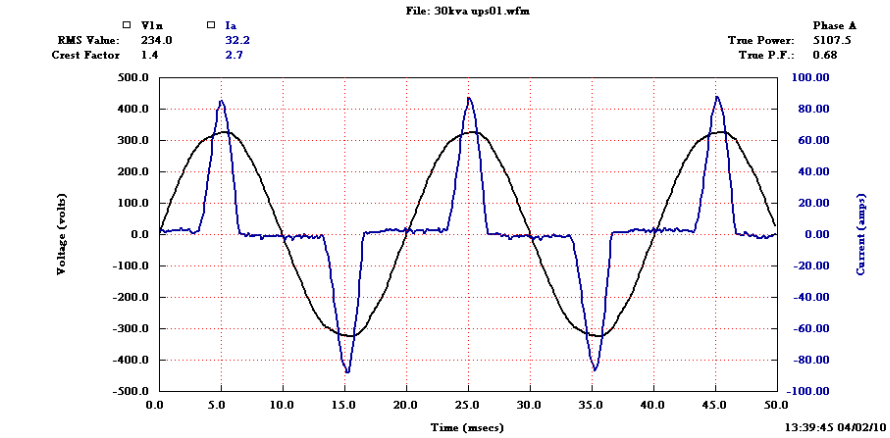
Amplitude: Time<1cycle (Transients)
Fast voltage changes
Steps and Pulses with high dv/dt



VFD Noise Generation:

1. Common Mode (Line-Line)
2. Differential Mode (Line-Ground)
3. Electromagnetic: 0.5 MHz to 1.7 MHz (EMI)
4. Radiofrequency: 1.7 MHz to 30 MHz (RFI)

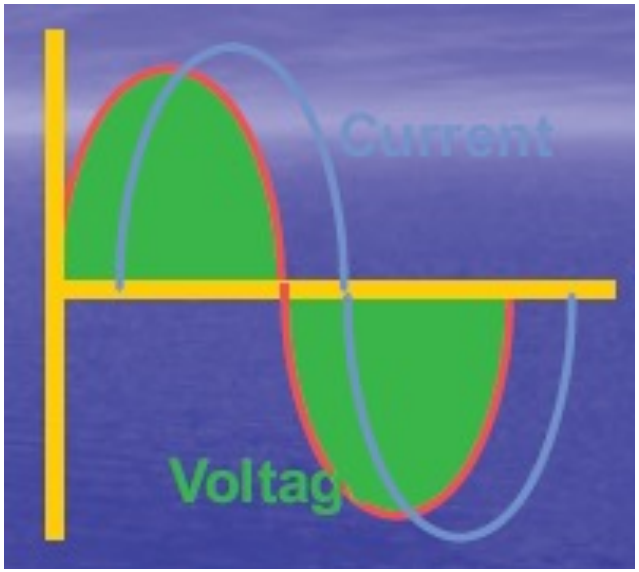
Amplitude: Time<1cycle (Periodic)
Harmonics, signals from 100Hz to 2500Hz



Harmonics: Voltage and Current amplitudes vectors that include fundamental + higher order frequency signals and create a complex waveform which is non-sinusoidal or non-linear.

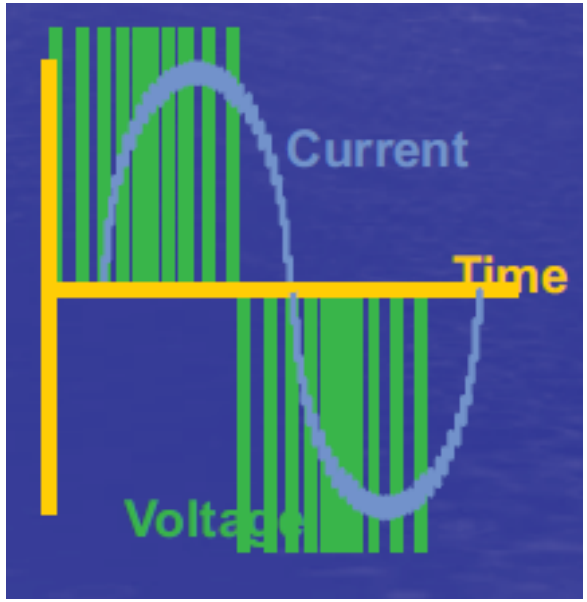
Three phase symmetry in Line (DOL/ Soft-starter) driven loads

- Motors powered by sine wave ac power may have a shaft/ bearing-to frame voltages of about 1 V to 2 V. Because of Linear relation between source voltage and motor current.



Three phase symmetry challenges in VFD driven loads

- Motors powered by PWM may have a shaft/bearing-to frame voltages > 15V, along with High frequency dv/dt pulses and bursts at 650+V
- Resulting unwanted voltage signals migrating from rotor to shaft.



Three phase symmetry challenges in VFD driven loads…contd.

- High Voltage noise signals > 8 V can overcome the insulating properties of bearing grease, and the resulting sparks can cause pitting, fluting and fusion craters, eventually, premature failure of the bearings and motor.

CASE STUDY

Paper Industry

Writing and Printing Paper Manufacturing Facility

Introduction

- This facility is one of the largest manufacturer of writing and printing (W&P) paper in India.
- Having six manufacturing units, that covers most of the domestic market with a dominant share of the high quality coated paper segment.

Client Pains and Problems

- Area: Winder Section
  - Failures of SLITTER MOTORS within first 6 months of operation.
  - Frequent Failure of I/O Control Card Power Supply Modules.
  - Heating and short circuiting of Control Cables

Events and Troubleshooting – at Client End

- Events: Tripping of VFDs for couple of Slitter Motor Drives with an earth fault alarm indication.
- Root Cause diagnosis by Client: Failure of those Slitter Motors caused VFD tripping in earth fault.

Troubleshooting:

- Operator isolated the faulty Slitter Motors and re-started the VFDs which were working healthy.
- Those two motor units were replaced.
- Power restored to VFDs after routine elect network test.

Events and Troubleshooting at Client End…contd.

- Few days later one more Slitter Motor failed and Drive tripped on earth fault. Then client approached VFD supplier and service provider.
- VFD supplier and service provider suggested to replace 600V VFD with 400V VFD.
- As advised by VFD supplier 600V Slitter drive was replaced with 400V drive.
- After replacement of 600V VFD with 400V VFD, Failures of Slitter Motors stopped.
- However above troubleshooting did not stop failures of I/O control card power supply modules and short circuits in control circuits. Then client approached ECPL team.

Efficienergi - Broad Approach -

1. Diagnosis: Electrical Network Root Cause Analysis to find out coupling channels behind failures.

- Are these failures because of Electrical wiring and installations, Power Quality and Earthing? Or Drive internal problem?

2. Recommendations of Solutions: to reduce/stop failures and improve efficiency.

- What rectifications and precautionary measures can be implemented to mitigate the power line disturbances, failures, malfunctions and irregularities at load end??

Diagnosis:
Electrical Network Root Cause Analysis

1. Power Quality Study
2. Earthing System study

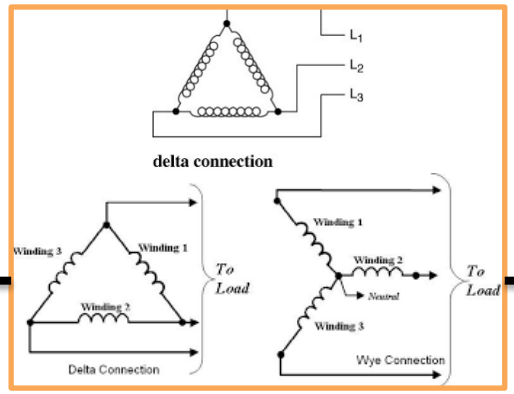
Understanding Electrical Distribution

Single Line Diagrams of Earthing and Power Distribution

Winder Machine Section

Typical Electrical Schematic

Dual Winding Transformer
Winder Machine



Delta winding output bus

Star winding output bus

VFD SM1

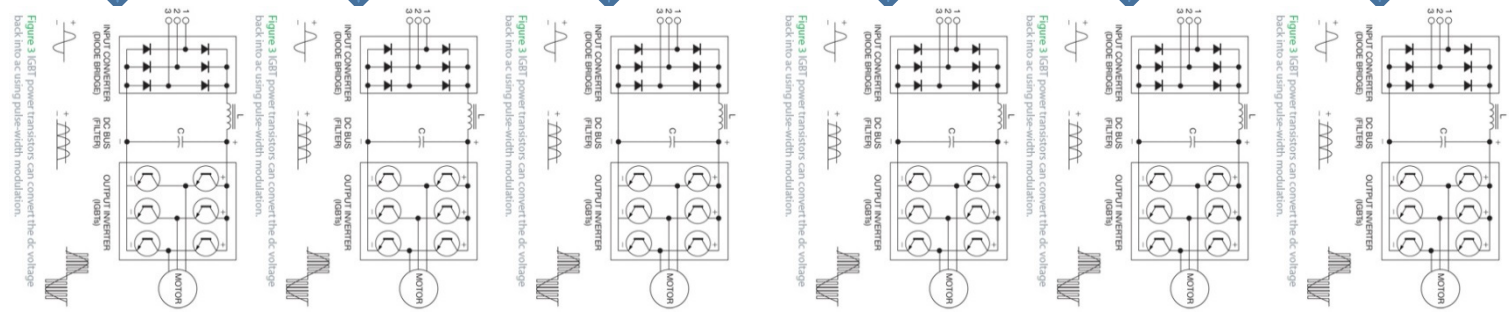
VFD SM2

VFD SM3

VFD SM4

VFD SM5

VFD SM6

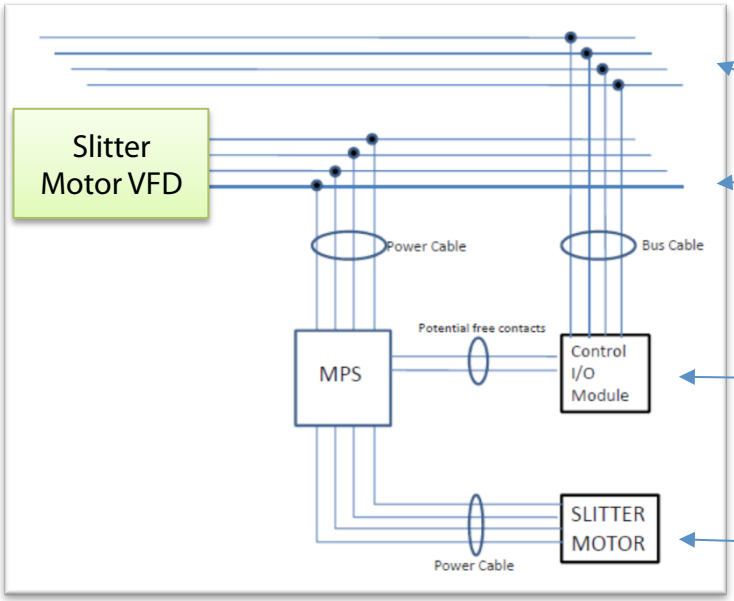


Slitter Motor1 Slitter Motor2 Slitter Motor3 Slitter Motor4 Slitter Motor5 Slitter Motor6

Failures in above 3 motors/ drives were experienced

Typical Electrical SLD – Winder Machine Section

Electrical Singe Line Diagram: Typical Slitter Motor Drive Panel



Separate Power and Control bus

Failure of I/O Modules Power Supply and Control Cables

Failure of Motors

Power Quality Study

Variable Frequency Drive Input

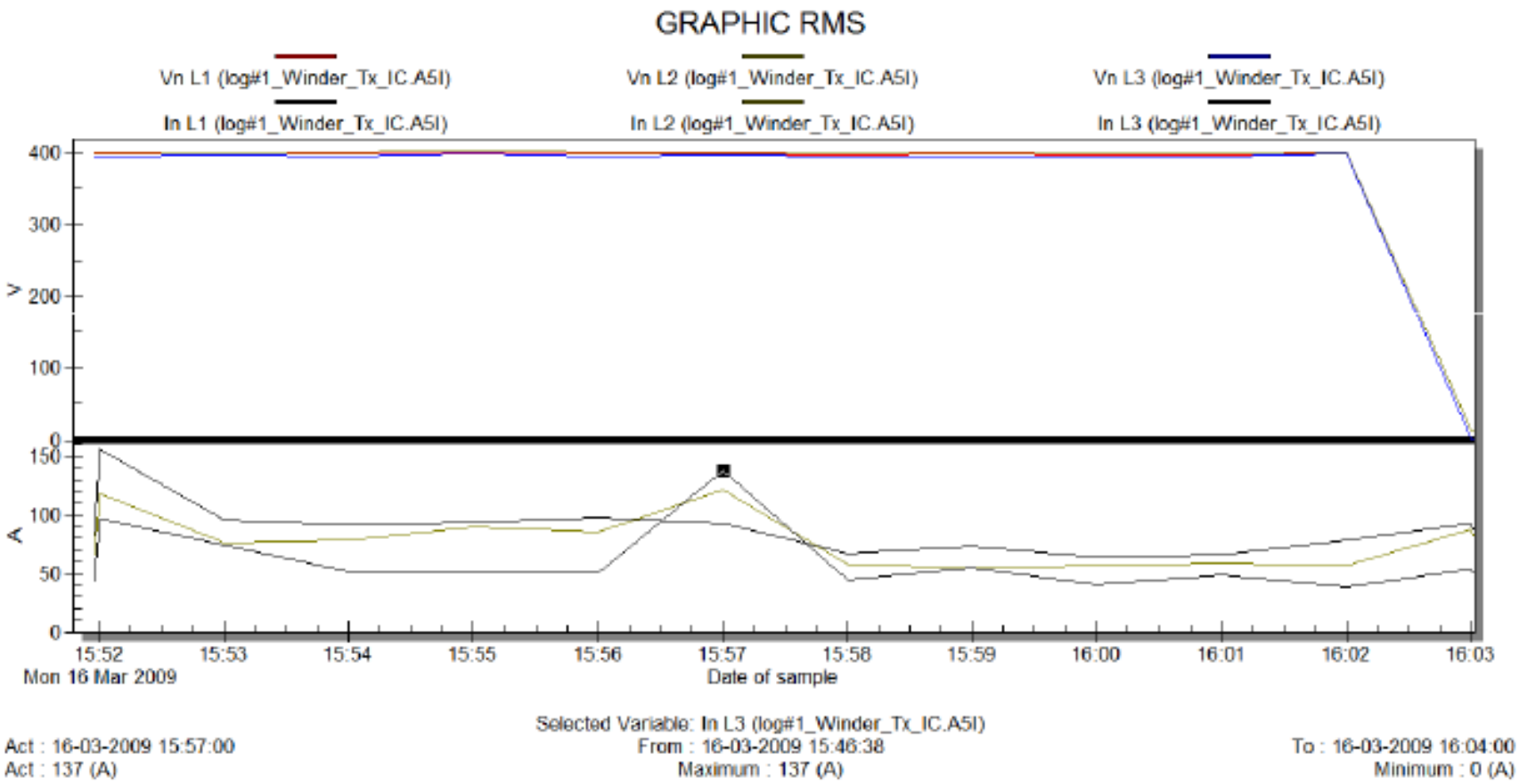
Points of Measurements

- Feeder 1: Winder Machine Transformer LT mains incomer (star winding – feeding to SM4, SM5, SM6).
- Feeder 2: Slitter Motor VFD Panel – VFD input mains incomer.
- Feeder 3: Slitter Motor VFD Panel – VFD output mains incomer.

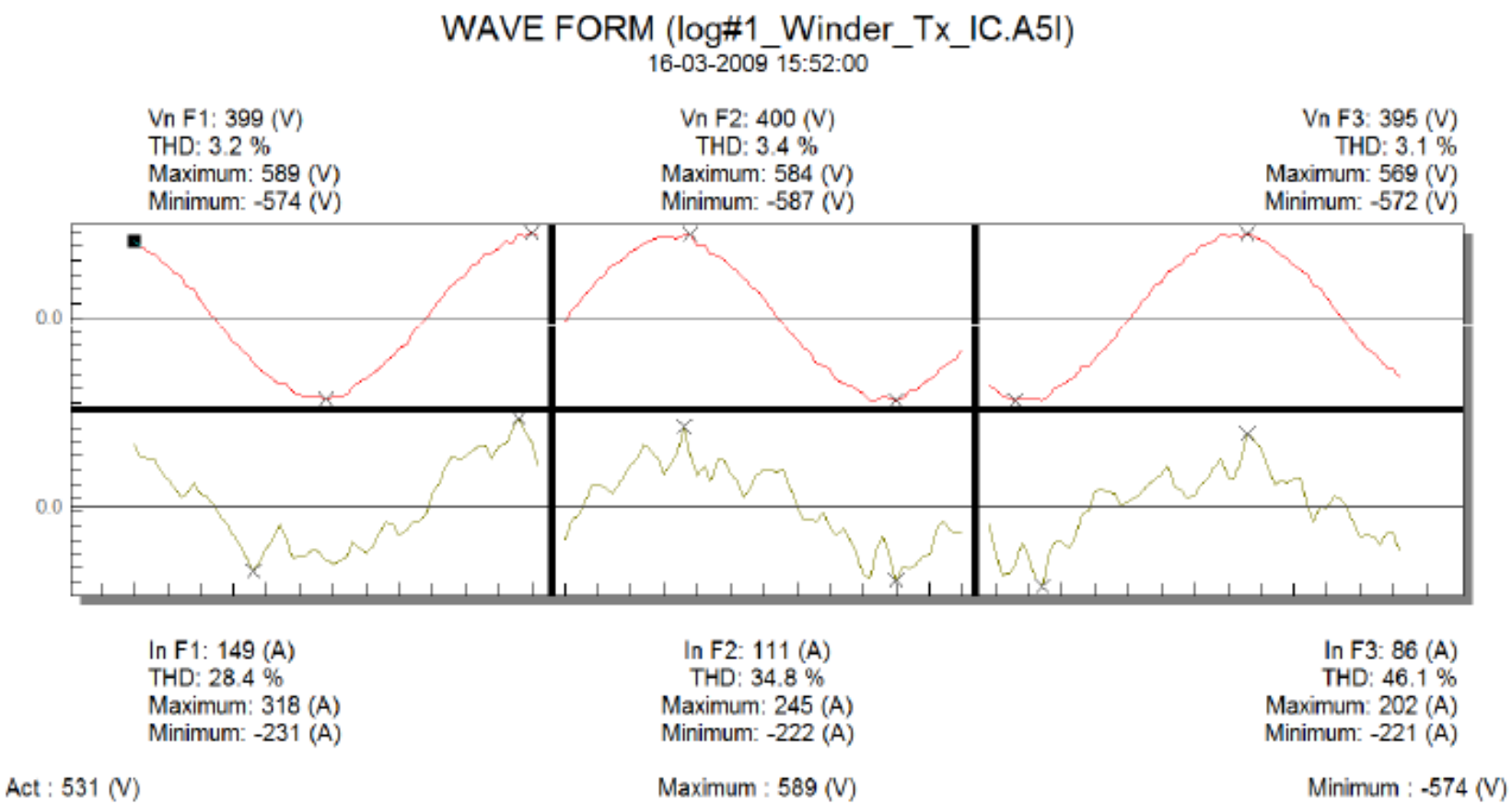
Feeder #1

- Winder Transformer
- LT Mains Incomer (Star winding)

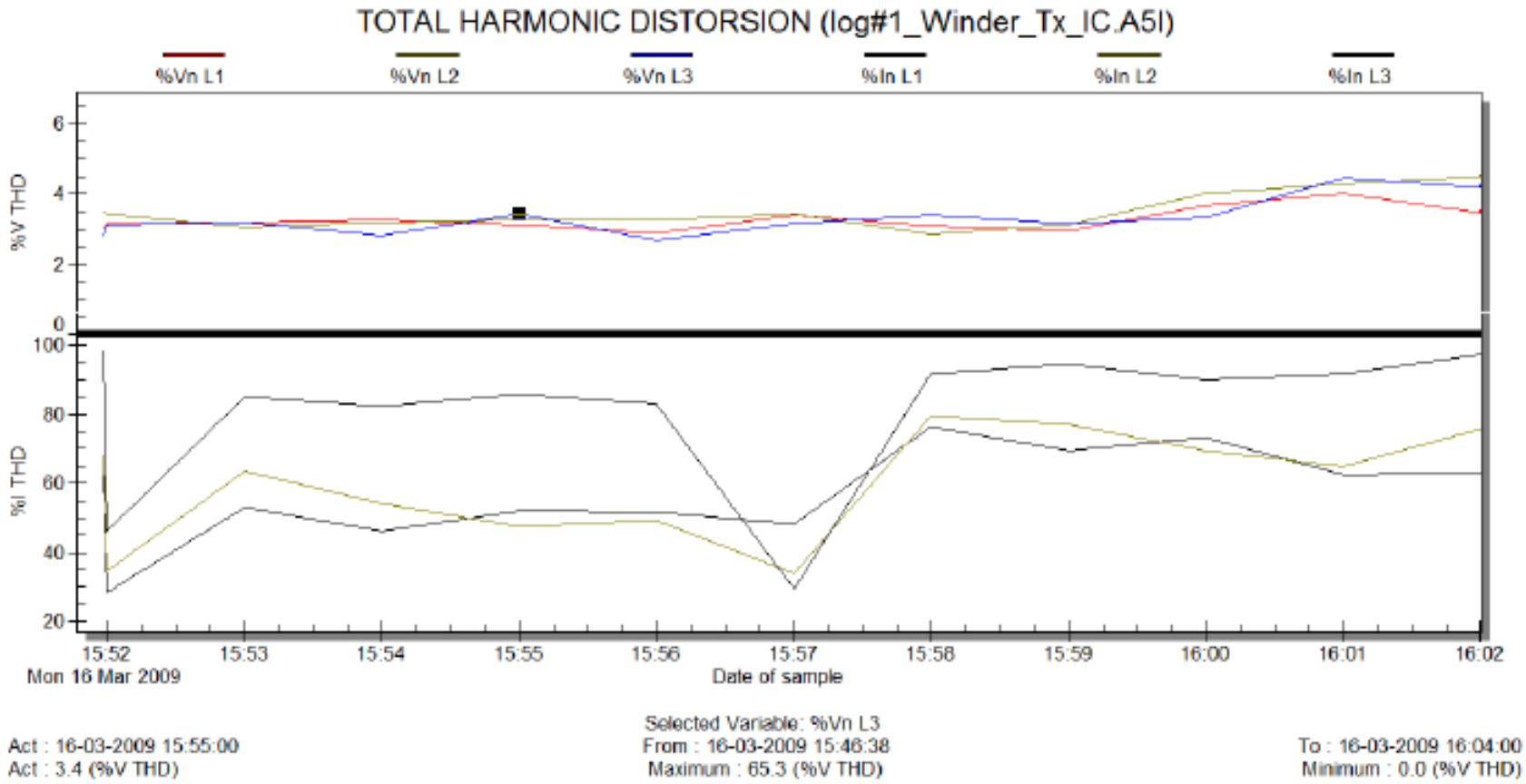
V & A – RMS



V & A – Waveforms



V & A – %THD: Total Harmonics Distortion



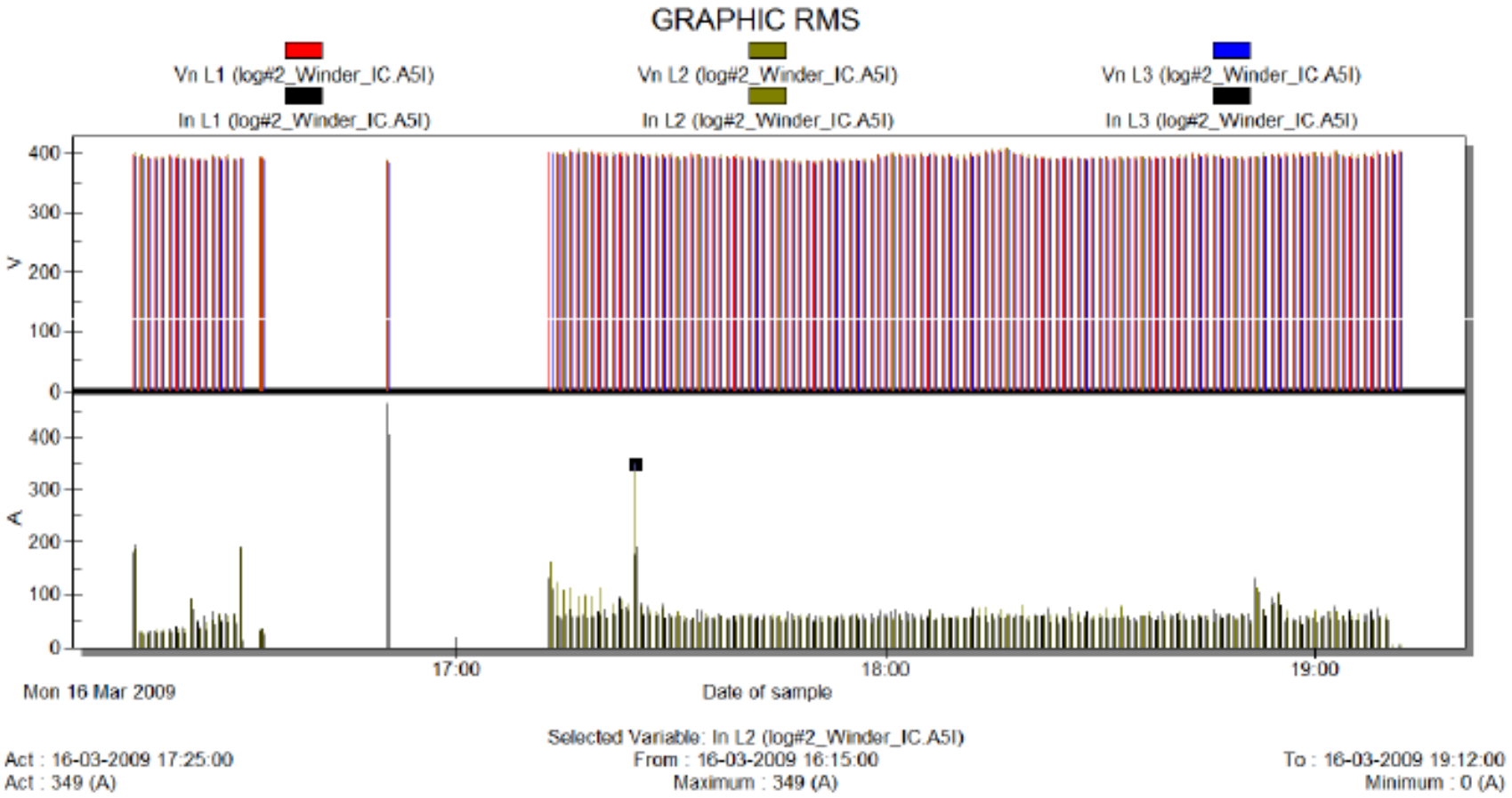
Observations:
Winder Transformer Secondary Mains Incomer

- V-THD: 3.4% < 6.0%
- I-THD: 28% < 80%
- Crest Factor: V – 1.45, I – 2.12
- Predominant Harmonics: 5, 7
- Neutral to Earth Voltage: 30V (floating neutral). This was due to common neutral-earth grid for all transformers.

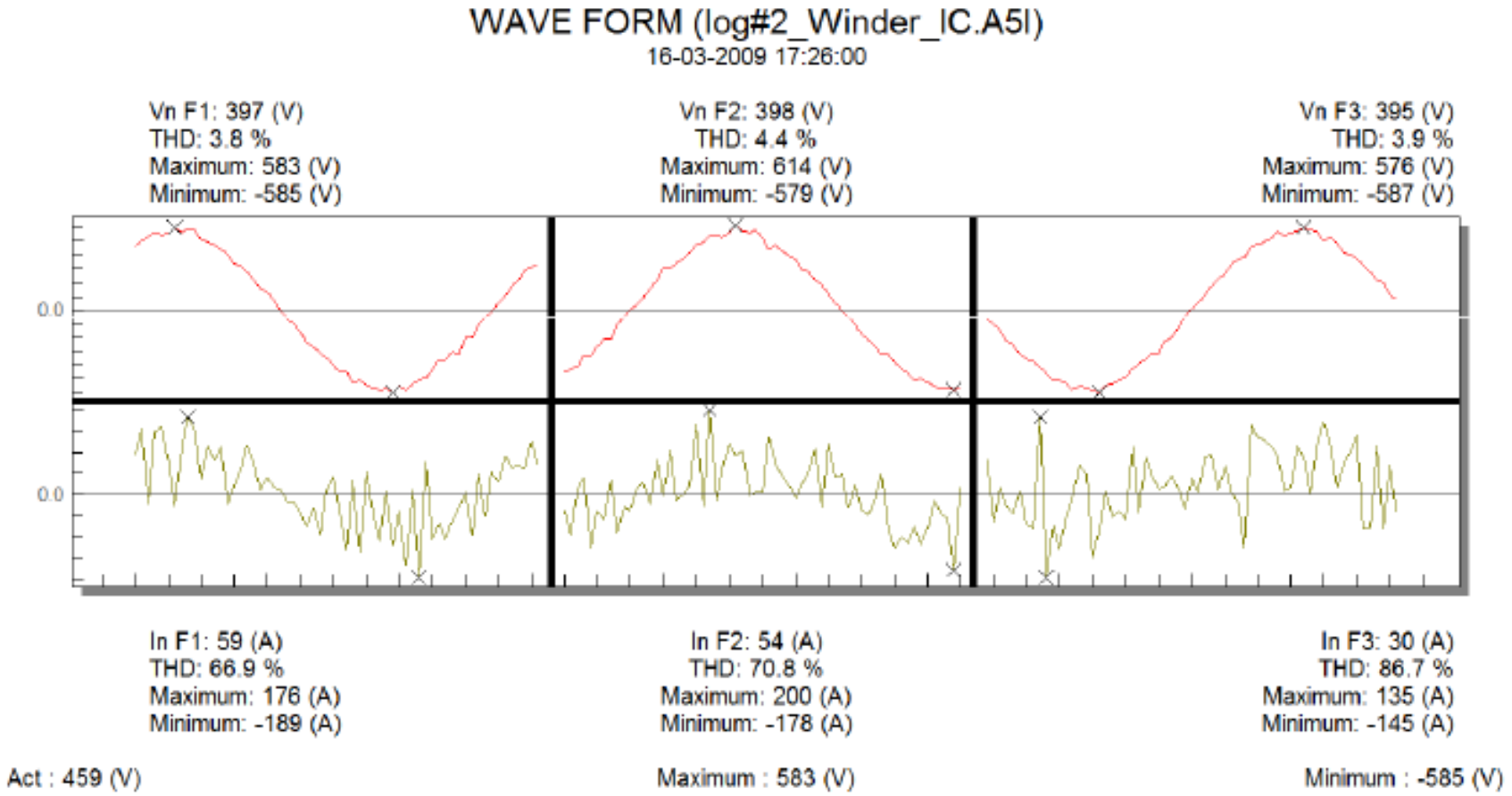
Feeder #2

- Winder VFD Panel
- Sub-mains Incomer (Input side of VFD)

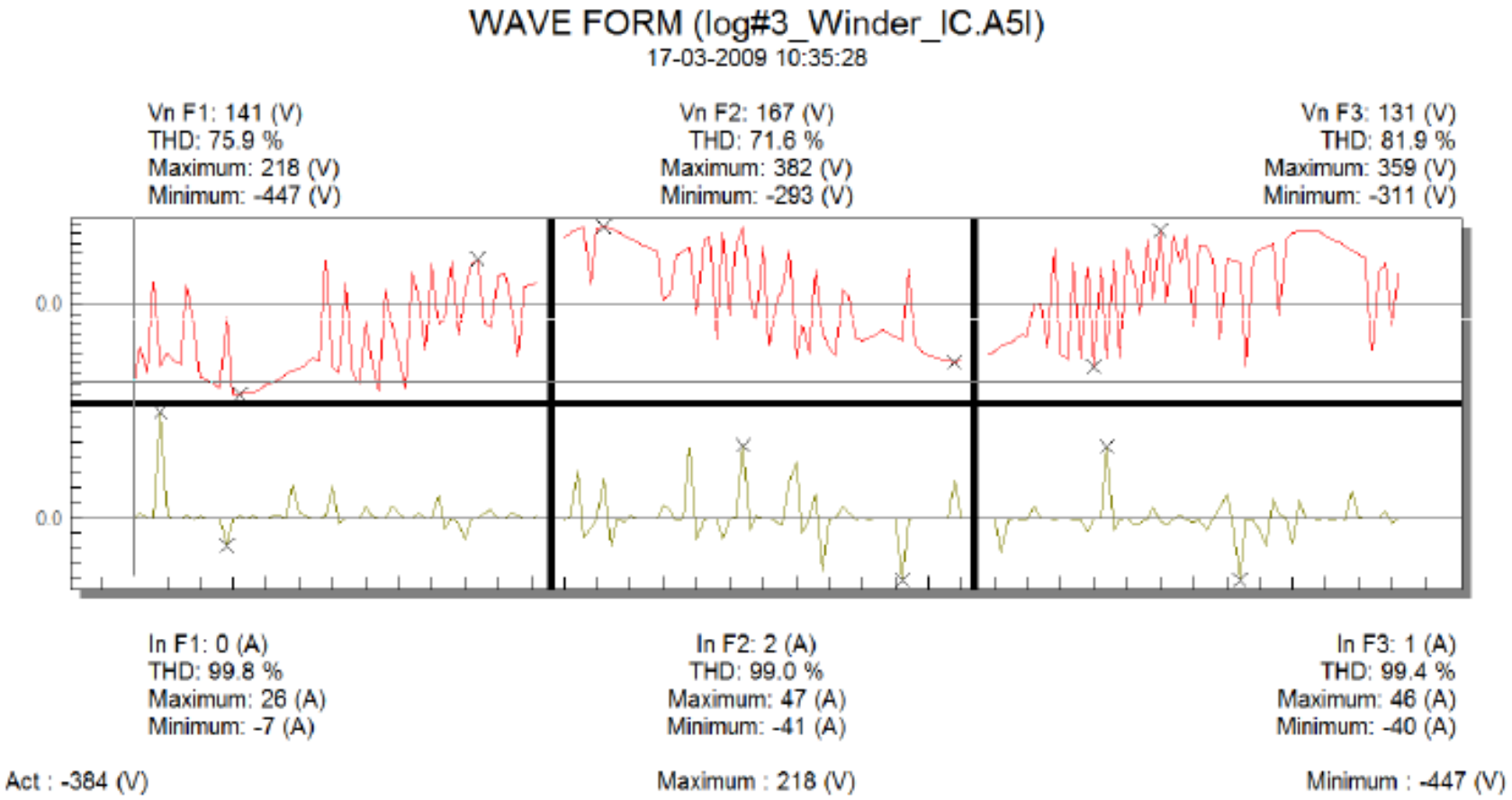
V & A – RMS



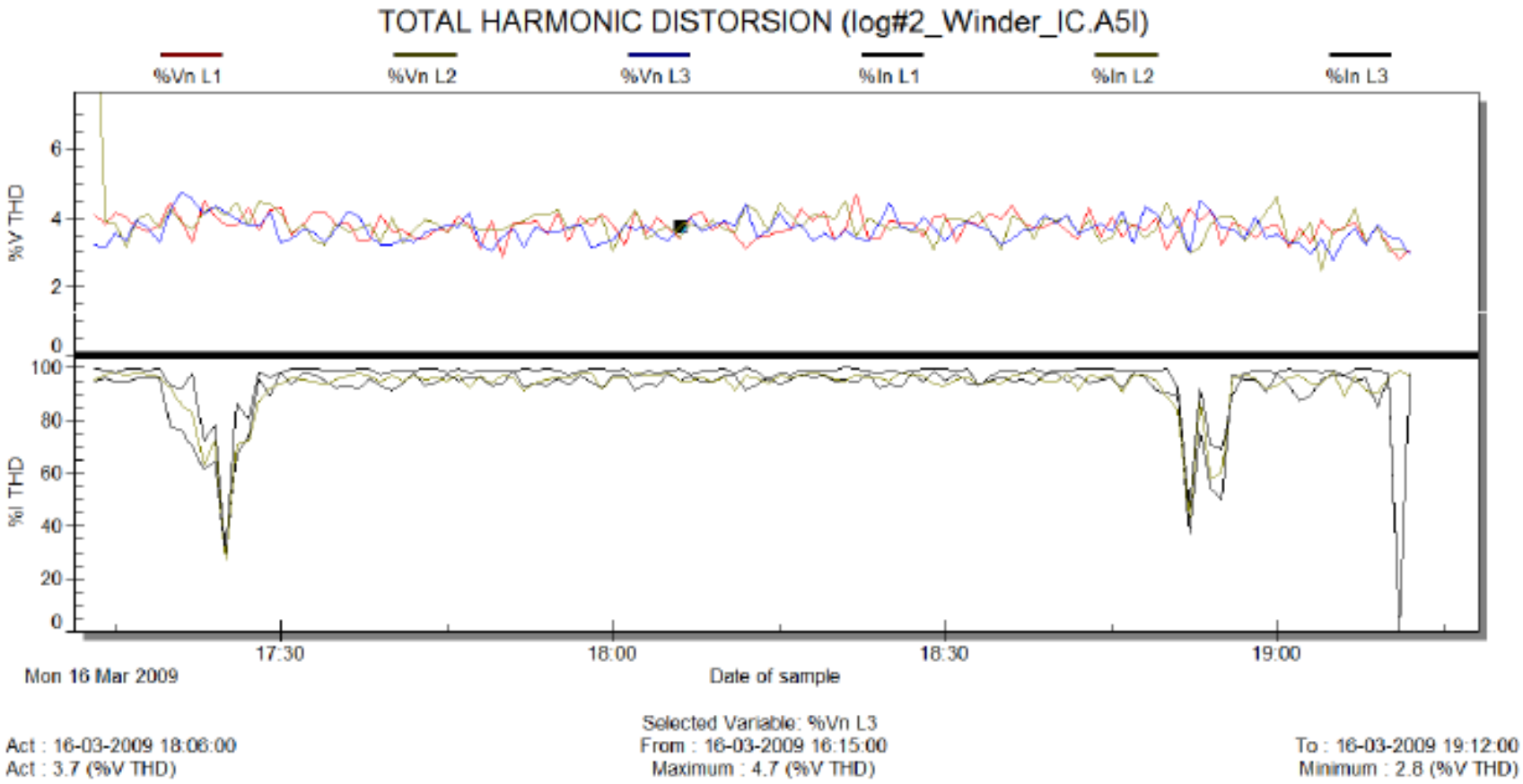
V & A – Waveforms: between Line-Line (Drive Input)



V & A – Waveforms: Line-Earth



V & A – %THD: Total Harmonics Distortion



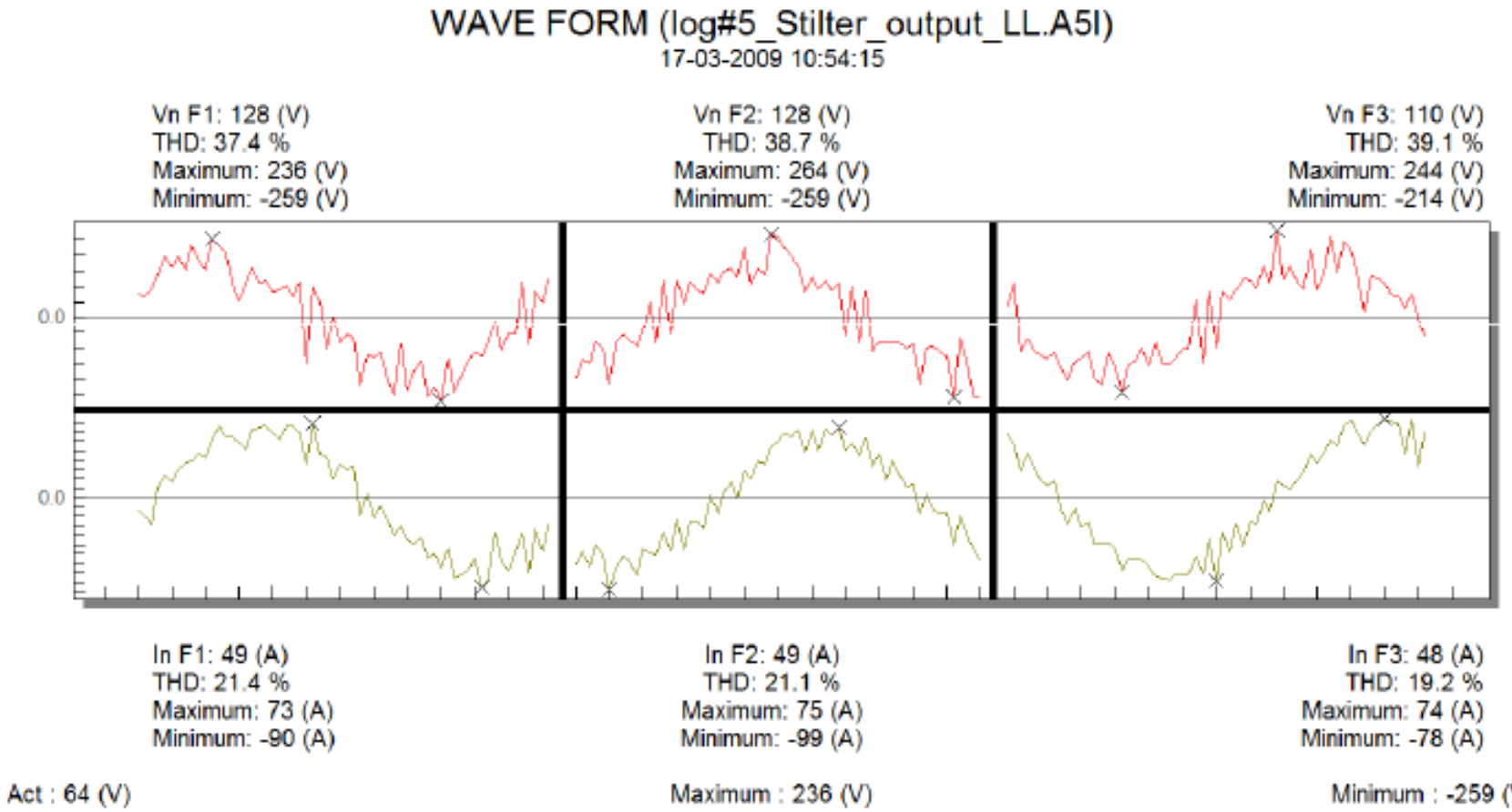
Observations

- V-THD: 3.4% < 5.0% (3 phase without Earth)
- V-THD: 70% <85% (3 phase with Earth)
- Crest Factor: V – 1.45, I – 3.5 to 4.0
- Predominant Level of Harmonics: 2^{nd}, 5^{th} , 7^{th}
- Neutral to Earth Voltage: 30V
- Unbalance condition of 3 phase voltages with high dv/dt pulses with reference Earth indicates presence of common and differential mode noise signals in the circuit.

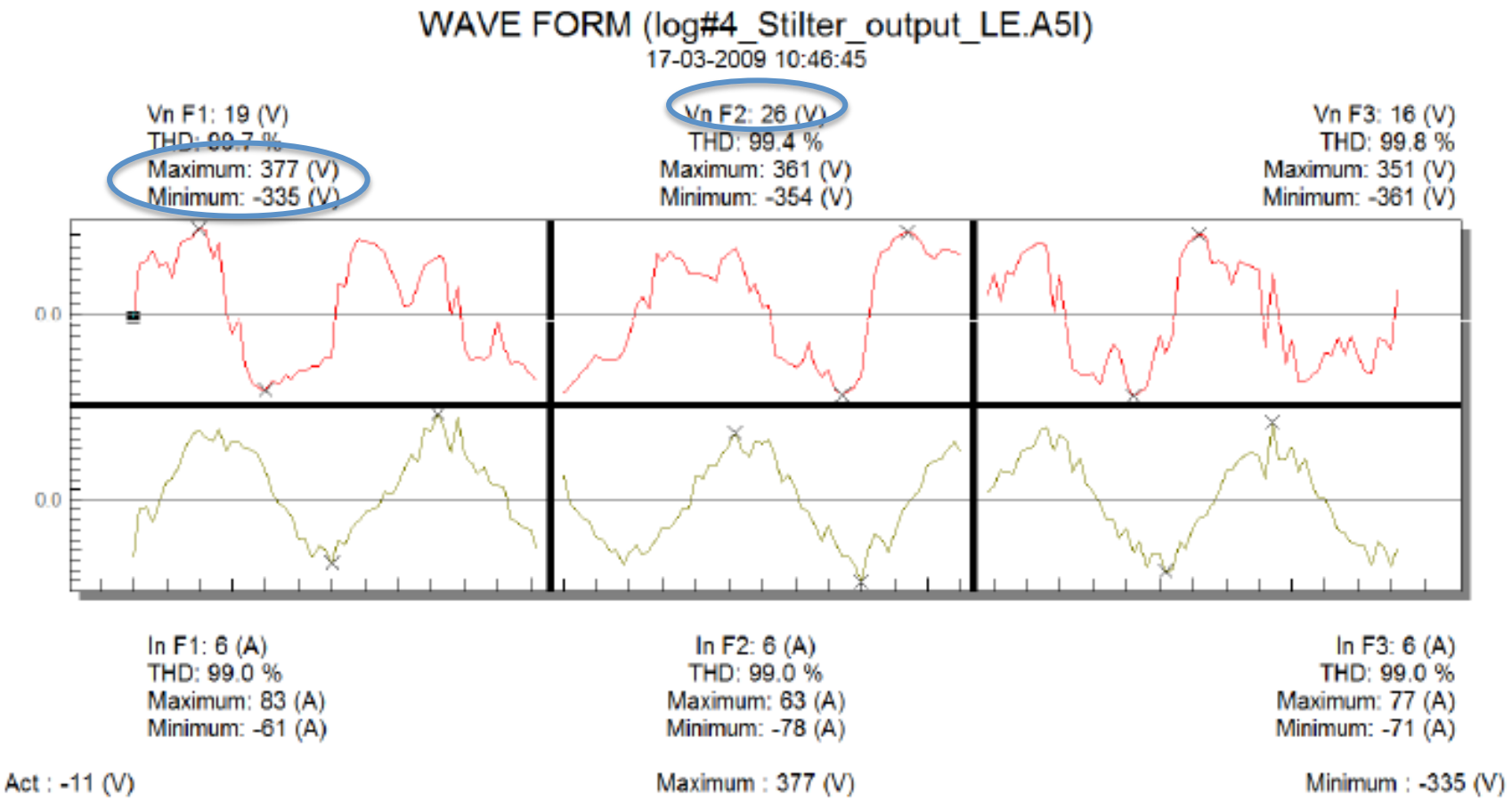
Feeder #3

- Slitter VF Drive
- Output Mains

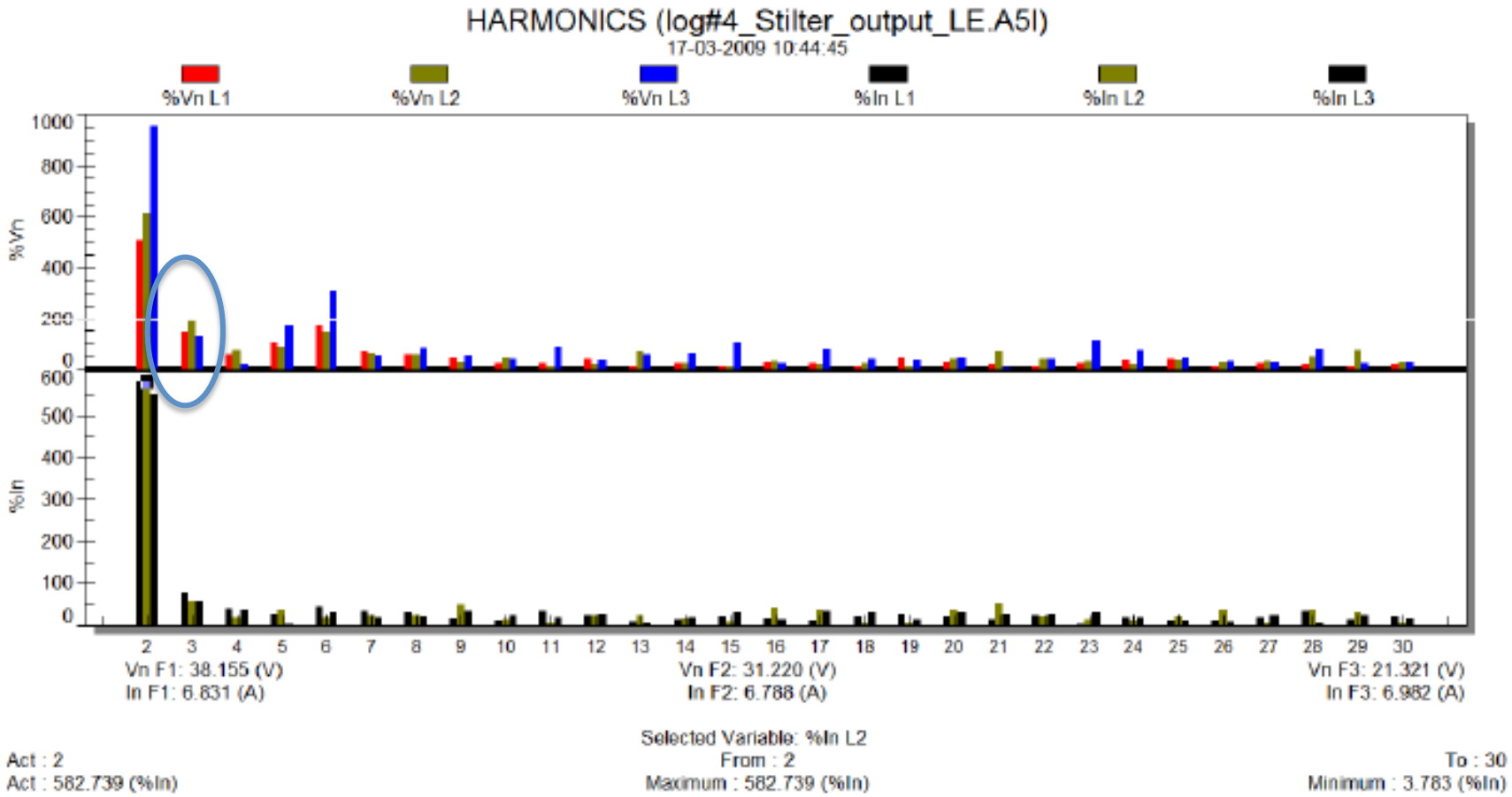
Waveforms: Line-Line



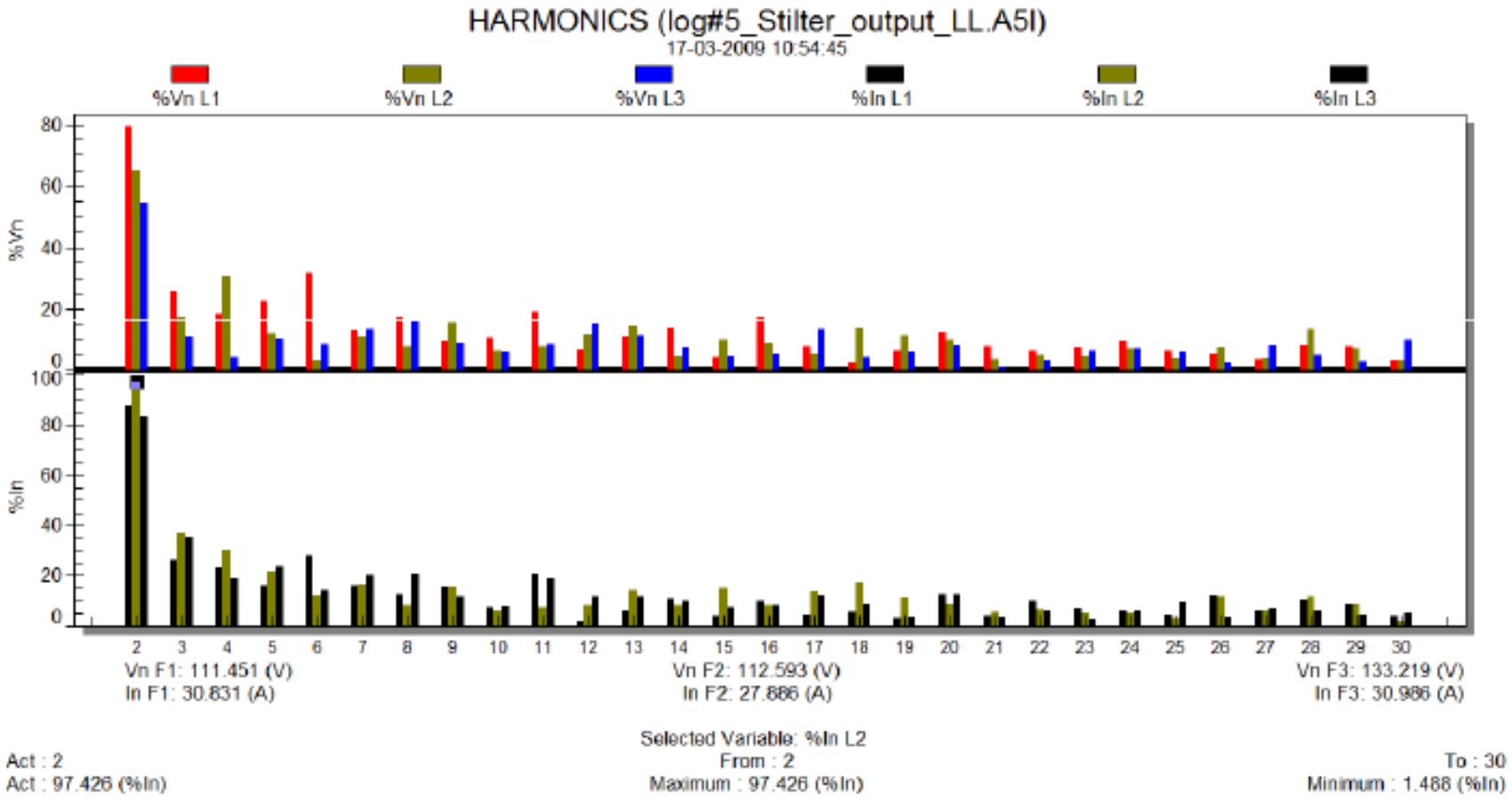
Waveforms: Line-Earth



Harmonics: Drive output Line-Earth



Harmonics: Drive output 3phase



Observations:
Power Quality Slitter Drive Output

- Feeder 3: Slitter Drive Output – Observations Summary
- V-THD: 98.5% < 101% (with earth reference)
- V-THD: 37% < 62% (without earth reference)
- Crest Factor: 1.41 upto > 20
- Predominant Level of Harmonics: 2nd (with & without earth reference) indicates differential mode noise signals.
- Voltage peak (with reference Earth): 377V, when RMS is 19V. Indicating severe leakage potentials in ground path.

Diagnosis of PQ measurements

Observations: Power Line Disturbances

- Presence of High frequency common mode & differential mode noise signals at VFD input and output between 3 phase and Reference Earth: 167V (at no-load), 377V to 600V (at loading condition)

- 2nd Harmonics (100Hz) in Voltage and Current found predominant at Drive input and output during loading conditions.

Findings: Mechanical Failures of Motors

- Common and differential mode noise signals in 3phase Power Lines which periodically exceeds dielectric strength of air gap between stator windings and rotor laminates, migrate from rotor to shaft looking for a ground path for discharge.

Findings: Failures of Motors…

- The stray voltages find opportunities to overcome dielectric strength of lubricating oil film between bearings and shaft.
- Relatively large discharge in a small area causes damage that starts with Pitting.
- Progressive Pitting leads to Frosting and Fluting.
- Added friction in the bearing raceway leads to heating and finally failure of the motor.

Findings: Failures of Control Module Power Supplies

- Failure of Control Cards' and Control Module Power Supply's electronics component was due to stray Voltages and noise pollution from common ground (all ground connected together and termed as equipotential bonding)

Earthing System

Observations and Findings

Findings: Earthing Configuration…contd.

- VFD POWER PANEL:
  - PE and Body earthing – connected to common Body Earth GI Bonding conductor – forming multiple ground loops.

- VFD Output Slitter Motor Earthing
  - Body Earthing – connected to Body Earth GI Bonding Conductor – forming ground loop.

Summary of findings and observations

- Power Quality Disturbances:
  - Common and Differential mode noise signals.

- Coupling Channels:
  - Formation of Multiple ground loops between Neutral, PE and Bonding Conductors.
  - Absence of Noise Mitigation Techniques & Devices.

Remedial Measures and Solutions

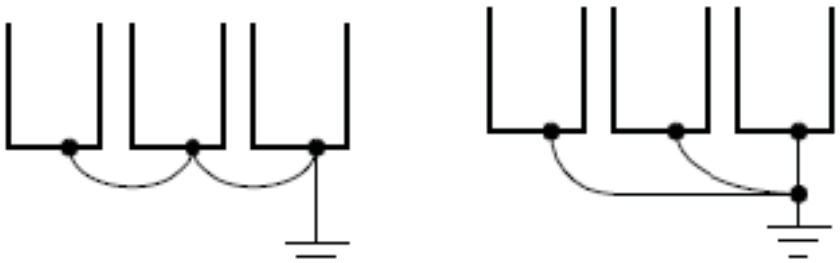
Rx-1: Earthing Recommendations

- Separation of Transformer Neutral Earth (from grid and from each other)
- Separation of Transformer Body Earth (from grid and from each other)
- Separation of Circuit Protective Conductor (PE) from Bonding Earth Conductor at VFD Power Panel.

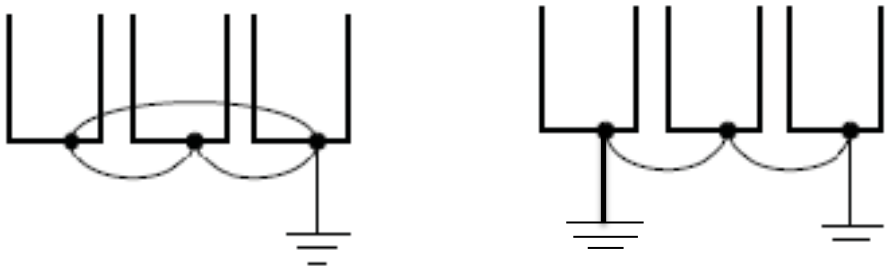
- Spark Gap Surge Arrestors for Equipotential Bonding between following Earth Grids / Points.
  - Neutral Earthing and Body Earthing for transformers
  - Circuit Protective Conductor (PE) and Bonding Earth Conductor for Drive panels.

Rx-1: Earthing Recommendations…

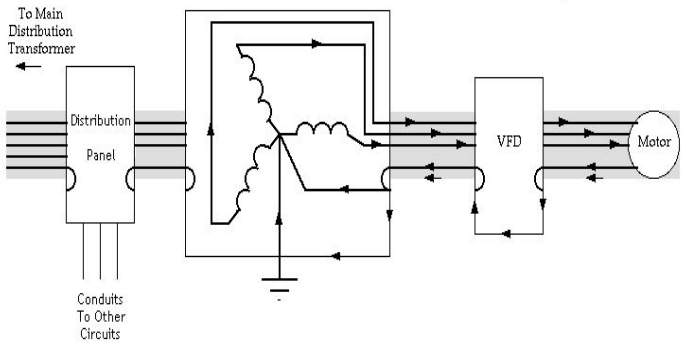
- Eliminate multiple Ground loops:
- Correct loops



- Incorrect loops

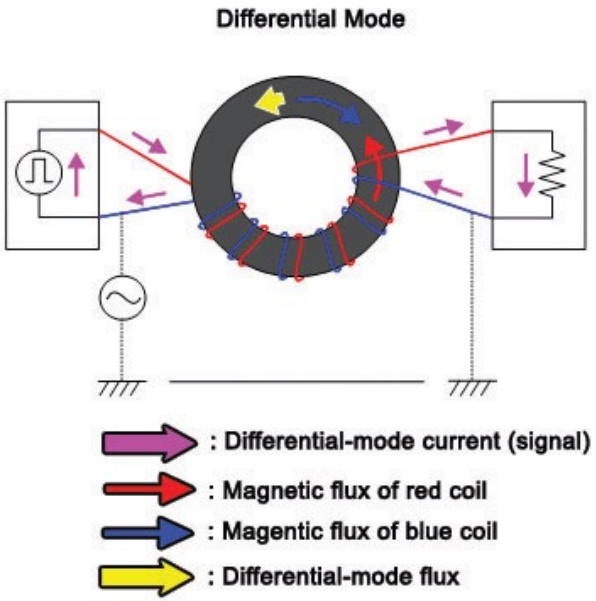


Rx 2. Noise Mitigation: VFD Input



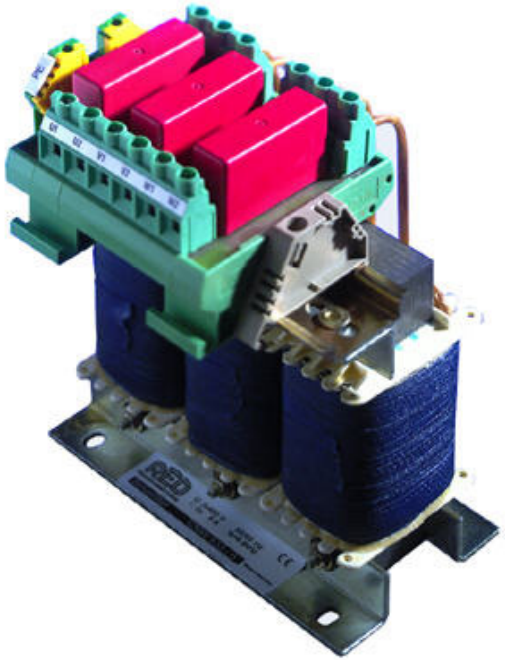
- Isolation Transformer to isolate power circuits from control modules and control circuits.

Rx 3. Noise Mitigation: VFD Output



- Toroidal Core series reactor to mitigate differential mode noise signals.

Rx 4. Noise Mitigation: VFD Output



- Provide suitable dv/dt filter

Rectification and Corrective Actions (RCA)

Variable Frequency Drive input and output

RCA: Earthing

- Earthing Recommendations – implemented.
  - Separation of Neutral Earthing and Body Earthing of all 8 transformers from the Earth Grids.
  - Separation of VFD Panel Body Earth and PE (Circuit Protective Earth) Conductors
  - Elimination of ground loops formation.

RCA: VFD

- Noise mitigations – implemented.
  - Instrument grade isolation transformer for I/O control modules Power Supply and control circuit wiring.
  - dv/dt filters to mitigate high frequency reflected or resonated amplified voltage signals by output cable length R-L-C tuning circuit components.
  - Toroidal core reactors to mitigate Diff. mode noise signals.

Post Rectification Audit

WINDER – VFD – INPUT & OUTPUT

Power Quality Study

Variable Frequency Drive Input & Output

Feeder #2

- Winder VF Drive Panel
- Sub-mains Incomer

Observations: Slitter VFD input

After

- V-THD: 20%-30% (3ph-Earth)
- Predominant Harmonics: 2, 5, 7
- Neutral to Earth Voltage: 2.5V < 6.9V

Before

- V-THD: 70% <85% (3ph-Earth)
- Predominant Level of Harmonics: 2, 5, 7
- Neutral to Earth Voltage: 2.5V to 30V

Feeder #3

- Slitter VFD
- Output Mains

Observations: Slitter VFD Output

After

- V-THD: 15% < 35% (with earth reference)
- V-THD: 10% < 30% (without earth reference)
- Crest Factor: <5
- Predominant Harmonics: 2nd (with & without earth reference)
- Voltage peak: 25V, when RMS is 19V.

Before

- V-THD: 98.5% < 101% (with earth reference)
- V-THD: 37% < 62% (without earth reference)
- Crest Factor: > 20
- Predominant Harmonics: 2nd (with & without earth reference)
- Voltage peak: 377V, when RMS is 19V.

VFD

Ground Noise Pollution

End Of
Presentation

EFFICIENERGI CONSULTING
PVT LTD.
MUMBAI
INDIA.