Understanding The Need For Dynamic Measurements

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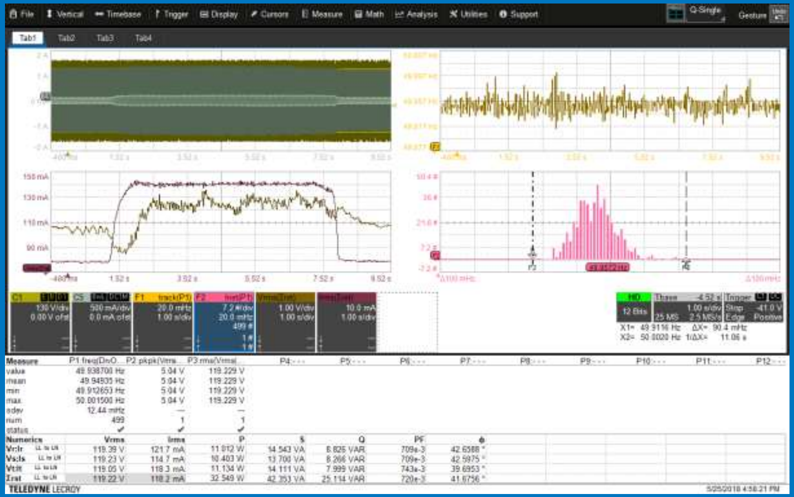
Stand Number 28.



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POWER ELECTRONICS 2018

Agenda

- Definition of terms.
- Washing Machine Example.
- The Design Complexity.
- Motor Stall Example.
- Well Controlled Motor Start Up Example.
- Less Well Controlled Motor Start up Example.
- What Happens When a Motor is turned off?
- Detailed Look At Load Change On A Motor.

Definition of Dynamic

dynamic

[dahy-**nam**-ik]

Examples Word Origin

See more synonyms on Thesaurus.com

adjective Also **dy·nam·i·cal.**

1. pertaining to or characterized by energy or effective action; vigorously active or forceful; energetic:

Presentation Title

Understanding The Need For Dynamic Measurements

- Dynamic means changing (in this context).
- Dynamic Measurements: Measurements on a changing (dynamic) system.
  - Complex measurements.
  - Requires sophisticated measurement equipment.

Definition of Static, the opposite of Dynamic.

static

[**stat**-ik]

Examples   Word Origin

See more synonyms on Thesaurus.com

adjective Also **stat·i·cal.**

1. pertaining to or characterized by a fixed or stationary condition.
2. showing little or no change:
   a static concept; a static relationship.
3. lacking movement, development, or vitality:

- Systems that are running with minimal change.
- Constant speed.
- Constant load.
- No change.
- Relatively easy measurements.

The Washing Machine Example

Basic Functioning of The Washing Machine Spin Cycle

- Starts in a static no motion state.
  - Beginning of the cycle.

- First step: ‘balancing’ the washing.
  - Wet washing has significant weight.
  - Balancing allows spin up with minimal vibration.
  - Initial balancing shows saw tooth load waveform.

- Second Step: Spin to drying speed.
  - Typically between 1000 and 1400 RPM.

The Washing Machine Example

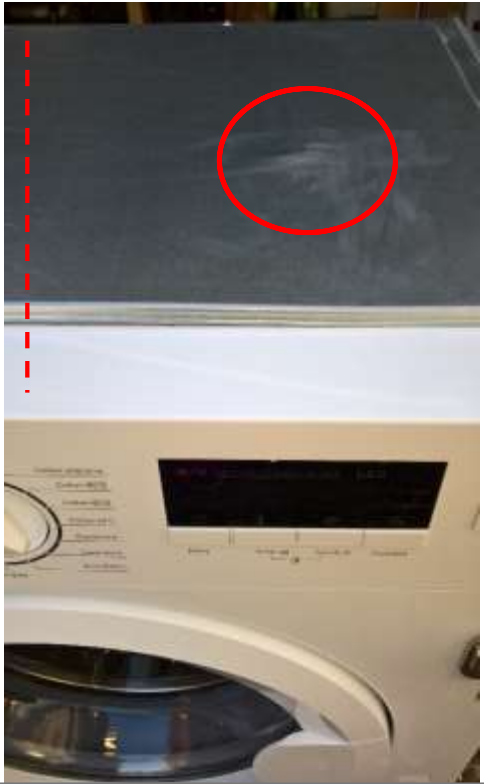
- A dent in the side.
  - Pushed out from the inside!!.
  - Dents in both sides.

- Significant lateral drum movement required to dent both sides of the washing machine.

- Also, significant front to back drum movement when in use.
  - Perhaps poor mechanical design?

The Washing Machine Example

- A dent in the top.
  - Again pushed out from the inside!!.
  - A dent in the top takes significant vertical drum movement



Product Observation

- The drum appears mechanically sound.
  - With similar anchor points, ballast and damping as other washing machines.

- Drum spin up speed seems excessively rapid, causing drum movement.
  - Rapid spin up creates large torque.

torque

[tawrk]

Examples   Word Origin

See more synonyms on Thesaurus.com

noun

1. *Mechanics*. something that produces or tends to produce torsion or rotation; the moment of a force or system of forces tending to cause rotation.
2. *Machinery*. the measured ability of a rotating element, as of a gear or shaft, to overcome turning resistance.

Product Observation

- The drum bounces around the inside of the washing machine like a beach ball thrown in a box!!
- Significant noise.
- Significant product damage (dents).
- Significant washing machine movement.
  - The entire washing machine ‘bounces around’, not just drum movement.

Washing Machine Issues.

- Violent movement of the drum causes violent movement of the whole washing machine.
  - Causes damage to itself
  - Causes damage to adjacent kitchen units
  - Causes damage to kitchen work surfaces
    - Who is liable for the damage
  - Causes significant noise
  - Causes significant stress to the product owner
  - Product reliability issues

Washing Machine Conclusions

- The washing machine is a proven mechanical design.

- This model has a new ‘updated’ electronic control system.

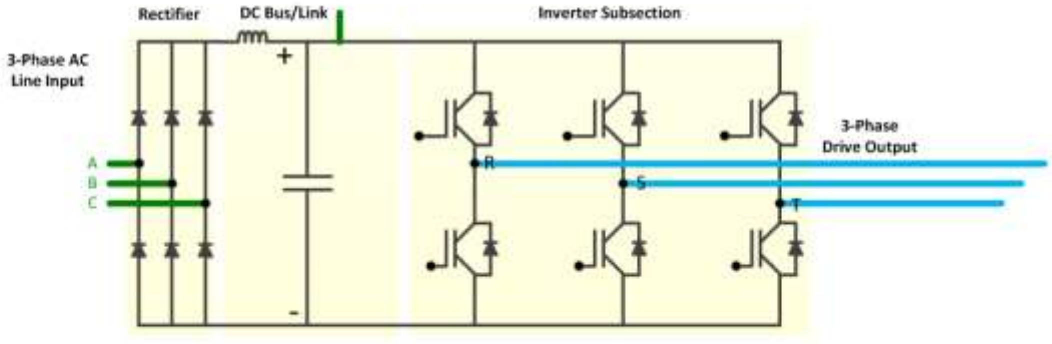
- Measurements of the motors’ dynamic performance shows the issue.
  - Very rapid speed change from low speed to high speed (1400 rpm).
  - Further investigation points to software issues.
  - SW Issue: Motor speed ‘ramp up’ between load balancing speed and high speed not controlled.

- Cost: More than 1000 units in the supply chain, each with ‘ramp up’ SW issue.
  - Find each unit, unpack it, reprogram, repackage…..
  - In retail outlets, in the distribution channel…..
  - Loss of brand credibility and customer loyalty.
  - Huge financial cost.

The design complexity of a “drive” system is very high…

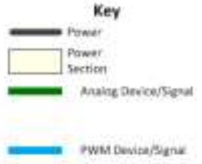
There is no single tool for design engineers to use for complete system debug

- Power Section Measurements
  - Line input
  - PWM output
  - Efficiencies



Primarily low frequency
(1-5 MHz) measurements

Ideally, Power Section behaviors could be correlated to high frequency Embedded Control behaviors



The design complexity of a “drive” system is very high…

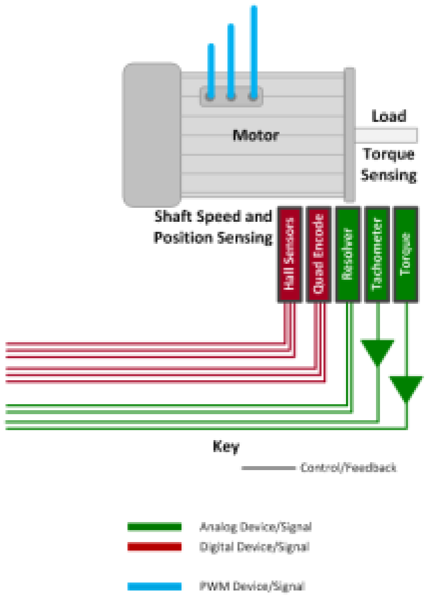
There is no single tool for design engineers to use for complete system debug

- Motor Integration
  - Torque
  - Speed
  - Position
  - Power

Very low frequency (kHz) measurements

Simple integration to instrument is desired

Motor (mechanical) power = Torque x Speed

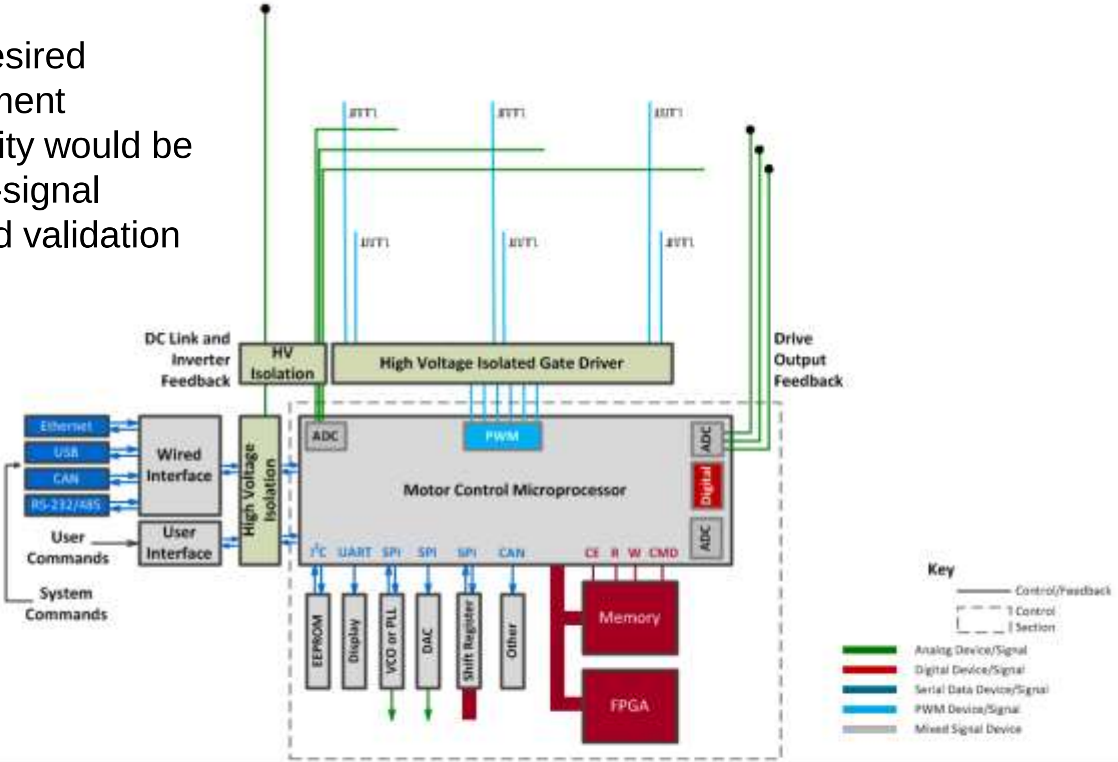


The design complexity of a "drive" system is very high…

There is no single tool for design engineers to use for complete system debug

High frequency (>100 MHz) measurements

Typical desired measurement functionality would be for mixed-signal debug and validation



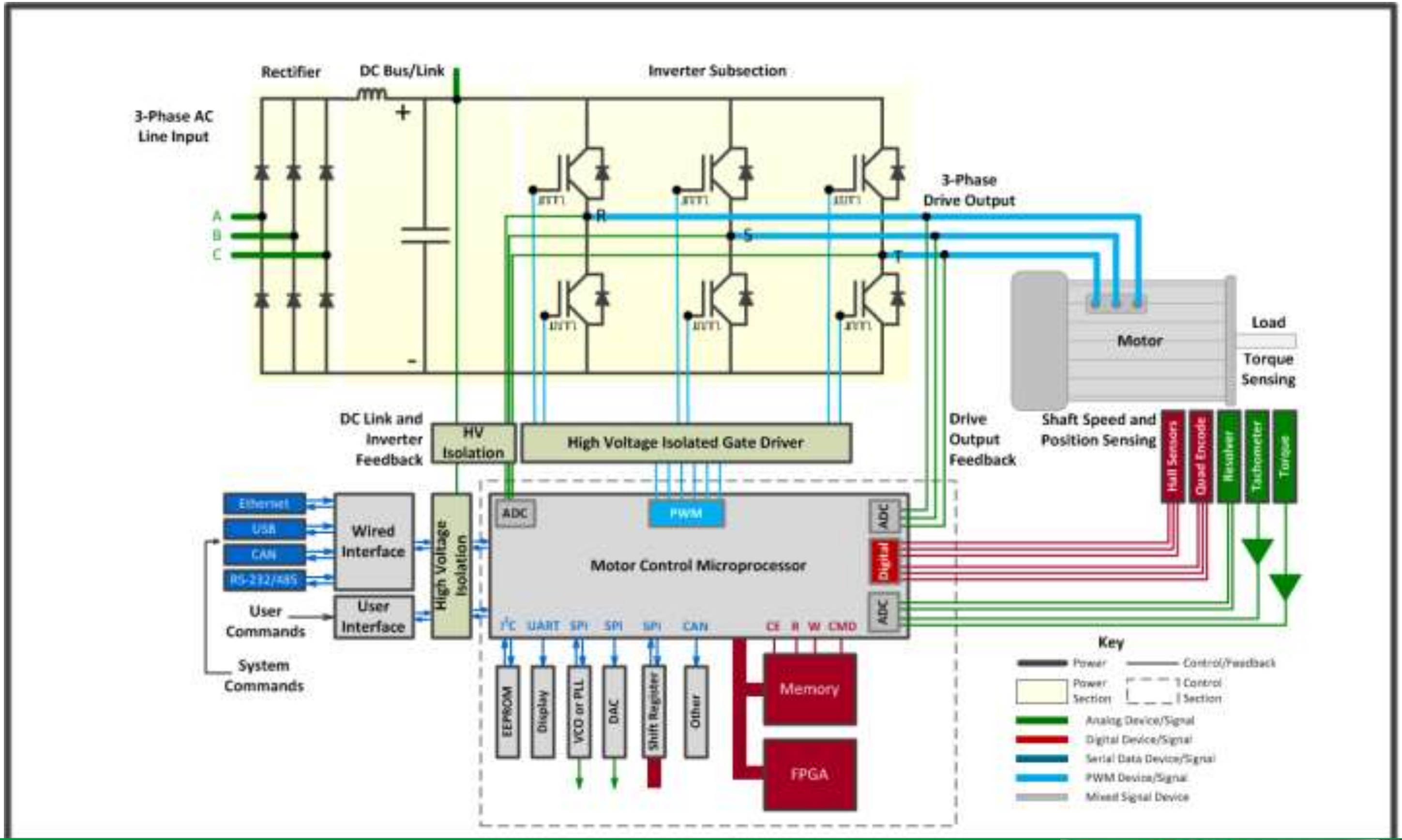
Control Debug

- Analog
- Digital
- Serial Data
- Control Loop
- PWM

This is the complete design and debug challenge

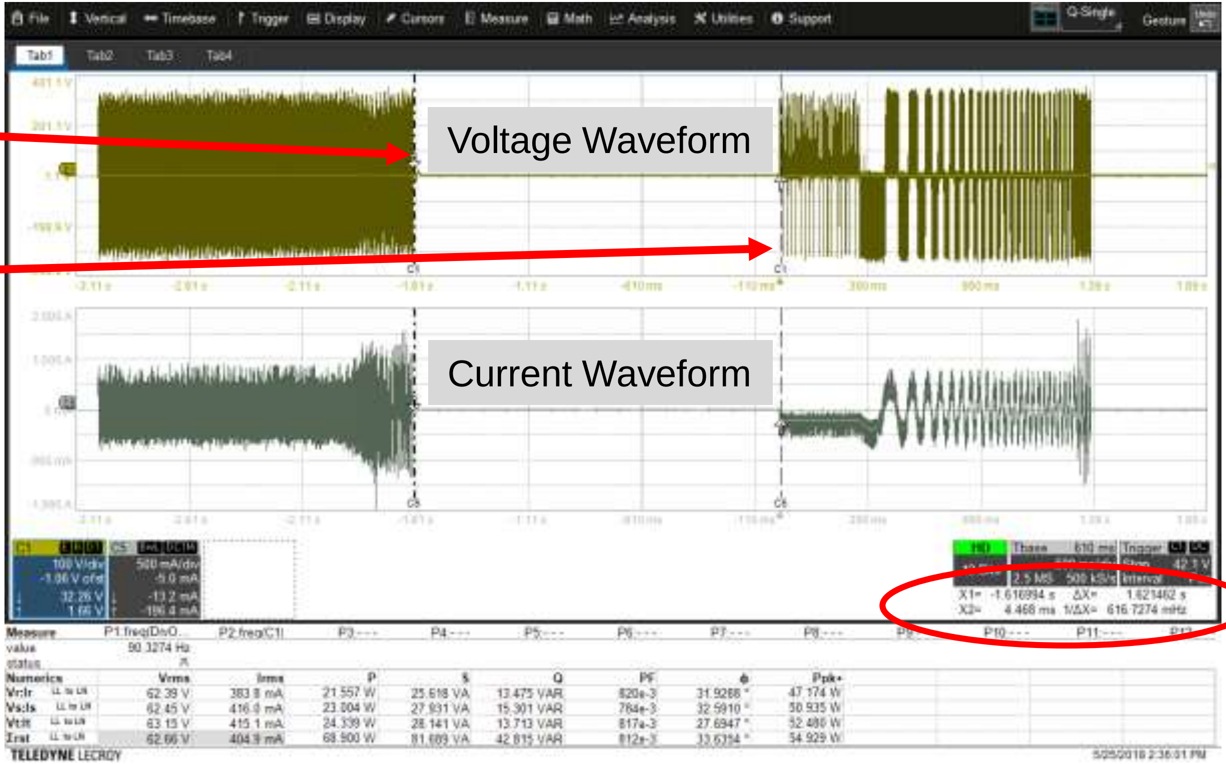
for the motor drive engineer

- Power Section Measurements
  - Line input
  - PWM output
  - Efficiencies
- Motor Integration
  - Torque
  - Speed
  - Position
  - Power
- Embedded Control Debug
  - Analog
  - Digital
  - Serial Data
  - Control Loop
  - PWM



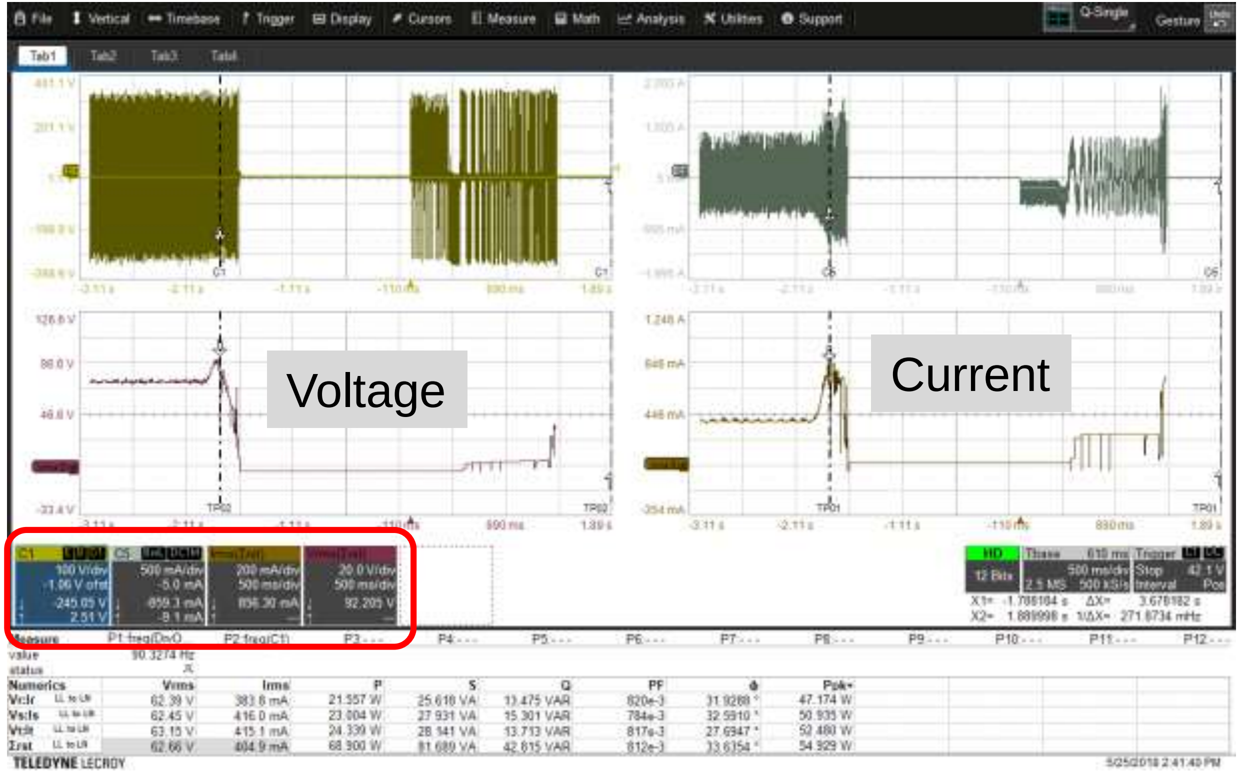
Motor Stall Example

- Motor stall point
- Motor restart
- Time between stall and restart
  - 1.62 Seconds



Motor Stall Example

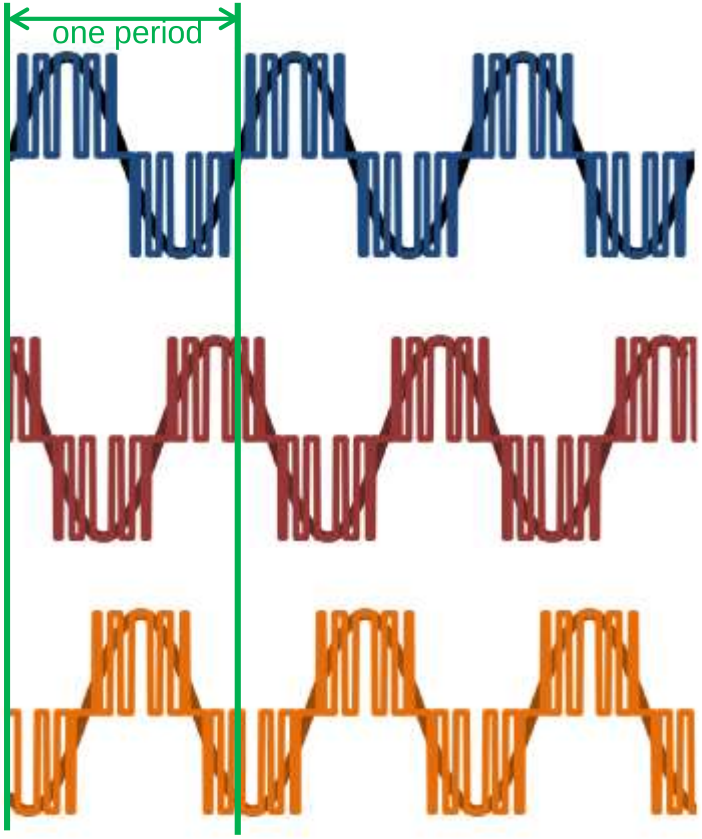
- Captured waveforms.
- Cycle by cycle calculated values.
  - Shown as waveforms.
- Cursors measure Voltage and Current maximum values at stall point.
  - 92.2 Vrms
  - 856.3 mA rms



“Per Cycle” Measurement Technique for Power Analysis

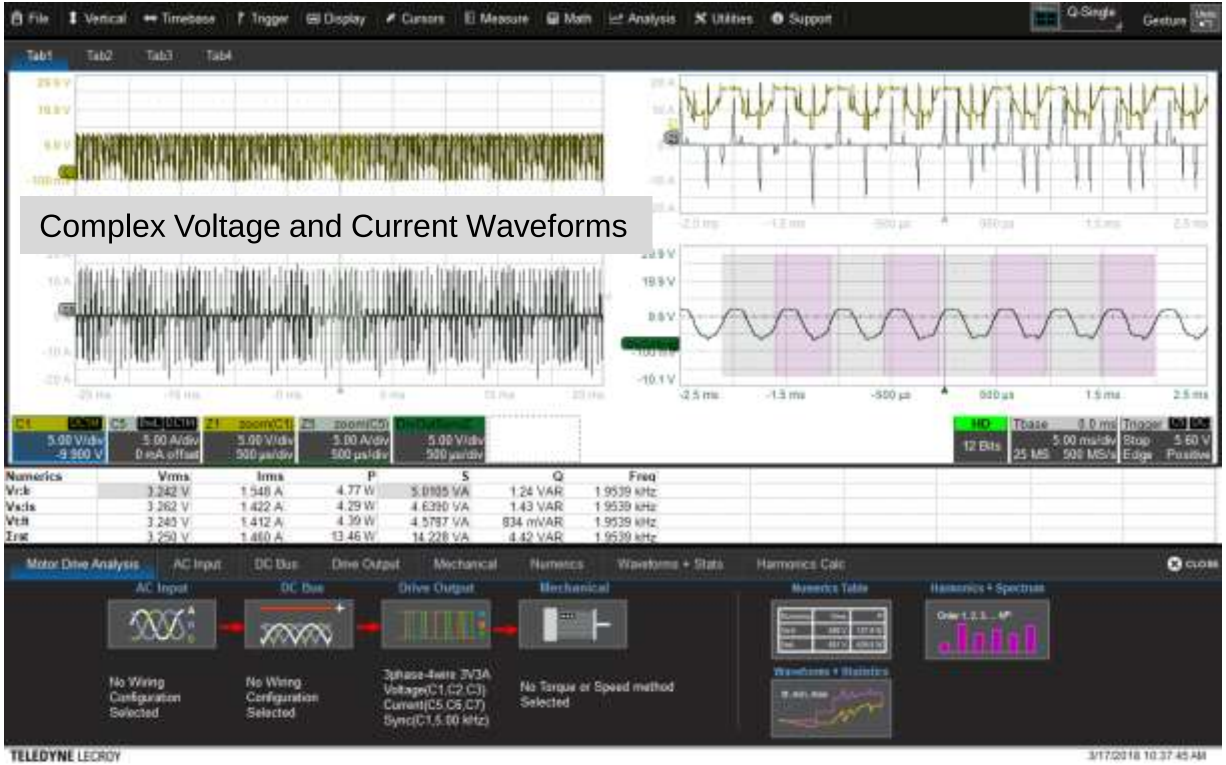
The selected Sync signal determines the measurement period

- Take a long acquisition
  - Only two cycles are shown, to the right, as an example
- Detect the cyclical period, and “slice” the waveforms into these periods
  - Also works with changing time periods.
- In each “sliced” period
  - Calculate Real Power (P) as instantaneously V * I sampled data
  - Calculate Apparent Power (S) as V_{rms} * I_{rms} for each cyclical period
  - “N” measurement values for “N” cyclical periods in each acquisition
  - Solve for Q, as before.
- Calculate V_{DC}, I_{DC}, I_{peak}, V_{peak}, etc. as well on a per-cycle basis



“Per Cycle” Measurement Technique for Power Analysis

The selected Sync signal determines the measurement period



Zoom of complex Voltage.

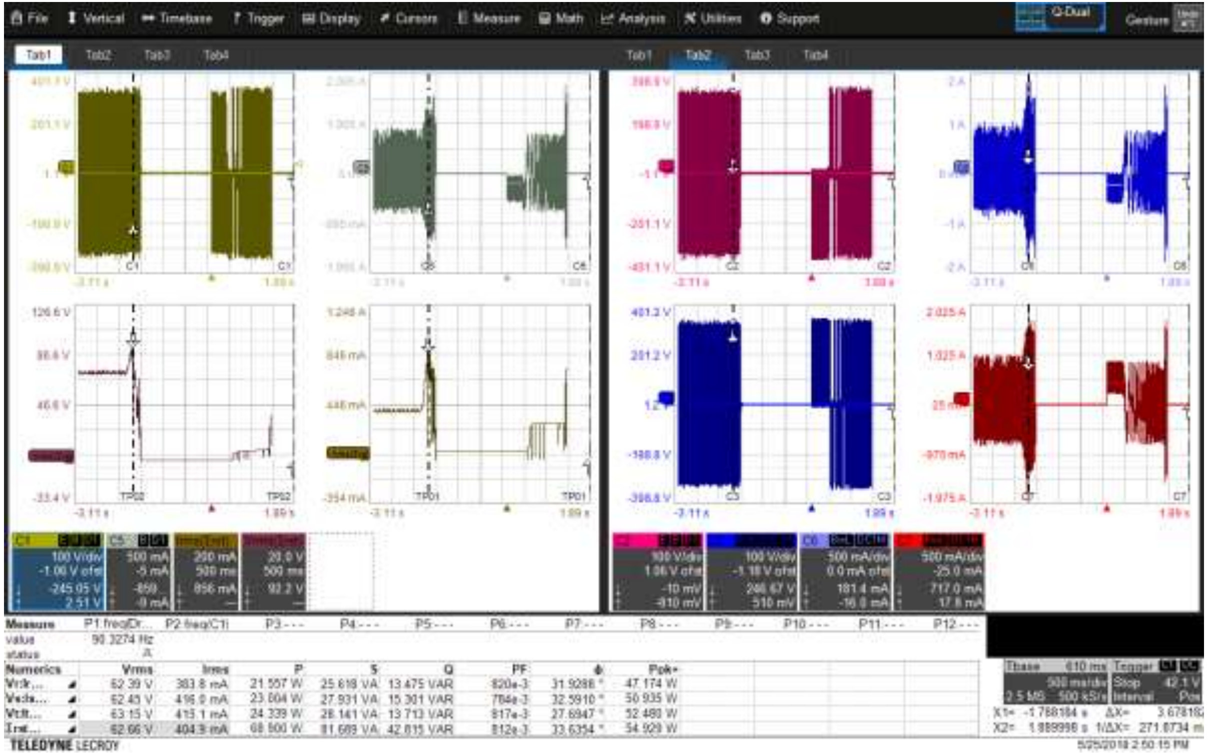
And Current waveforms.

“Per Cycle” extraction from the Voltage Waveform.

Used to determine the “Per Cycle” measurement periods.

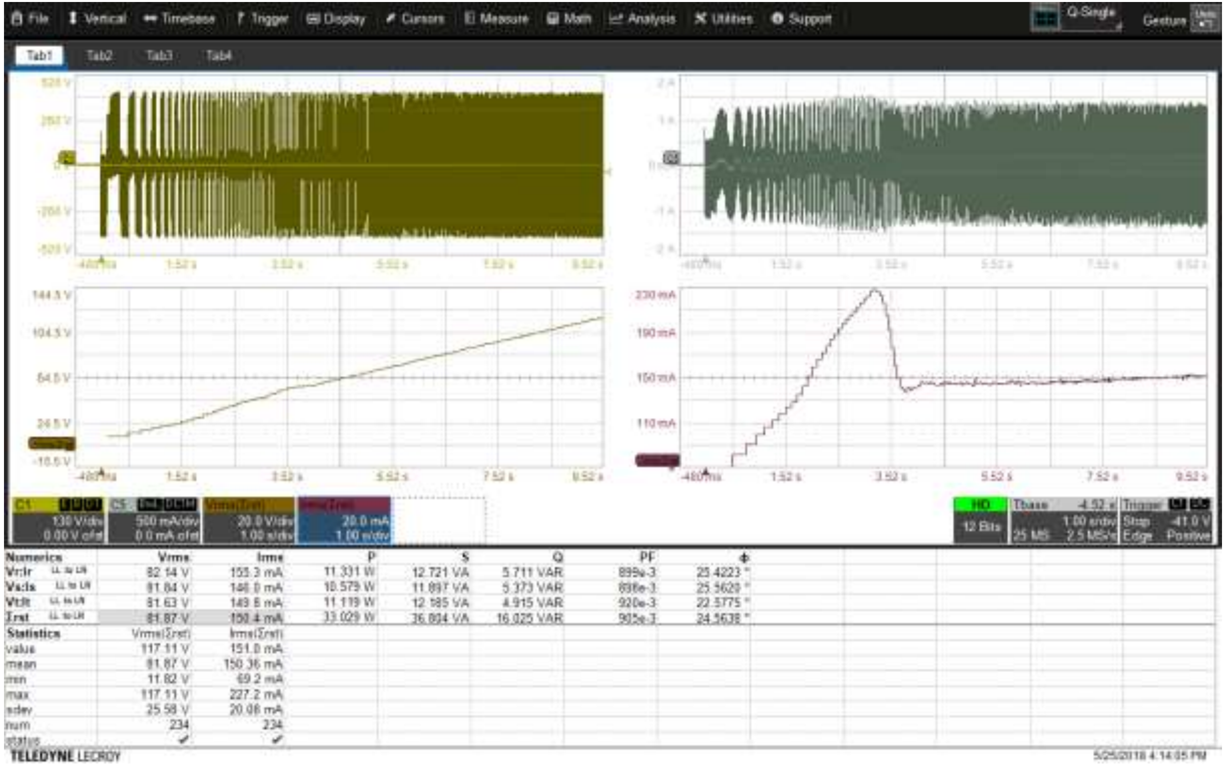
Motor Stall Example

- All phases are captured for analysis.
- Results calculated on a ‘per phase’ and total basis.



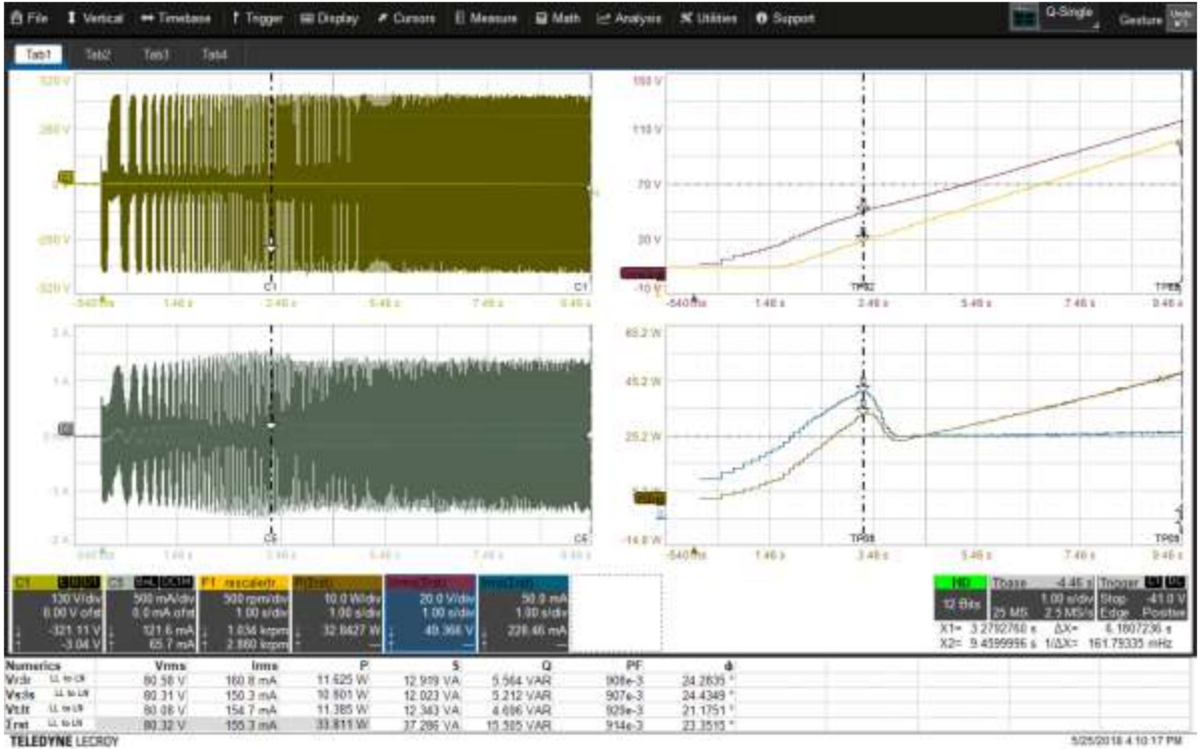
Well Controlled Motor Start Up Example.

- Actual 3 phase waveforms.
  - Voltage.
  - Current.
- Calculated waveforms.
  - Voltage.
  - Current.
- Table of values for each phase.
  - And for calculated waveforms.
- Very well controlled motor example.



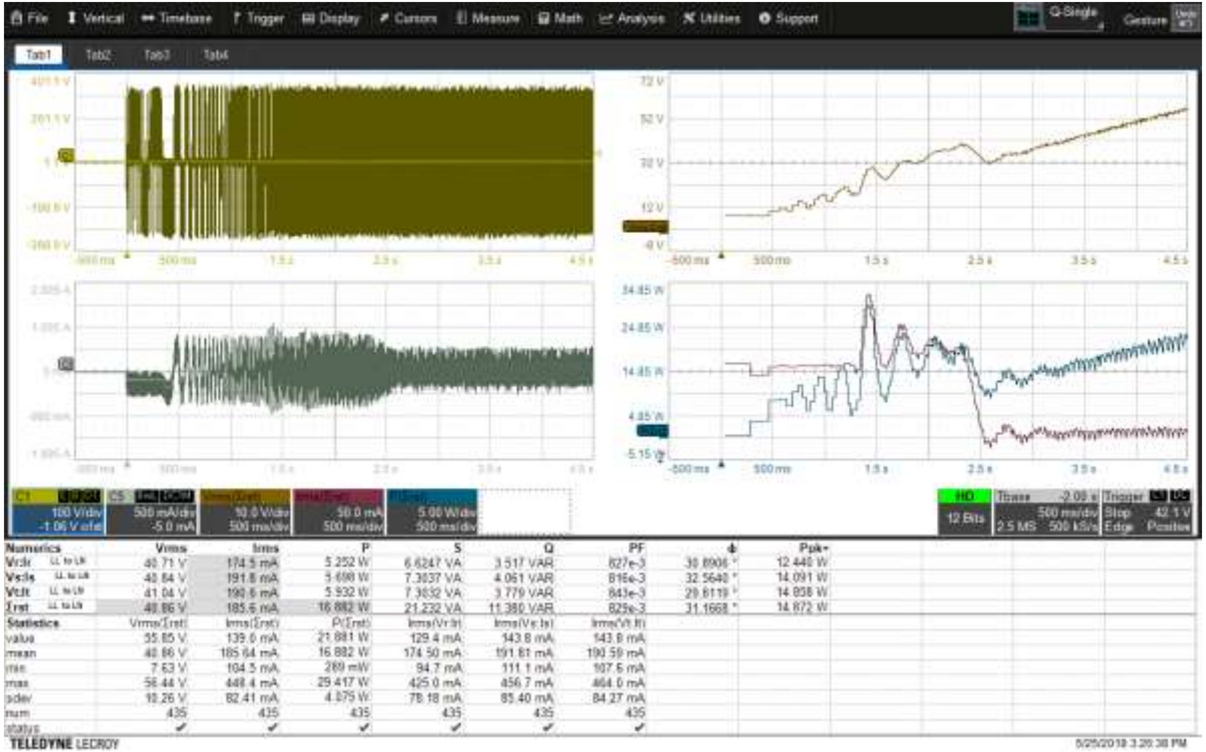
Well Controlled Motor Start Up Example (same as previous slide).

- Extra calculated waveforms added.
  - Vrms and Irms waveforms still present.
  - Added Power and RPM waveforms.
  - Also added Cursors for measurements at specific points.



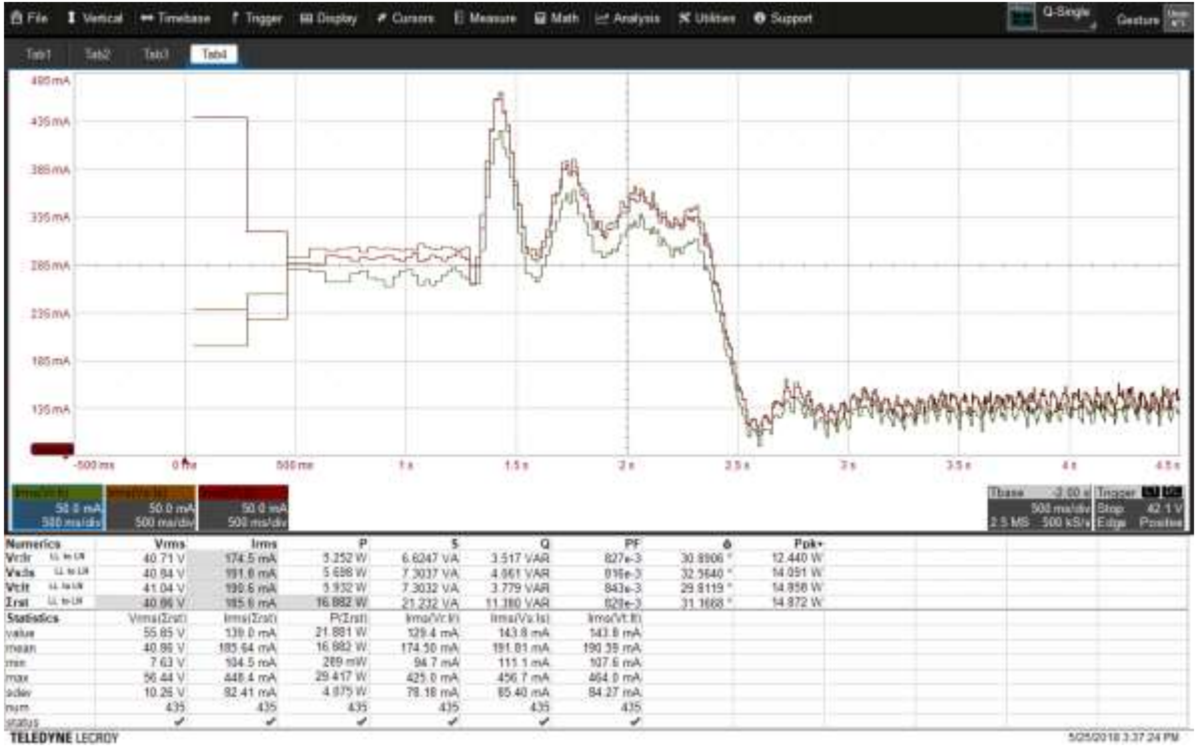
Less Well Controlled Motor Start up Example.

- Less well controlled motor example
  - Oscillation on the Voltage, Current and Power waveforms.



Less Well Controlled Motor Start up Example.

- Comparing the Current waveforms across all three phases shows similar waveforms.
  - The same phase comparisons could have been done for Voltage and Power.
  - Motor Speed may also have been interesting and may have shown inconsistent spin up speed, or mechanical jitter.

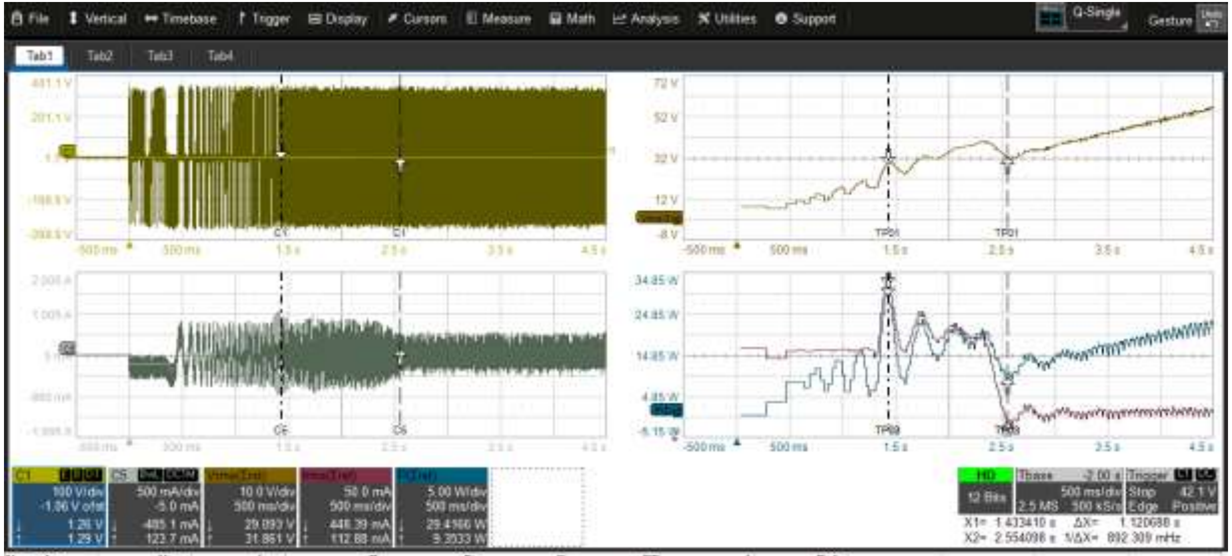


Numerics		Vrms	Irms	P	S	Q	PF	ϕ	Ppk+
Vcılr	LL to LN	40.71 V	174.5 mA	5.252 W	6.6247 VA	3.517 VAR	827e-3	30.8906 °	12.440 W
Vads	LL to LN	40.84 V	191.8 mA	5.698 W	7.3037 VA	4.061 VAR	816e-3	32.5640 °	14.051 W
Vctt	LL to LN	41.04 V	190.6 mA	5.932 W	7.3032 VA	3.779 VAR	843e-3	29.8119 °	14.858 W
Σrst	LL to LN	40.86 V	185.6 mA	16.882 W	21.232 VA	11.380 VAR	829e-3	31.1668 °	14.872 W

Statistics	Vrms(Σrst)	Irms(Σrst)	P(Σrst)	Irms(Vc:Ir)	Irms(Va:Is)	Irms(Vt:It)
value	55.85 V	139.0 mA	21.881 W	129.4 mA	143.8 mA	143.8 mA
mean	40.86 V	185.64 mA	16.882 W	174.50 mA	191.81 mA	190.39 mA
min	7.63 V	104.5 mA	289 mW	94.7 mA	111.1 mA	107.6 mA
max	56.44 V	448.4 mA	29.417 W	425.0 mA	456.7 mA	464.0 mA
sdev	10.26 V	92.41 mA	4.875 W	78.18 mA	85.40 mA	84.27 mA
num	435	435	435	435	435	435
status	✔	✔	✔	✔	✔	✔

Less Well Controlled Motor Start up Example.

- Full analysis can be made using cursors and the data tables.



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Vr:Ir LL to LN	40.71 V	174.5 mA	5.252 W	6.6247 VA	3.517 VAR	827e-3	30.8906 °	12.440 W
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Vt:It LL to LN	41.04 V	190.6 mA	5.932 W	7.3032 VA	3.779 VAR	843e-3	29.8119 °	14.858 W
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min	7.63 V	104.5 mA	289 mW	94.7 mA	111.1 mA	107.6 mA
max	56.44 V	448.4 mA	29.417 W	425.0 mA	456.7 mA	464.0 mA
sdev	10.26 V	82.41 mA	4.075 W	78.18 mA	85.40 mA	84.27 mA
num	435	435	435	435	435	435
status	✓	✓	✓	✓	✓	✓

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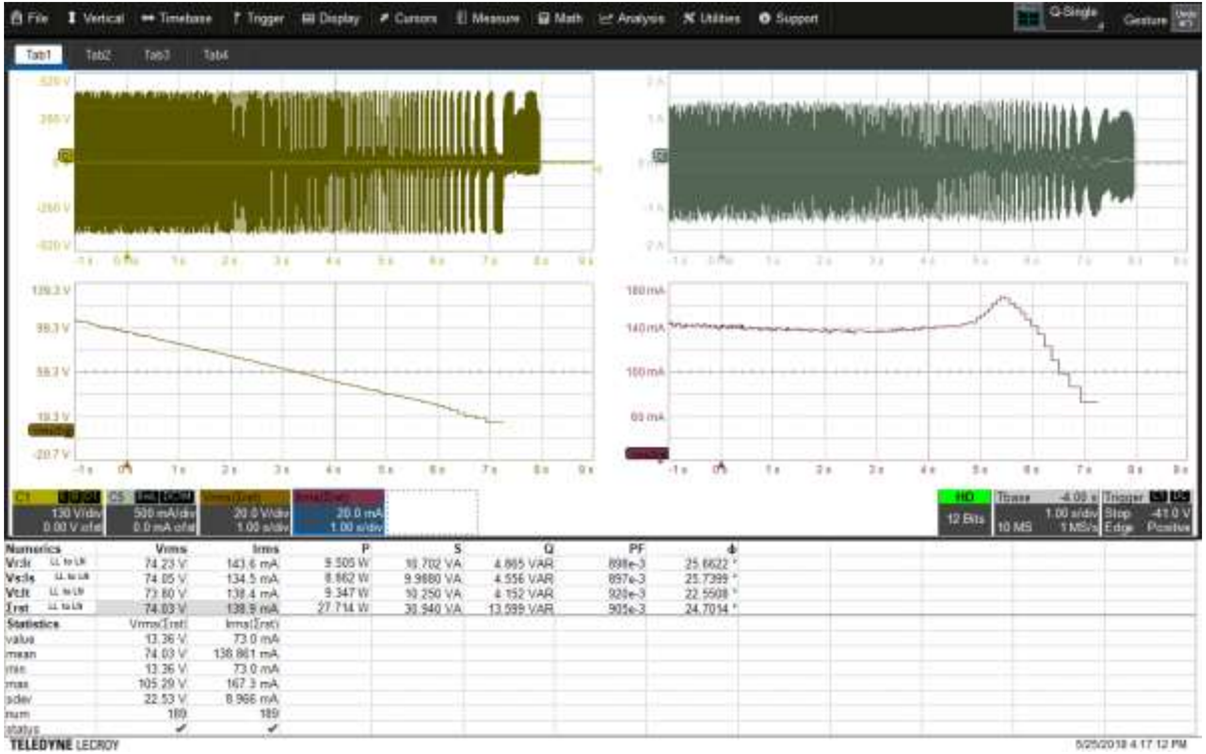
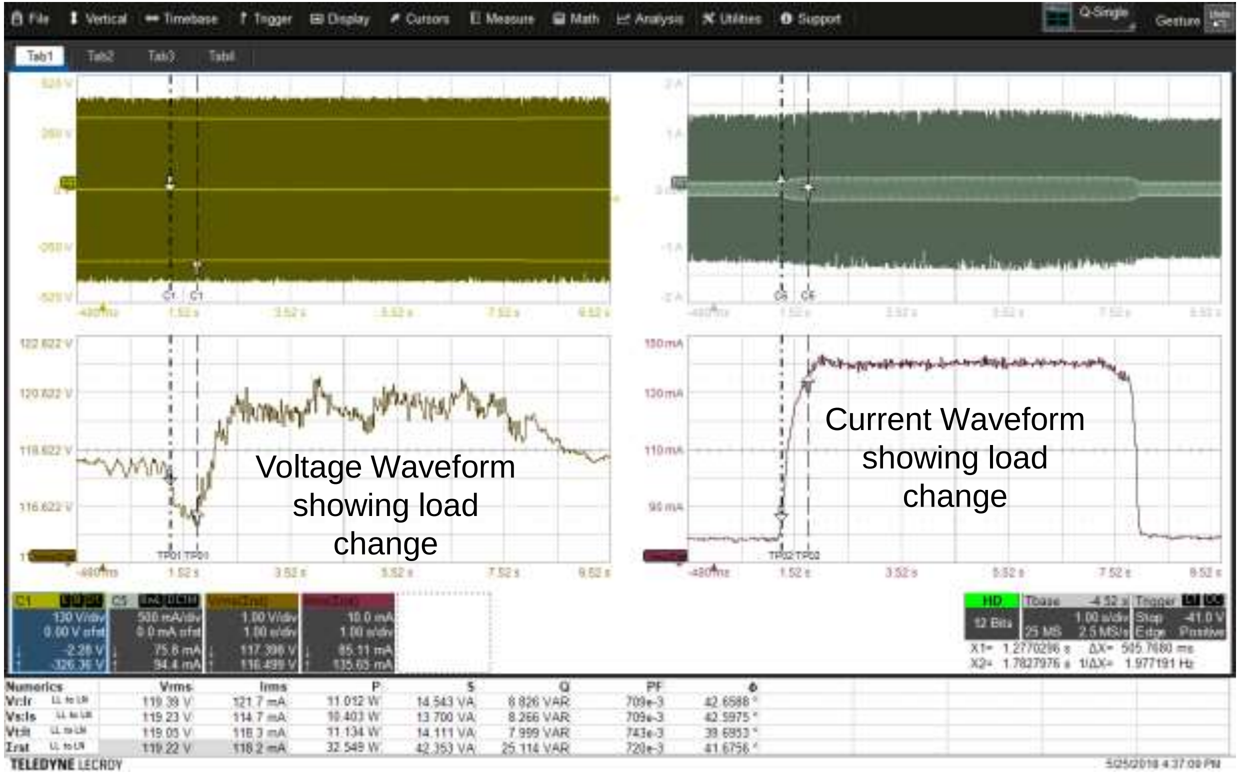
What Happens When a Motor is turned off?

- It depends on the motor design and its situation.
  - Ability to verify motor turn off / shutdown process.



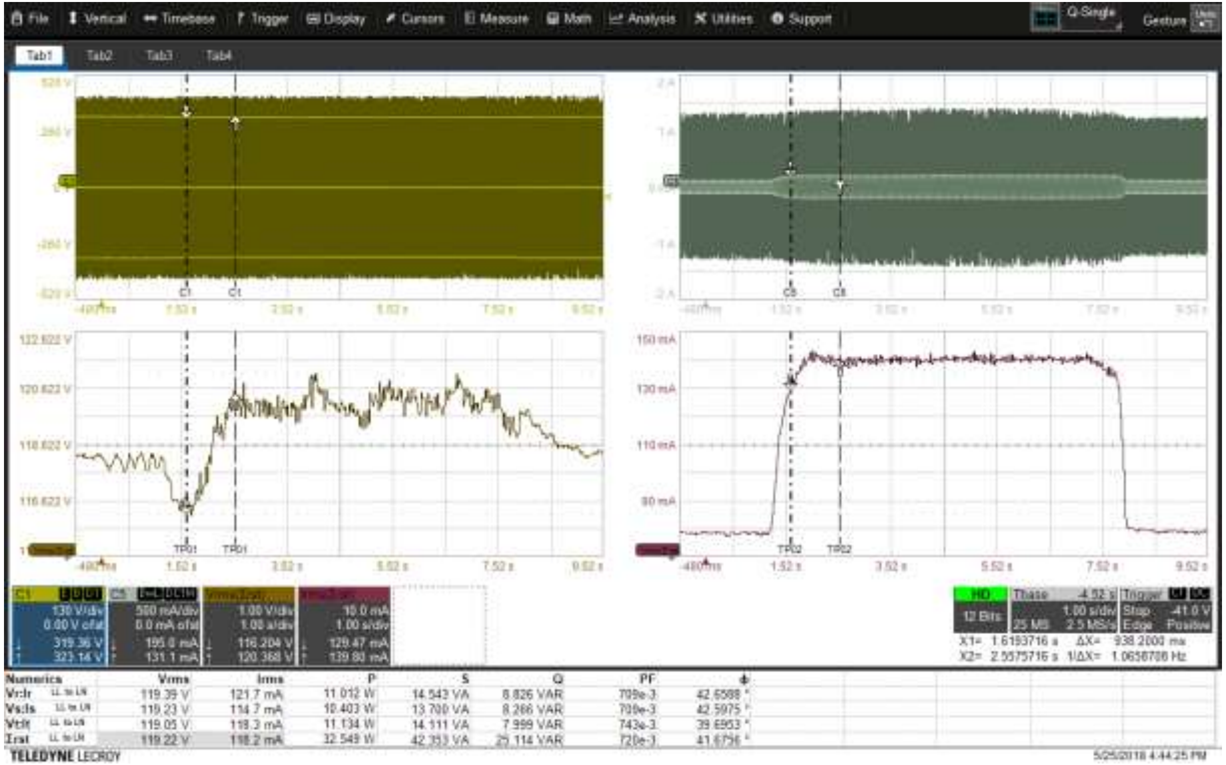
Detailed Look At Load Change On A Motor.

- Load change can be seen by the shape of the current waveform.
- Current waveform risetime measured.
  - Shows response time of the system to load change.
  - Voltage droop approx. 1V.
  - Voltage Pk-Pk deviation can be seen (and measured).



Detailed Look At Load Change On A Motor.

- Cursors used to make Voltage measurements.



Detailed Look At Load Change On A Motor.

- Measurements Added.
  - Frequency of the motor, voltage Pk-Pk swing (P1 & P2).
- Other possible measurements include Min, Max, Pk-Pk, RMS, etc, for Current or Voltage.
- Frequency Deviation of motor extracted.
  - Also displayed as a histogram
  - Measurements show motor deviation of less than 100mHz over load change period.

Conclusion.

- Dynamic Power Measurements measure what is happening in a changing system.
  - When the motor is not in a static state.
  - When the load is changing.
  - To check design performance in dynamic situations.

- Dynamic Power Measurements.
  - On motors.
  - On Inverters.
  - Other multiphase systems.
  - In electric vehicles, white goods, industrial machinery.

A Teledyne LeCroy Motor Drive Power Analyzer.

A Perfect Combination!

Teledyne LeCroy
Motor Drive Analyser
8ch, 12-bits, up to 1 GHz
with Motor Drive Power Analyzer software
and Mixed Signal Capability

Measure	Vrms	Irms	P	S	Q	PF	Phase
Vr:Ir	5.2358 V	1.67293 A	3.9975 W	8.7598 VA	8.1937 VAR	354e-3	69.298 °
Vs:Is	5.2077 V	1.61739 A	2.9370 W	8.4239 VA	7.8951 VAR	349e-3	69.600 °
Vt:It	5.2485 V	1.62216 A	3.0193 W	8.5149 VA	7.9815 VAR	354e-3	69.237 °
Total	5.2306 V	1.63750 A	9.9536 W	25.6984 VA	24.0504 VAR	352e-3	69.377 °

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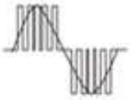

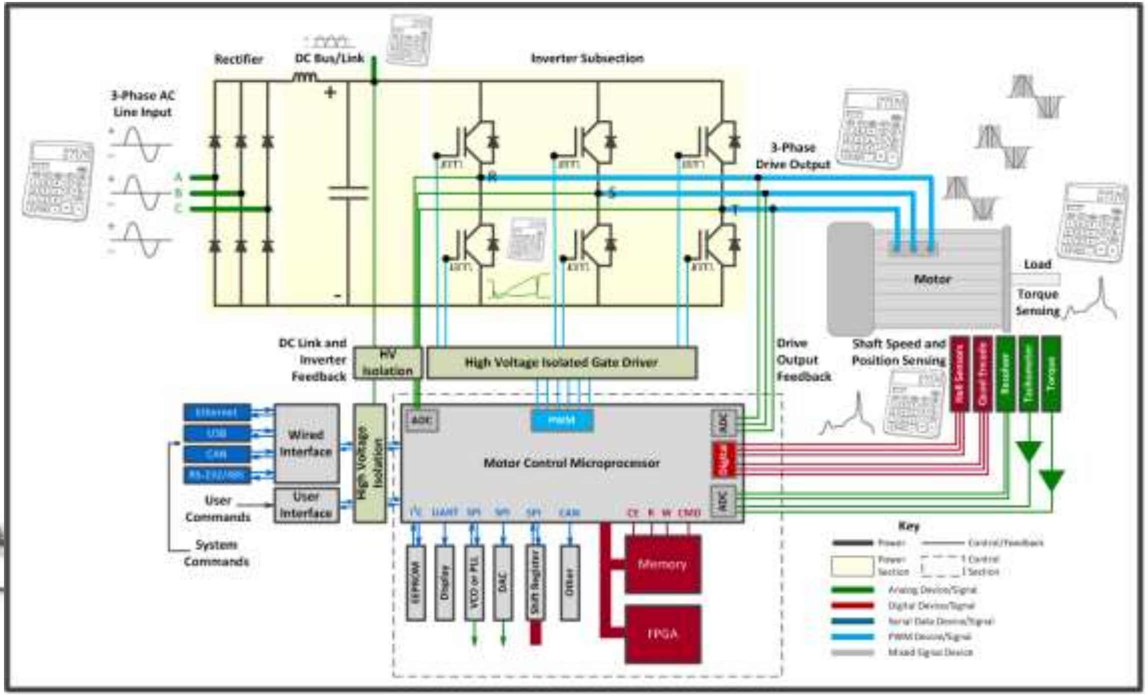

For Further Enquiries

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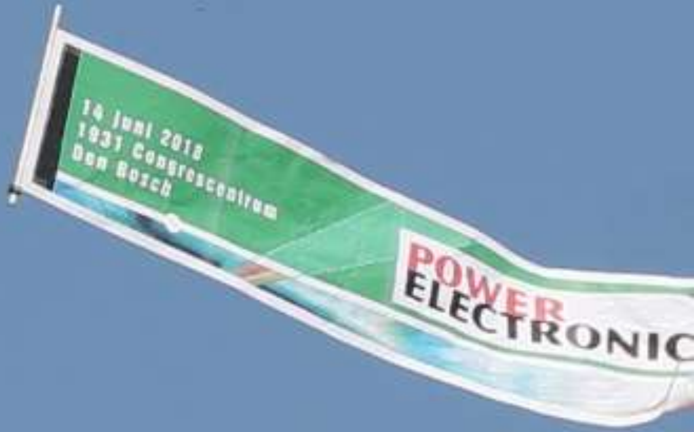

Motor Drive Power Analysis

Teledyne LeCroy builds on the MDA platform

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