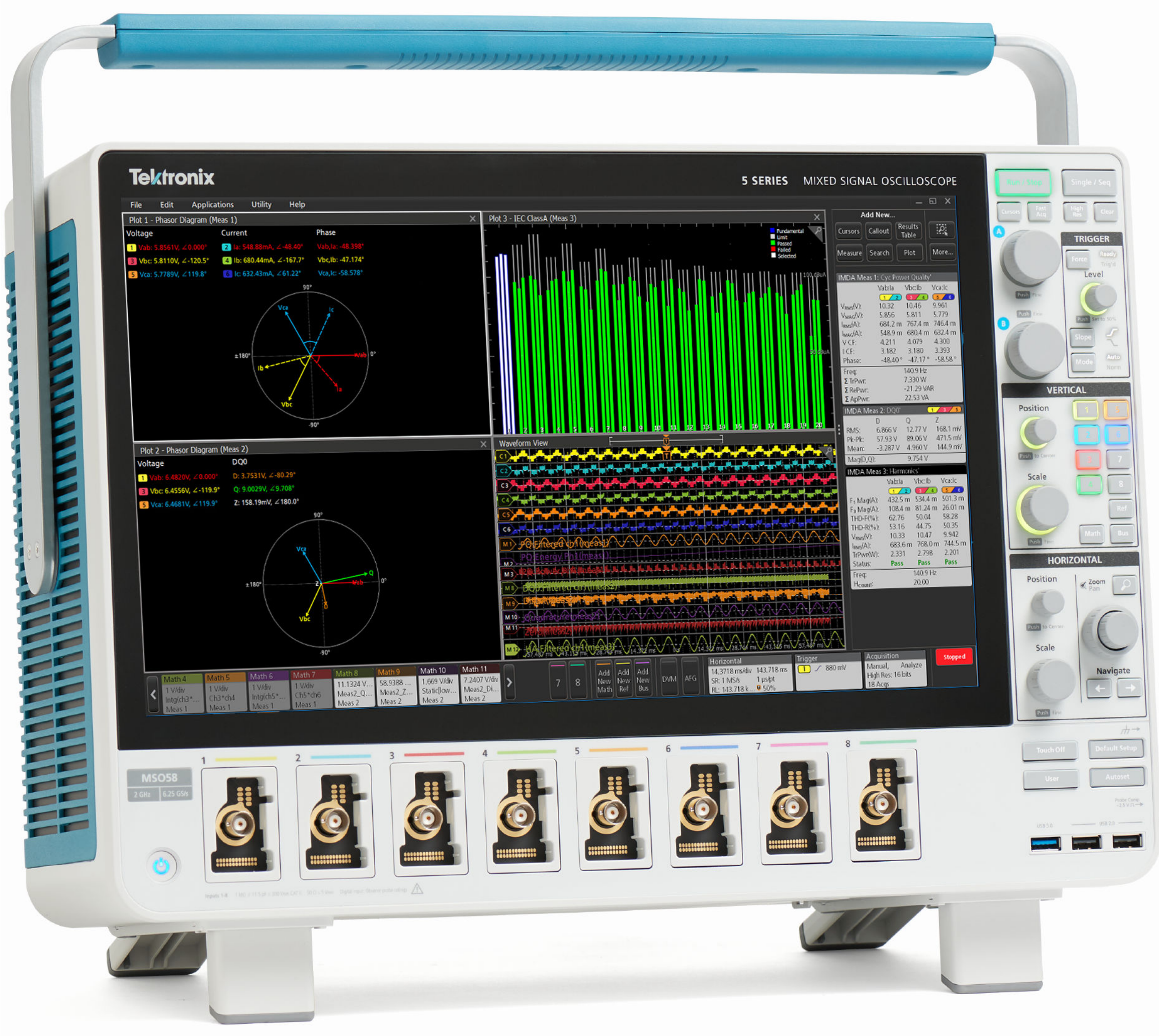
Tektronix®

3-Phase Inverter Motor Drive Analysis

5 Series/6 Series B MSO Option 5-IMDA/6-IMDA Application Datasheet

Get more visibility into your inverters, motors, and drive systems



Measurements and analysis on three-phase power systems are inherently more complex than on single-phase systems. Although oscilloscopes can capture voltage and current waveforms with high sample rates, further calculations are required to produce key power measurements from the data. The oscilloscope based three-phase solution allows to capture three-phase voltage and current waveforms with higher sample rates, longer record lengths using the HiRes acquisition mode that goes up to 16-bits and with the support of automated measurements produce key power test results. The Power converters based on Pulse Width Modulation (PWM), such as variable-frequency motor drives can complicate measurements since it is very important to extract precise zero crossings for the PWM signals, thus making an oscilloscope a recommended test tool for validation and troubleshooting for motor designers. Special software, designed to automate power analysis on inverters, motors, and drives, greatly simplifies important three-phase power measurements on PWM systems and can help engineers get faster insights into their designs. The Inverter Motor Drive Analysis (IMDA) solution from Tektronix helps engineers design better and more efficient three-phase motor drive systems, taking full advantage of the advanced user interface, six or eight analog input channels, and 'High Res' mode (16 bits) on the 5 Series/6 Series B MSO. The IMDA solution provides fast, accurate, and repeatable results for electrical measurements on industrial motors and drive systems for AC induction motors, permanent magnet synchronous motors (PMSM), and brushless DC (BLDC) motors. It can be configured to measure DC to three-phase AC converters, such as those used in the electric vehicles.

Key features and specifications

- Accurately analyze three-phase PWM signals used to drive AC induction, BLDC, and PMSM motors.
- Unique oscilloscope based phasor diagrams indicate V_{RMS}, I_{RMS}, V_{MAG}, I_{MAG}, and phase relationships at a glance for the configured wiring pairs.
- Debug motor drive designs by viewing the drive input/output voltage and current signals in the time domain simultaneously with the phasor diagram.
- Three-phase Autoset feature configures the oscilloscope for optimal horizontal, vertical, trigger, and acquisition parameters for acquiring three-phase signals.
- Measures three-phase harmonics per the IEC-61000-3-2, IEEE-519, or custom limits.
- Measures the system efficiency based on the selected wiring configurations.
- Quickly add and configure measurements through the intuitive drag and drop interface on the 5 Series / 6 Series B MSO.
- Analyze Inverter and Automotive three-phase designs for DC input and AC output wiring configuration.
- Displays the PWM filtered edge qualifier waveform during analysis.
- Displays the test results per Record, or per Cycle mode during analysis for specific measurements.
- Supports Time trend and Acquisition trend plots for specific measurements.
- Supports mathematical conversion of Line-Line to Line-Neutral for specific wiring.
- Supports DQ0 measurements with the phasor plot.

Measurement overview

Three-phase power converters such as variable frequency drives require a range of measurements during the design process. The Inverters, Motors, and Drives Analysis package for the 5 Series/6 Series B MSO automates key electrical measurements which are grouped into the Electrical Analysis group. The measurements can be configured to measure the Input or Output wiring configuration.

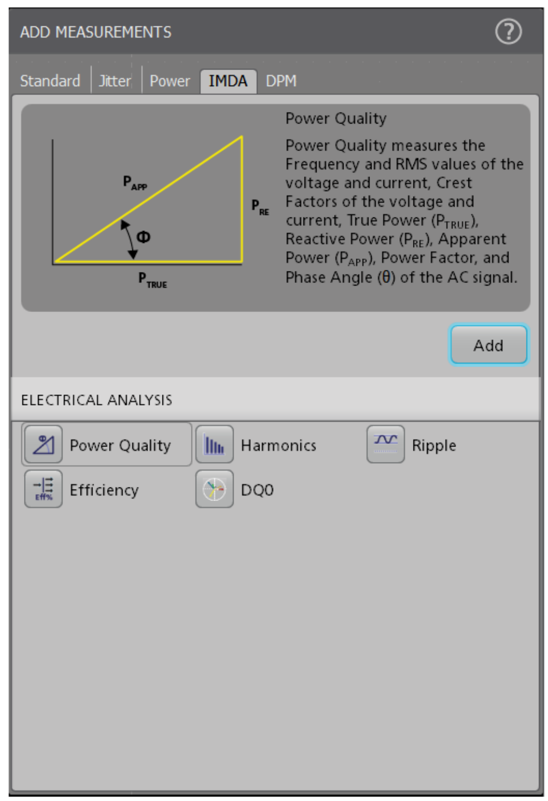


Figure 1: IMDA measurements under Electrical Analysis group

The measurements can be set to measure 1V1I (1-Phase-2-Wire), 2V2I (1-Phase-3-Wire), 2V2I (3-Phase-3-Wire), 1V1I (1-Phase 2-Wire DC) or 3V3I (3-Phase-3-Wire), and 3P4W (3-Phase-4-Wire) to support various supply and motor configurations. Measurements can be performed line-to-line or line-to-neutral, to support delta and wye or star configurations.

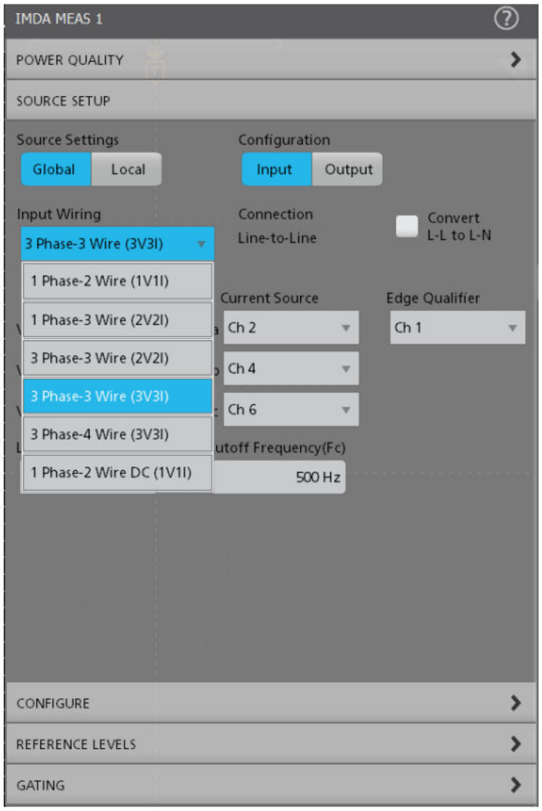


Figure 2: Configuring the measurement for Input wiring configuration

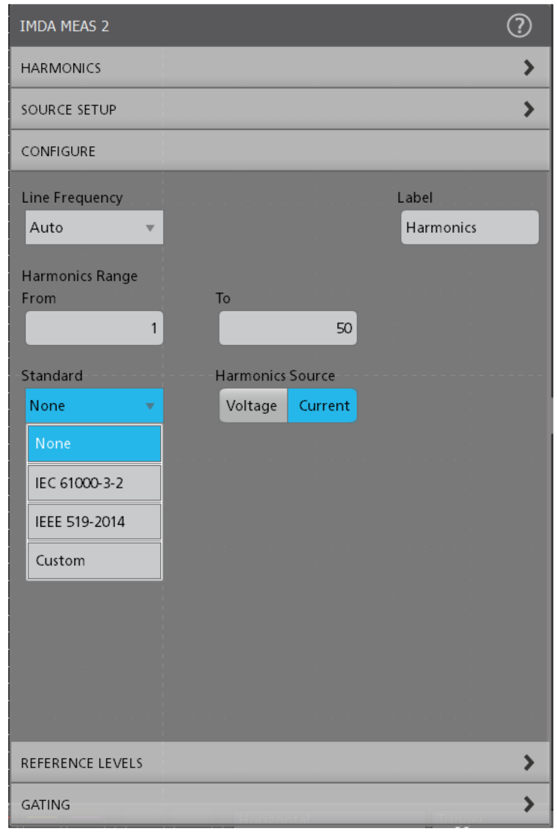


Figure 3: Compare harmonics measurements against industry standards or custom limits

Harmonics

Power waveforms are rarely textbook sinusoids. Harmonics measurements break down non-sinusoidal voltage or current waveforms into their sinusoidal components, indicating the frequency and amplitude for each component.

Harmonics analysis can be performed up to 200th harmonic order. The maximum harmonic order can be set to suit your needs by specifying the range in the measurement configuration. THD-F, THD-R and fundamental values are measured for each phase. Measurements can be evaluated against the IEEE-519 or IEC 61000-3-2 standard, or custom limits. Test results can be recorded in a detailed report indicating pass/fail status.

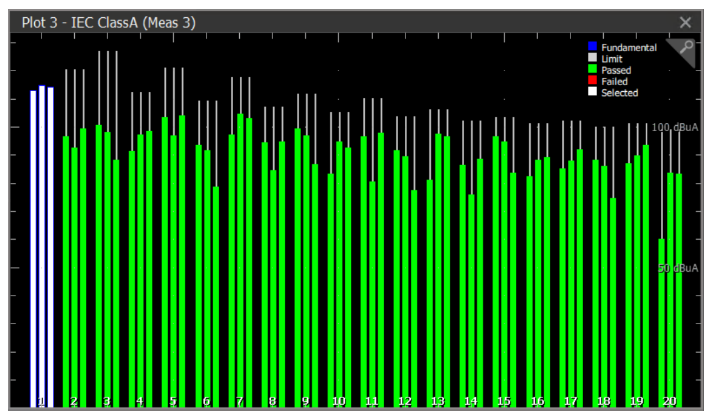


Figure 4: A sample harmonics plot indicates passing harmonics test results. Each set of bars contains results for Phase A, B, and C for easy correlation.

The Harmonics plot shows the test results for all three phases grouped together so user can correlate the test results between the phases. The plot also shows the test results visually. The harmonics bars are highlighted in green color during a pass condition, and highlight to red color when it exceeds the test limits. This gives a quick insight to the user when debugging for harmonics design.

Power quality

This measurement provides critical three-phase power sub-measurements including: frequency and RMS magnitudes of voltage and current, crest factors of voltage and current, PWM frequency, and phase angle for each phase. It also displays the sum of true power, sum of reactive power, sum of apparent power components.

Additionally, in the Line-Neutral configuration, this measurement displays True Power, Reactive Power, and Apparent Power components of all the three-phases.

Voltage and current vectors can be displayed on a phasor diagram so you can quickly judge phase shift for each phase and the balance among phases. Each vector is represented by an RMS value and phase is computed using the Discrete Fourier Transform (DFT) method.

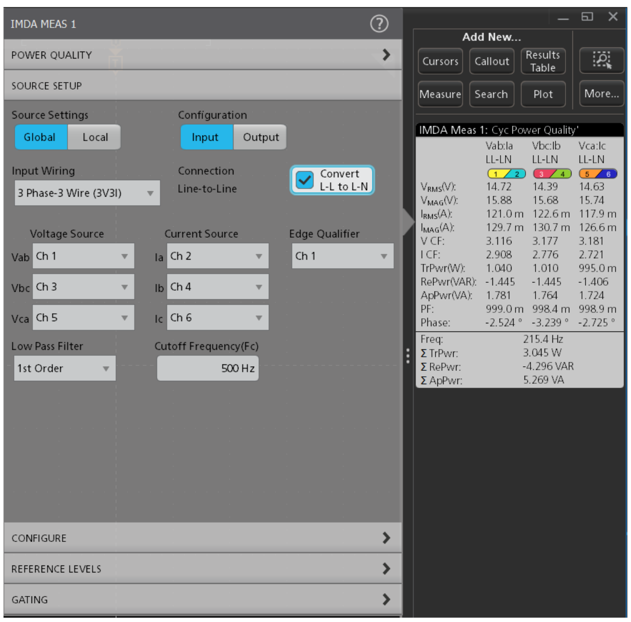


Figure 5: Easily configure the settings to get insight into the power quality

The Power quality measurement can be configured to provide critical three-phase power measurements on the output side, including: frequency and RMS magnitudes of voltage and current, crest factors of voltage and current, PWM frequency, true power, reactive power, apparent power, power factor, and phase angle for each phase.

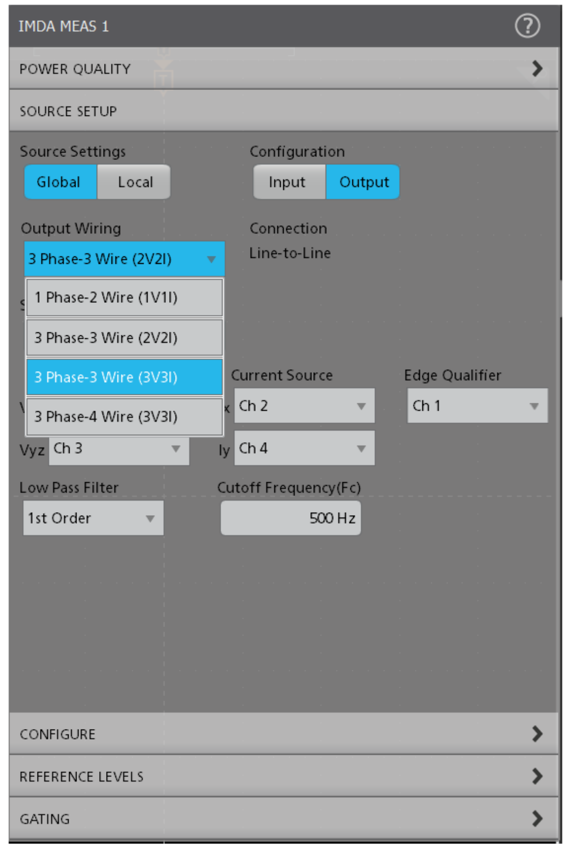


Figure 6: Easily configure the voltage and current inputs on the Power Quality measurement to display phasor diagrams

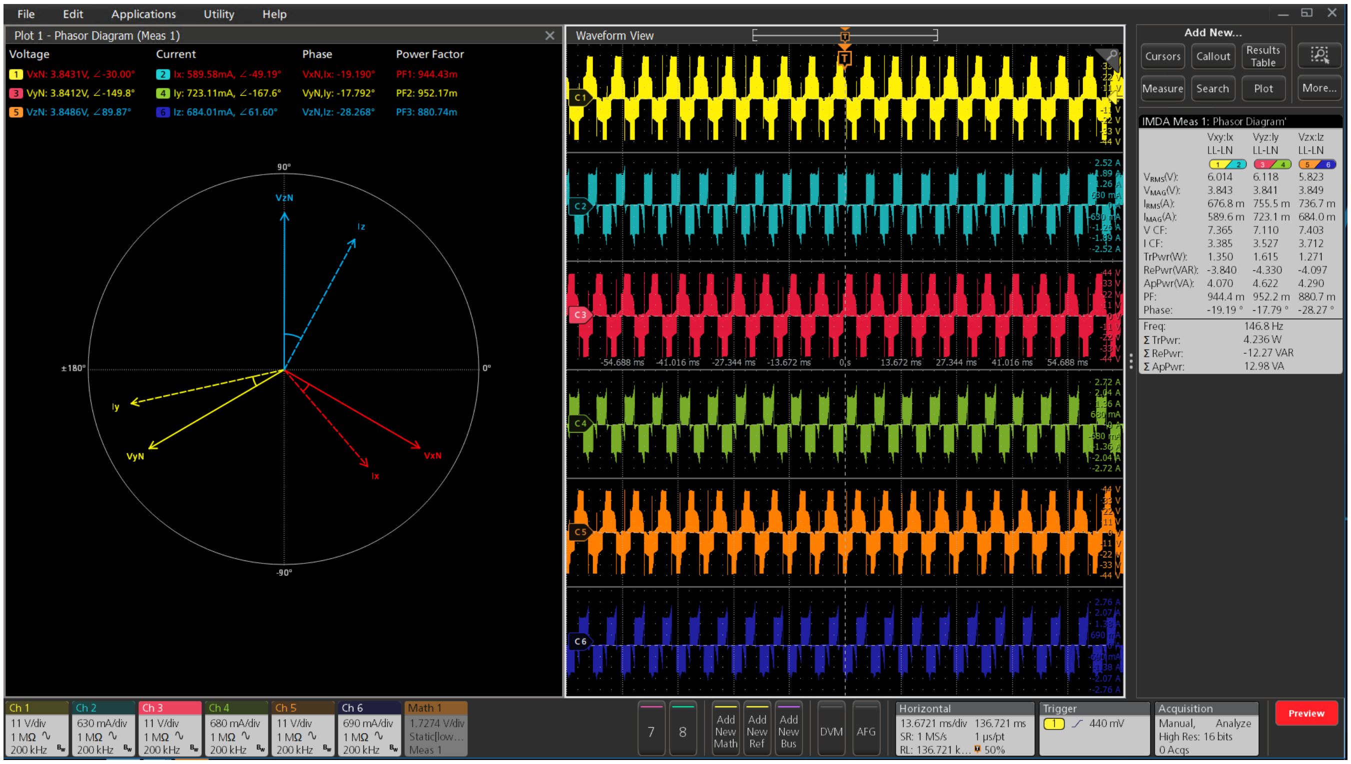


Figure 7: Unique oscilloscope based phasor diagram feature provides the relation between the voltage and current vectors

Efficiency

Efficiency measures the ratio of the output power to input power. The IMDA solution supports efficiency of three-phase AC and Inverter configurations. By using the 2V2I method, three-phase efficiency can be measured using eight oscilloscope channels (2 voltage and 2 current sources on the input side and 2 voltage and 2 current sources on the output side). The solution calculates efficiency at each phase (for 3V3I configuration) and the total (average) efficiency of the system based on the different input and output wiring combinations.

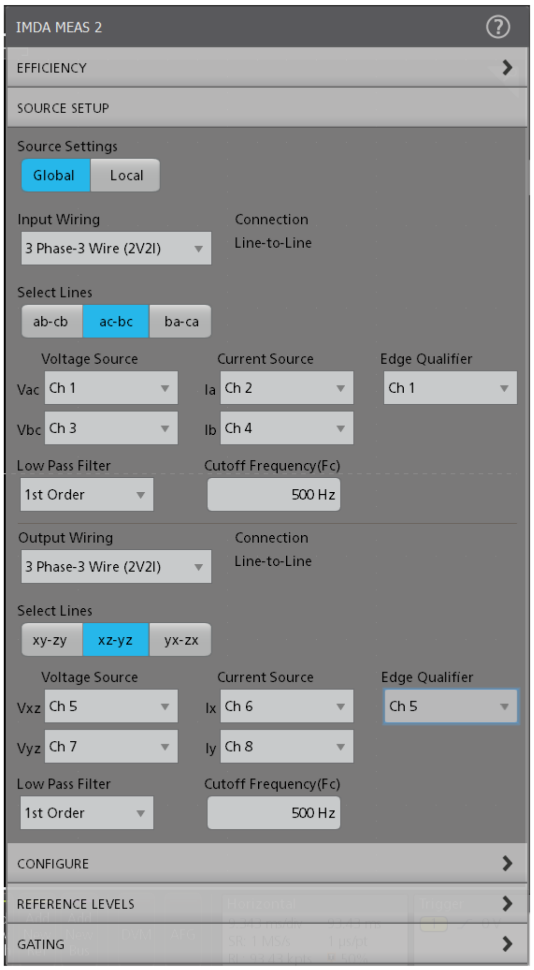


Figure 8: Configure wiring and filters to perform efficiency measurements for an Industrial motor

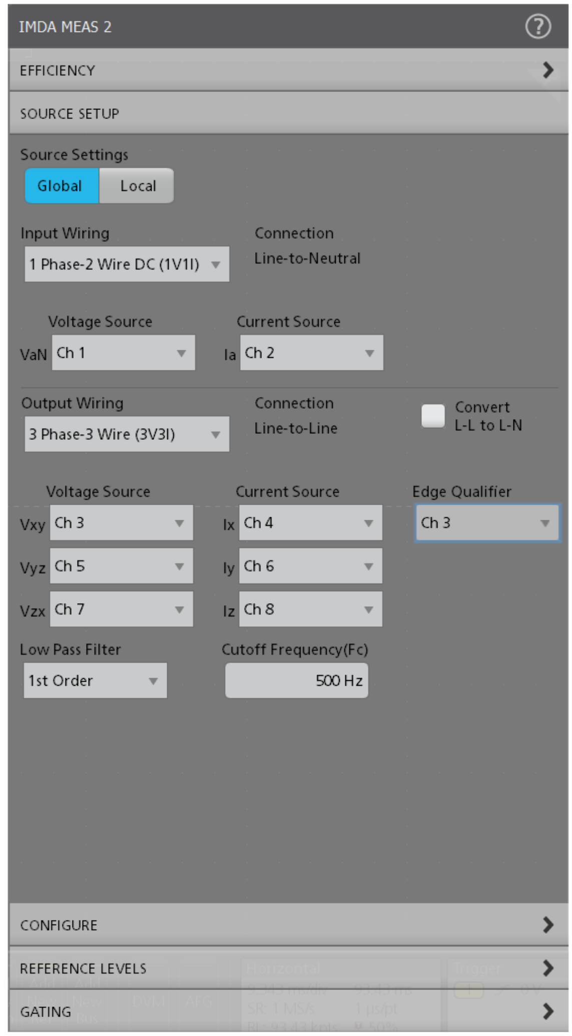


Figure 9: Configure wiring and filters to perform efficiency measurements for a DC-AC topology most suitable for inverter testing

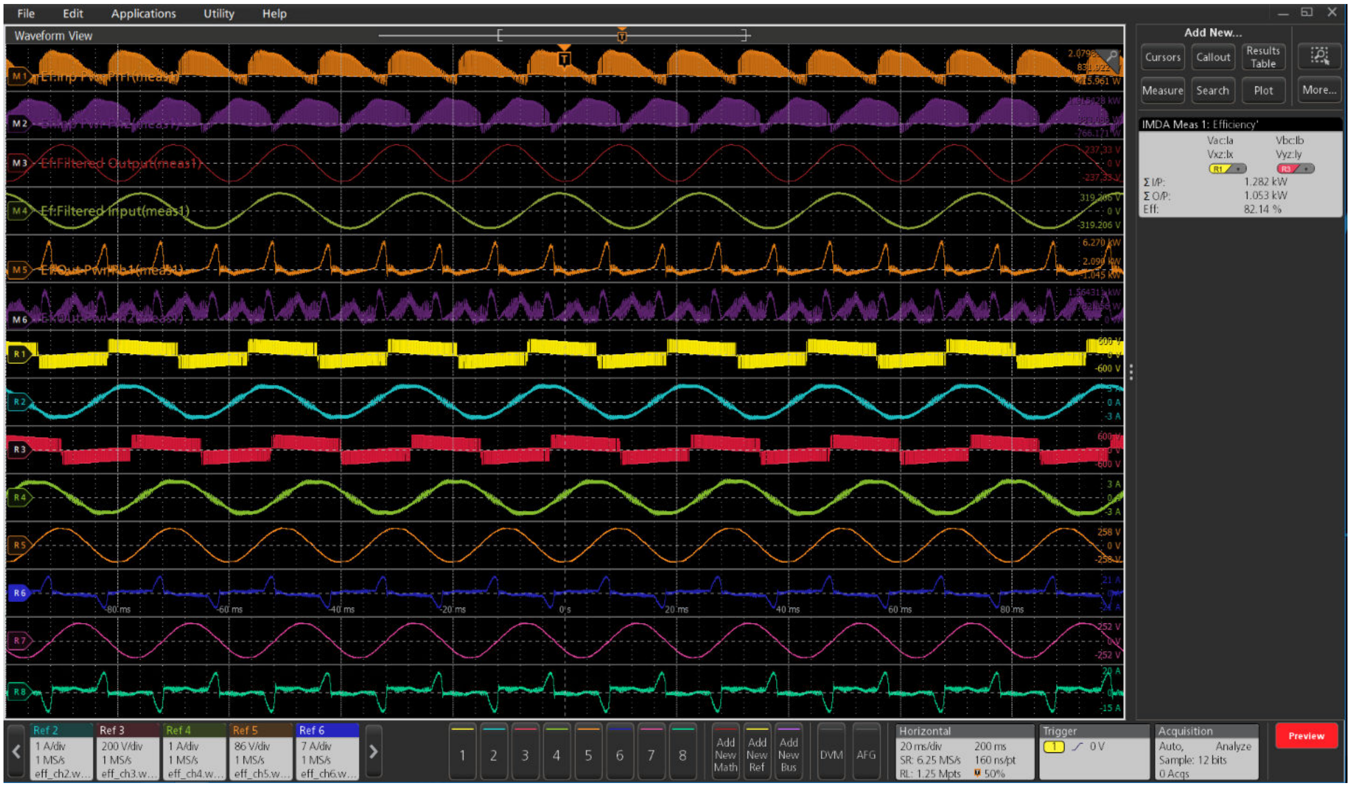


Figure 10: Get complete insight into the overall system efficiency

Ripple analysis

Ripple is defined as the residual or unwanted AC voltage on a constant DC component. It is typically measured on the DC bus. This measurement helps to understand how efficiently the signal is getting converted from AC-DC on the input side, and the impact of unwanted components on the PWM signal on the output side.

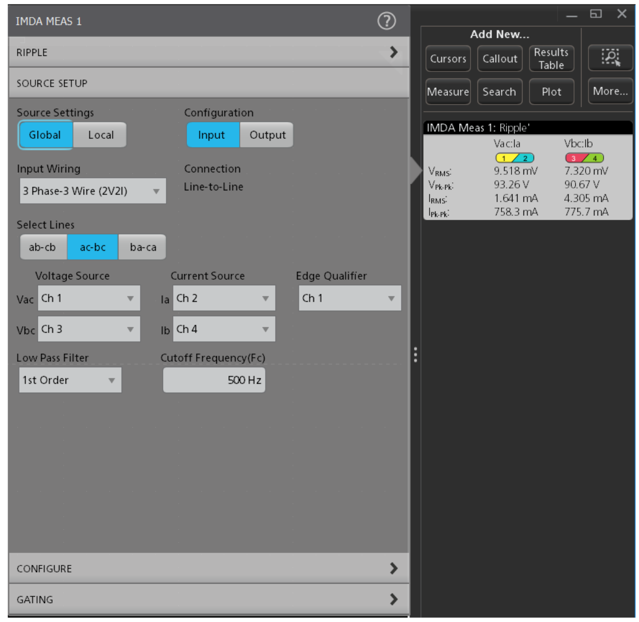


Figure 11: Ripple analysis configuration can be set to look into line and switching ripple

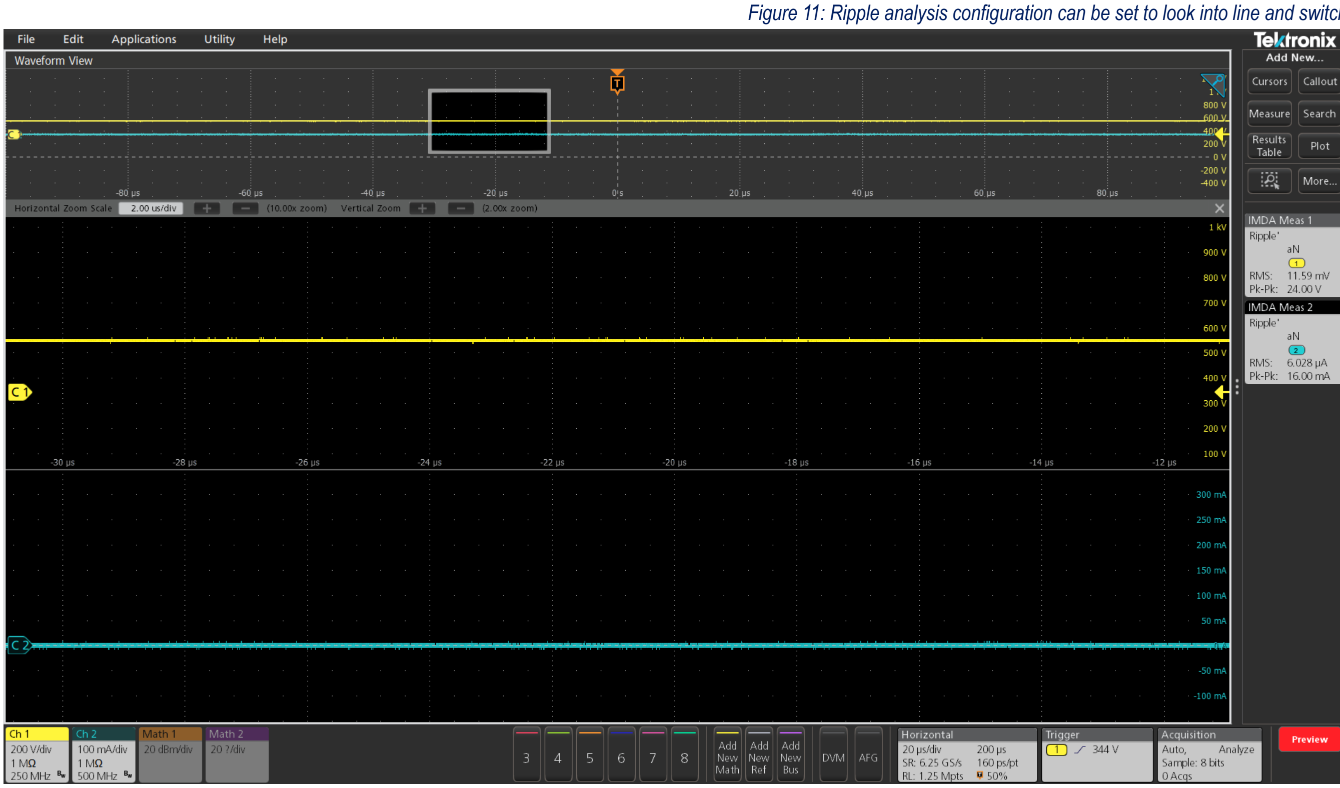


Figure 12: Ripple measurement being carried out on the DC-input signals when testing an Inverter

DQ0 analysis

Optimizing the drive system translates directly into improvements in system efficiency. An important challenge is to tune the drive system control logic optimally based on the three-phase AC signals. Analyzing the system in the AC domain is inherently difficult, hence a conversion from AC to DC domain makes it easier to look into the parameters, and measure them. The direct-quadrature-zero (DQZ or DQ0) transformation is a tensor that rotates the reference frame of a three-element vector, or a three-by-three element matrix to simplify this analysis. The transform is used to rotate the reference frames of three-phase AC waveforms such that they become DC signals. Simplified calculations are carried out on these DC quantities before performing an inverse transform (Inverse DQ0) to recover the actual three-phase AC results.

The most common approach to computing a DQ0 transform involves FPGA programming and complex computations. In addition to performing the transform calculations, probing the feedback signals can be very challenging. Tektronix offers a patented on-scope measurement called DQ0 (Direct Quadrature Zero) under the DQ0 analysis measurement category as an added option. This measurement is supported in the 3V3I configuration, takes the three-phase voltage or current signals from the motor as inputs and converts into D-Q-0 coefficients acting as a powerful debugging tool for the motor designers to tune their PWM controller circuit designs.

This offers unique advantages. First, probing needs are simplified as the same configuration is used for DQ0 computation as Input or Output analysis, and second, the DQ0 values are reported on the scope, both using scalar values on the measurement badge, and as vectors on the phasor diagram for easy correlation between the two plots.

The DQ0 feature is available as an option 5-IMDA-DQ0/6-IMDA-DQ0 on the 5/6 Series MSO.

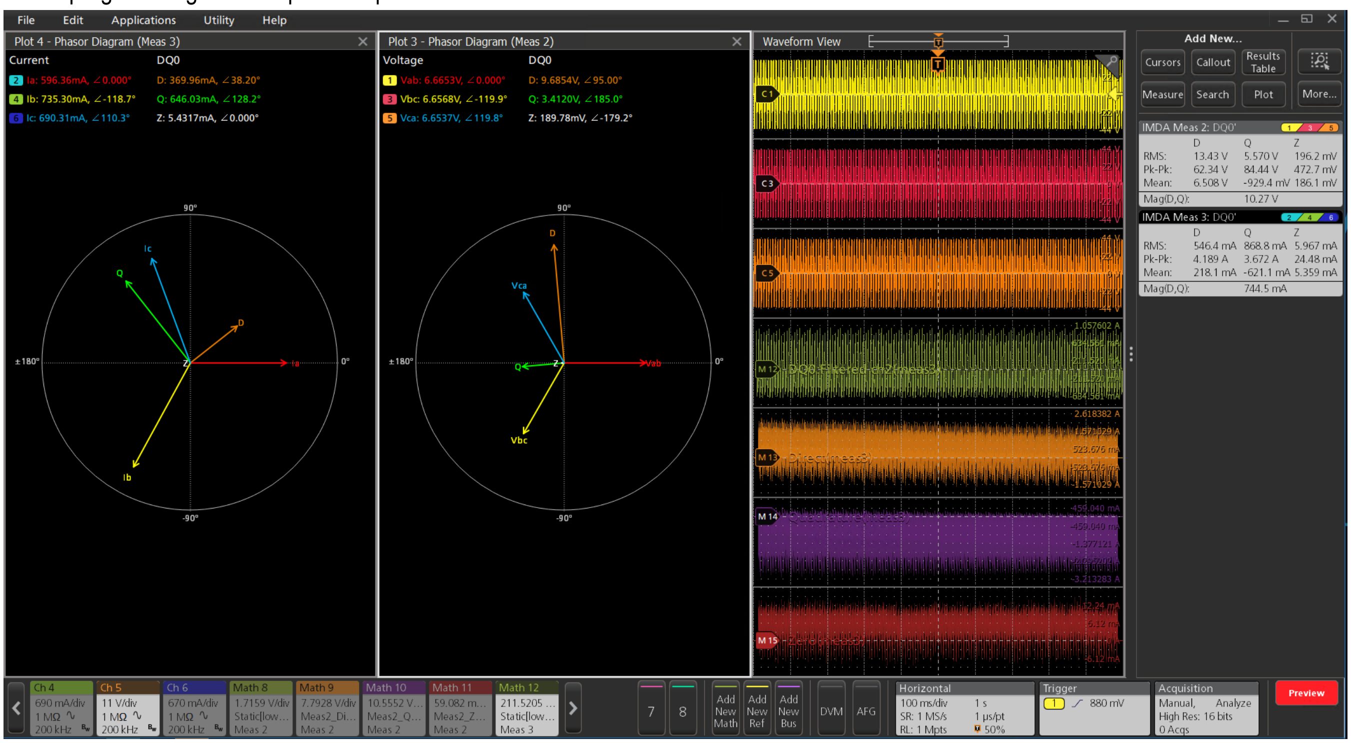


Figure 13: DQ0 measurements running on the 5 Series MSO. They are represented on the phasor diagram as VQ (green), VD(orange), and VZ (white) vectors and their scalar values are available in the results badge on the right.

Dynamic measurements using trend analysis

A common requirement in motor drive analysis is an ability to look at the motor response over longer test times, records, and an extended number of acquisitions to monitor the DUT behavior over varying load conditions. This dynamic measurement helps to understand optimal designs and interdependency between different parameters like voltage, current, power, frequency, and their variance based on the load conditions. The user can manually zoom and get the specific region of interest to look at test results at the particular region of the waveform.

IMDA solution offers two unique trend plots on the power quality measurement to support such requirements:

- Time trend plot
- Acq trend plot

Each plot has its advantages and can be used to plot the supported sub-measurements under power quality measurement. The time trend plot shows the measured value per cycle, or for an acquired waveform (a record), while the acq trend plot shows a mean of the measured value per record, over each of the acquisitions. The acquisition count can be set by the user during the test configuration. This allows users to capture long records of data to perform deep record analysis and understand the dynamic behaviors of the motor response. The plots can be saved as a CSV file for post-processing.

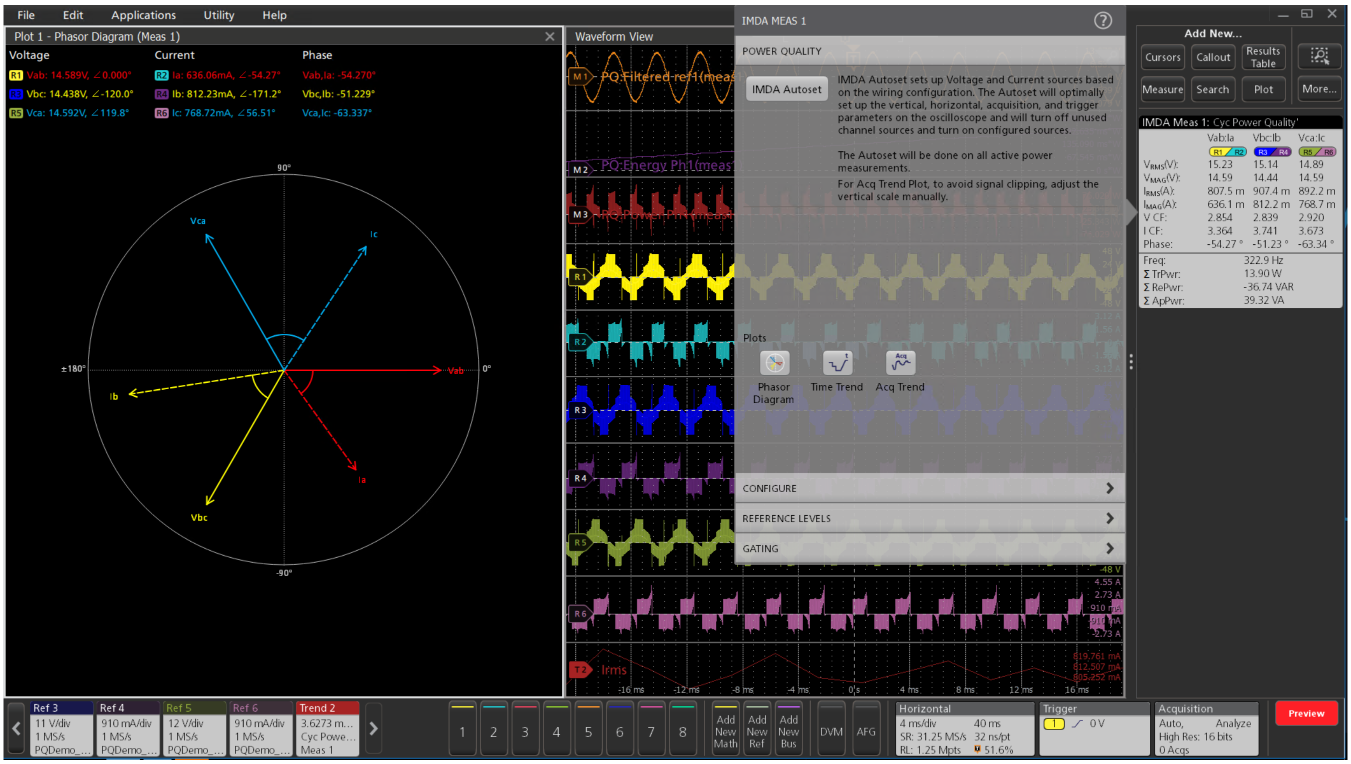


Figure 14: Time trends enable you to graphically analyze power measurements within one acquisition record. Acquisition trends can plot power measurements over many acquisitions for longer-term testing.

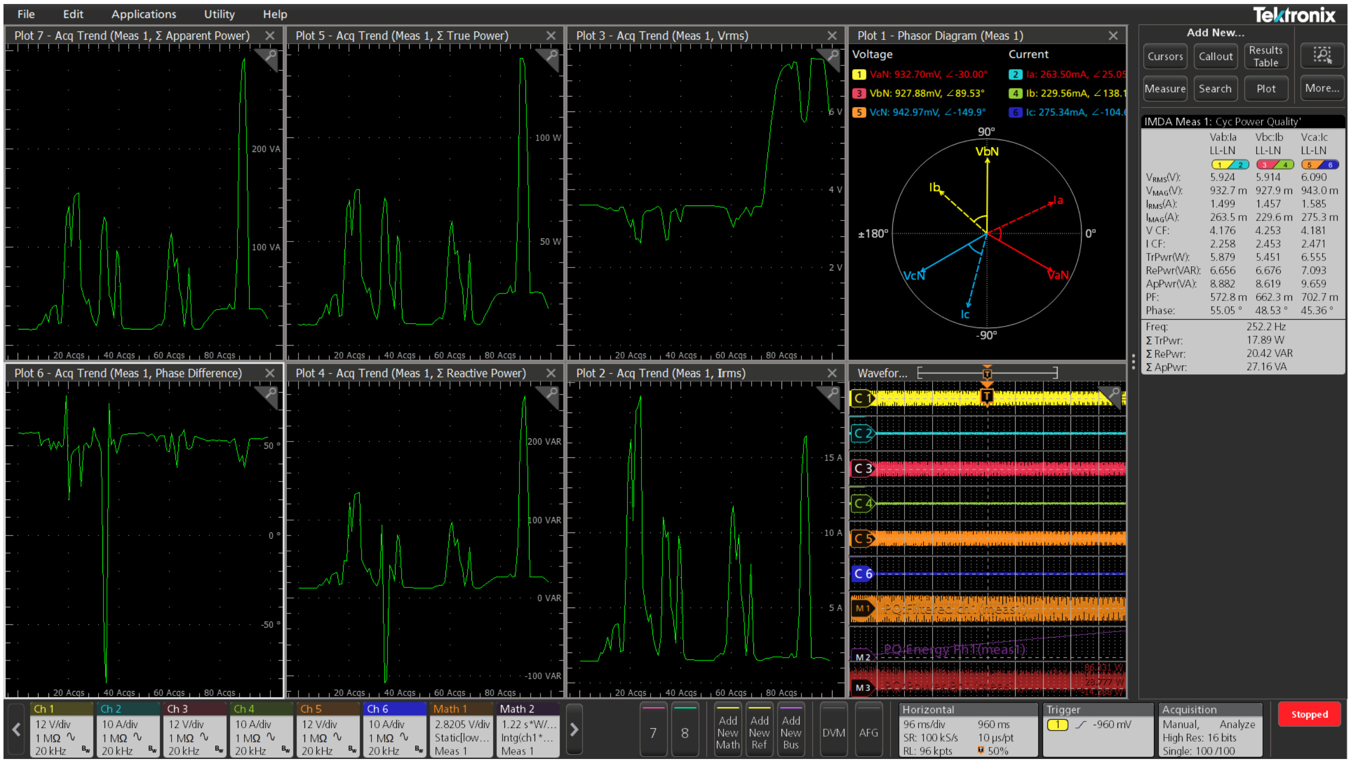


Figure 15: This example shows acquisition trend plots of mean power measurements for 100 acquisitions, including - Vrms, Irms, phase difference, sum of true power, apparent power, and reactive power.

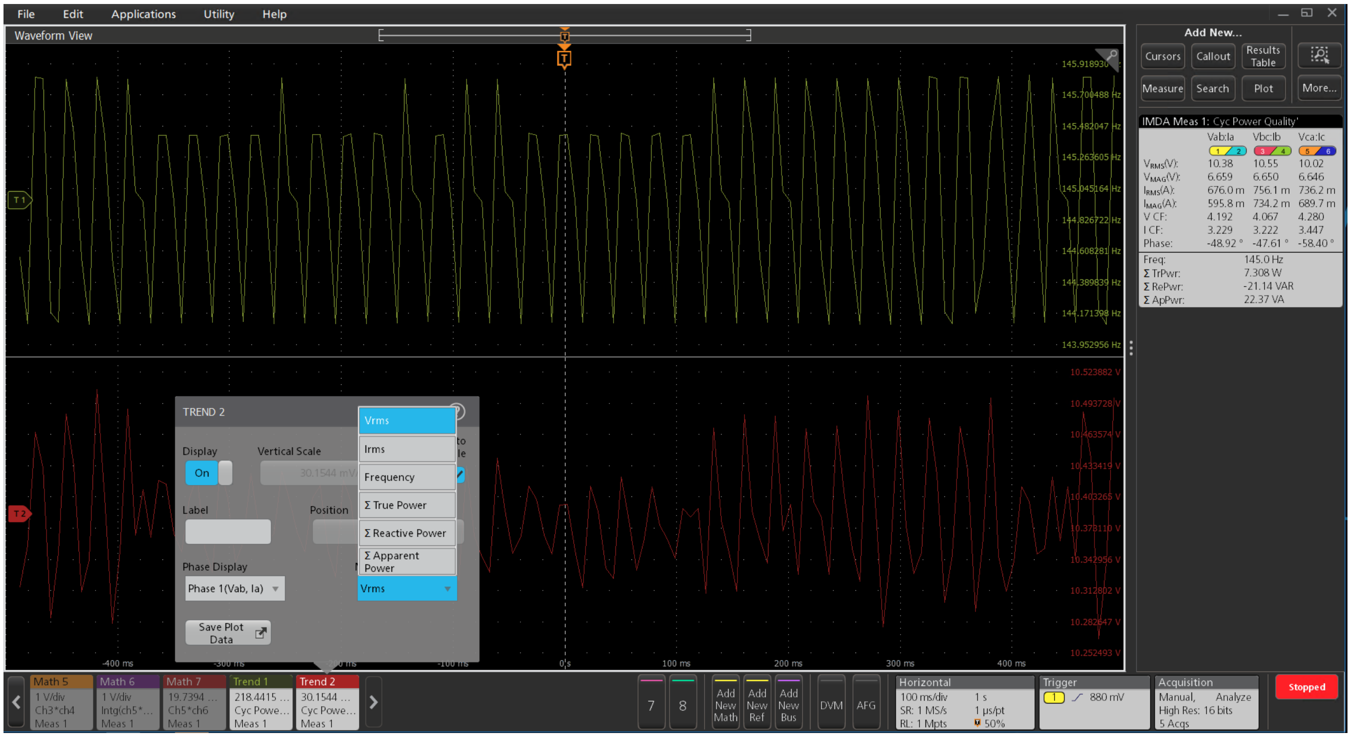


Figure 16: Add and configure the Time Trend plot on different sub-measurements of Power Quality measurement. The image shows two time-tend plots monitoring Vrms and Frequency parameters.

Report generation

The IMDA software simplifies data collection, archiving, documentation of your design, and development process. It supports the report generation in MHT or PDF formats with pass/fail results for easy analysis.

Measurement Report — Tektronix

Monday February 3 2020 10:54:56

Setup Configuration

Scope Details			
Scope Model Number	Scope Serial Number	TekScope Version	Scope Calibration Status
MSO58	Q100118	1.24.6	Pass

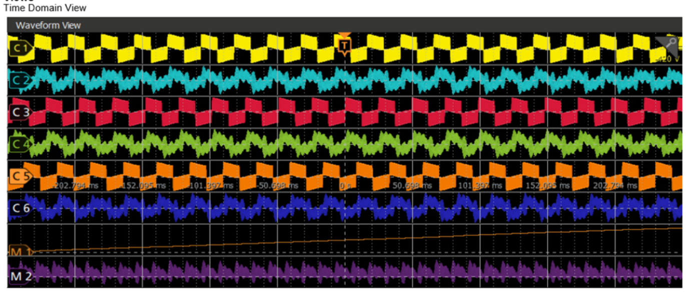
IMDA High Level Configuration

Measurement Type	Wiring	Connection	L-L to L-N
Industrial	3 Phase-3 Wire (3V3I)	Line-to- Line	False

Name	Measurement	Src(s)	Mean'	Min'	Max'	Pk-Pk'	Std Dev'	Population'	Accum Mean	Accum Min	Accum Max	Accum Pk-Pk	Accum Std Dev	Accum Pop
IMDA Meas 1 - Power Quality	VRMS	Ch 1,Ch 2 - Phase 1 (Vab, Ia)	375.12 V	375.12 V	375.12 V	0.0000 V	0.0000 V	1	375.12 V	375.12 V	375.12 V	0.0000 V	0.0000 V	1
	IRMS		330.21 mA	330.21 mA	330.21 mA	0.0000 A	0.0000 A	1	330.21 mA	330.21 mA	330.21 mA	0.0000 A	0.0000 A	1
	Voltage Crest Factor		1.7386	1.7386	1.7386	0.0000	0.0000	1	1.7386	1.7386	1.7386	0.0000	0.0000	1
	Current Crest Factor		3.0543	3.0543	3.0543	0.0000	0.0000	1	3.0543	3.0543	3.0543	0.0000	0.0000	1
	True Power		83.258 W	83.258 W	83.258 W	0.0000 W	0.0000 W	1	83.258 W	83.258 W	83.258 W	0.0000 W	0.0000 W	1
	Reactive Power		-91.713 VAR	-91.713 VAR	-91.713 VAR	0.0000 VAR	0.0000 VAR	1	-91.713 VAR	-91.713 VAR	-91.713 VAR	0.0000 VAR	0.0000 VAR	1
	Apparent Power		123.87 VA	123.87 VA	123.87 VA	0.0000 VA	0.0000 VA	1	123.87 VA	123.87 VA	123.87 VA	0.0000 VA	0.0000 VA	1
	Power Factor		980.75 m	980.75 m	980.75 m	0.0000	0.0000	1	980.75 m	980.75 m	980.75 m	0.0000	0.0000	1
	Phase Angle		-11.260 Degrees	-11.260 Degrees	-11.260 Degrees	0.0000 Degrees	0.0000 Degrees	1	-11.260 Degrees	-11.260 Degrees	-11.260 Degrees	0.0000 Degrees	0.0000 Degrees	1
	V Phase		0.0000 Degrees	0.0000 Degrees	0.0000 Degrees	0.0000 Degrees	0.0000 Degrees	1	0.0000 Degrees	0.0000 Degrees	0.0000 Degrees	0.0000 Degrees	0.0000 Degrees	1
	I Phase		-11.260 Degrees	-11.260 Degrees	-11.260 Degrees	0.0000 Degrees	0.0000 Degrees	1	-11.260 Degrees	-11.260 Degrees	-11.260 Degrees	0.0000 Degrees	0.0000 Degrees	1

Views

Time Domain View



Global Configuration

Gating	Jitter Separation Model	Dual Dirac Model	Display Unit Type	Standard Reference Levels	Jitter Reference Levels	Lock RJ
None	SpectralOnly	PCIExpress	Seconds	Every Acquisition	First Acquisition	false

Reference Levels Configuration

Ref Levels	Ch1, Ch2, Ch3, Ch4, Ch5, Ch6
Ref Level Type	Global
Base Top Method	MinMax
RiseHigh	90%
RiseMid	50%
RiseLow	10%
FallHigh	90%
FallMid	50%
FallLow	10%
Hysteresis	10%

Figure 17: A sample IMDA test report file with summary, details, and corresponding images

Specifications

Wiring configuration	1V1I (1-Phase-2Wire), 2V2I (1 Phase-3-Wire), 2V2I (3-Phase-3-Wire), 2V2I (DC In-AC Out), 3V3I (DC In-AC Out) or 3V3I (3-Phase-3Wire), and 3P4W (3-Phase-4Wire)
L-L to L-N conversion	Applicable for 3 Phase-3 Wire (3V3I)[1]
Electrical analysis	Power quality, Harmonics[2], Ripple, DQ0[3], Efficiency[4]
Three-phase autoset	For all measurements
Plots	Time Trend plot, ACQ trend plot, Phasor diagram and harmonics bar graph [5]
Report	MHT and PDF format, Data export to CSV format
Degauss/Deskew (static)	Automatic detection of probes, Auto Zero. User can deskew voltage and current probes, degauss the current probe from the menus for each channel
Source support	Live analog signals, reference waveforms, and math waveforms

1 For 3 Phase-4 Wire (3V3I) the connection is always Line to Neutral and for 3 Phase-3 Wire (2V2I), it is Line to Line.
2 Supports custom limits.
3 Applicable for 3V3I wiring only.
4 For 2V2I wiring only.
5 Range filter as part of measurement configuration.

Ordering information

Models

Product	Options	Supported instruments	Bandwidth available
New instrument order option	5-IMDA	5 Series MSO (MSO56, MSO58)	• 350 MHz • 500 MHz • 1 GHz • 2 GHz
Product upgrade option	SUP5-IMDA		
Floating license	SUP5-IMDA-FL		
Product	**Options[6]**	**Supported instruments**	**Bandwidth available**
New instrument order option	5-IMDA-DQ0	5 Series MSO (MSO56, MSO58)	• 350 MHz • 500 MHz • 1 GHz • 2 GHz
Product upgrade option	SUP5-IMDA-DQ0		
Floating license	SUP5-IMDA-DQ0-FL		
Product	**Options**	**Supported instruments**	**Bandwidth available**
New instrument order option	6-IMDA	6 Series B MSO (MSO66B, MSO68B)	• 1 GHz • 2.5 GHz • 4 GHz • 6 GHz • 8 GHz • 10 GHz
Product upgrade option	SUP6B-IMDA		
Floating license	SUP6B-IMDA-FL		
Product	**Options[6]**	**Supported instruments**	**Bandwidth available**
New instrument order option	6-IMDA-DQ0	6 Series B MSO (MSO66B, MSO68B)	• 1 GHz • 2.5 GHz • 4 GHz • 6 GHz • 8 GHz • 10 GHz
Product upgrade option	SUP6B-IMDA-DQ0		
Floating license	SUP6B-IMDA-DQ0-FL		

Software bundles

Bundle options	Supported instruments	Description
5-PRO-POWER-1Y	5 Series MSO	1 Year License Pro Power Bundle for 5 Series MSO
5-PRO-POWER-PER	5 Series MSO	Perpetual License Pro Power Bundle for 5 Series MSO
5-ULTIMATE-1Y	5 Series MSO	1 Year License Ultimate Bundle for 5 Series MSO
5-ULTIMATE-PER	5 Series MSO	Perpetual License Ultimate Bundle for 5 Series MSO
6-PRO-POWER-1Y	6 Series MSO	1 Year License Pro Power Bundle for 6 Series MSO
6-PRO-POWER-PER	6 Series MSO	Perpetual License Pro Power Bundle for 6 Series MSO
6-ULTIMATE-1Y	6 Series MSO	1 Year License Ultimate Bundle for 6 Series MSO
6-ULTIMATE-PER	6 Series MSO	Perpetual License Ultimate Bundle for 6 Series MSO

6 Option DQ0 requires Option IMDA as a pre-requisite

Recommended probes

Probe model	Description	Quantity
TCP0030A	Current Probes	3 for 3V3I wiring[7]
THDP0200 or TMDP0200	High Voltage Differential Probes	3 for 3V3I wiring [7]

Tektronix is registered to ISO 9001 and ISO 14001 by SRI Quality System Registrar.

Product(s) complies with IEEE Standard 488.1-1987, RS-232-C, and with Tektronix Standard Codes and Formats.

Product Area Assessed: The planning, design/development and manufacture of electronic Test and Measurement instruments.

7 For performing efficiency measurement, four quantities are required.

ASEAN / Australasia (65) 6356 3900
Belgium 00800 2255 4835*
Central East Europe and the Baltics +41 52 675 3777
Finland +41 52 675 3777
Hong Kong 400 820 5835
Japan 81 (3) 6714 3086
Middle East, Asia, and North Africa +41 52 675 3777
People's Republic of China 400 820 5835
Republic of Korea +822 6917 5084, 822 6917 5080
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Austria 00800 2255 4835*
Brazil +55 (11) 3759 7627
Central Europe & Greece +41 52 675 3777
France 00800 2255 4835*
India 000 800 650 1835
Luxembourg +41 52 675 3777
The Netherlands 00800 2255 4835*
Poland +41 52 675 3777
Russia & CIS +7 (495) 6647564
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United Kingdom & Ireland 00800 2255 4835*
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Norway 800 16098
Portugal 80 08 12370
South Africa +41 52 675 3777
Switzerland 00800 2255 4835*
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For Further Information. Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit *www.tek.com*.

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