SPE Electric Submersible Pumps Symposium
24–28 April 2017
The Woodlands Waterway Marriott Hotel & Convention Center
The Woodlands, Texas, USA

Power Quality Breakout

Sandy Williams – Artificial Lift Performance Ltd

Society of Petroleum Engineers

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Agenda

- Do ESPs run longer on VSDs or switchboards?
- Our operating environment is worse than other industries
- Why are we not applying other industry learnings
- Common problems and fixes
- Do we need a spec for downhole power?
  - What would it cover?
- Open discussion

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Do ESPs run longer on VSDs or switchboards?

- What is your experience?
- In 2004 worked on a project
  - ESPs producing over 10,000 bfpd with high HP
  - All had runlives 1000 days+
  - All on switchboards

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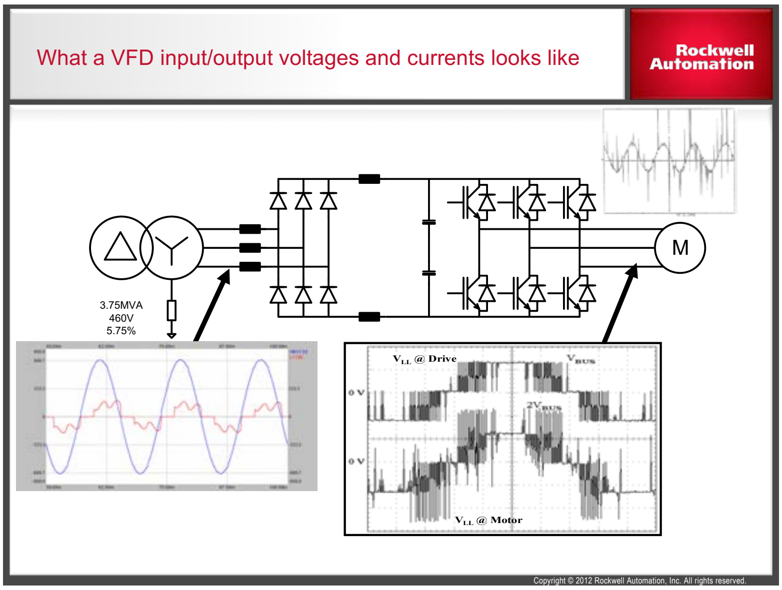
VSD and harmonics



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Our operating environment

- Extremely long cable lengths voltage drops vs current increase reflection
- Long, smaller diameter conductors, limited insulation (5kV)
  - Connections (splices and pothead)
  - Flat cables
- Long thin motors (vs. short and fat)
  - Long thin motors
  - No space for added insulation
  - No insulated bearings
  - Multiple rotors and bearings (instead of 1)
- High temperature downhole
- Irregular cooling
- Fluctuating temperature
- Changing load over time

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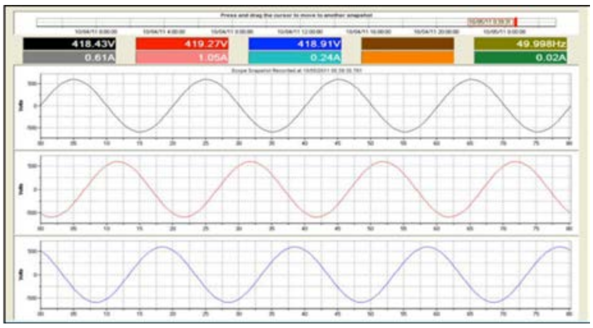
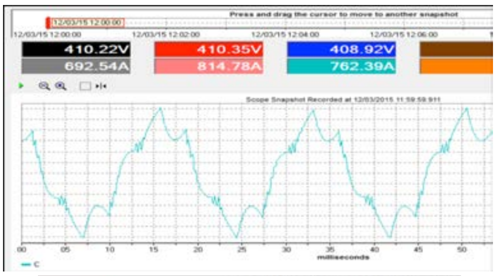
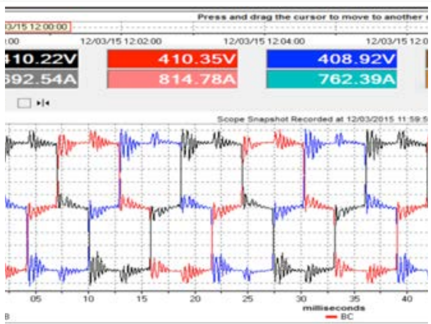
Sinewave vs. What we give ESPs (6 Step)







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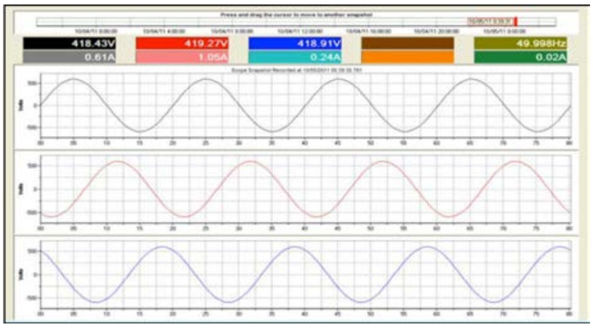
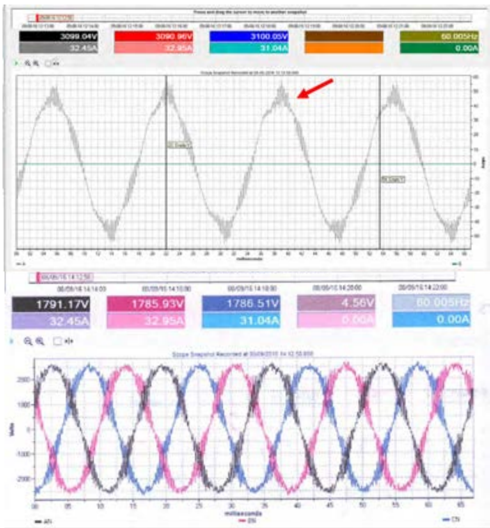
Sinewave vs. What we give ESPs (PWM w SWF)





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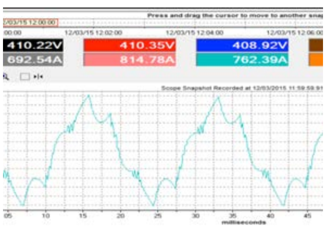
Terminology

- Harmonics = measurement of how non sinusoidal the waveform is

Voltage	AB	BC	CA
% THD	27.8	27.4	28.7
% Odd Harm	27.5	27.3	28.6
% Even Harm	3.3	3.0	2.6
Current	A	B	C
% THD	20.2	19.5	21.3
% Odd Harm	20.1	19.4	21.2
% Even Harm	1.3	1.8	2.0
% TDD	--	--	--
K Factor	5.2	4.4	6.0



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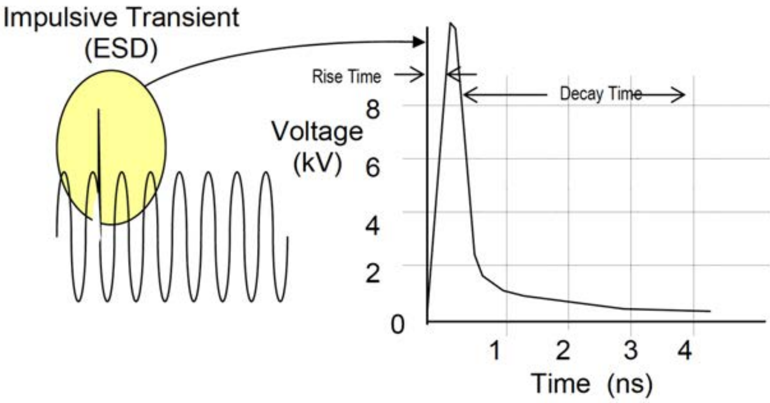
Terminology

- Transient very high voltage for short period



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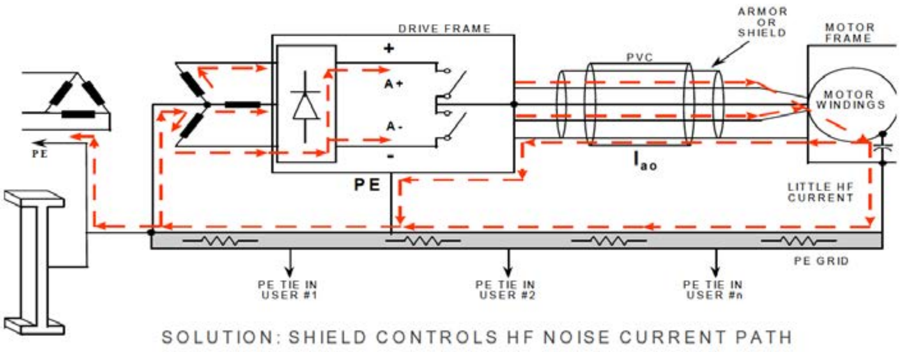
Terminology

- Common mode current



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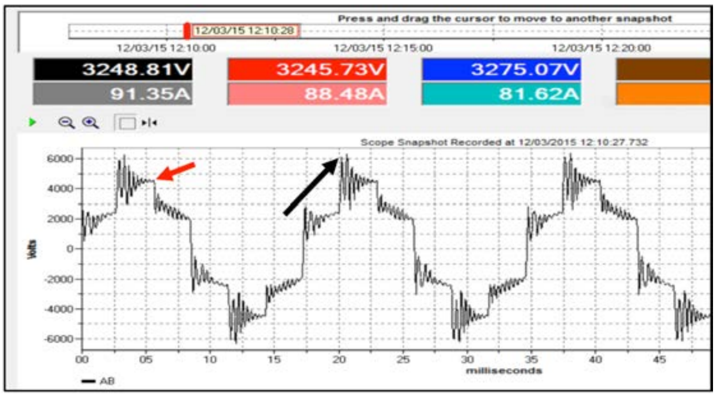
Terminology

- Ring waves
  - The ring wave adds another 1800V peak (longer black arrow: +6100V – 4500V = +1800V).
  - The ring wave component is subject to doubling when it hits the motor,
  - Yielding a maximum peak voltage of 4500V + 2x1800V = 8100V .



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Terminology

- Grounding
  - Safety
  - Protection of people & equipment
  - Lightning
- National Electric Code (Emerald Book) requires that for personnel safety, ground resistance shall be no more than 25Ω.

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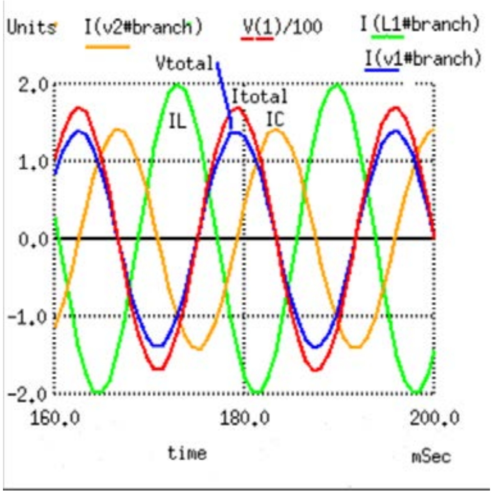
Terminology

- Current & Voltage Imbalance
  – Abnormal motor heating
  – Vibration

% Voltage Imbalance	% Motor Winding Temperature Increase
2%	8%
3%	18%
4%	32%
5%	50%
6%	72%
7%	98%
8%	128%



% voltage imbalance = Maximum deviation from the average ÷ average × 100

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Consequences of poor power quality

- Failures (and short runlives)
  – Penetrator
  – Cable
  – Splice
  – MLE / Pothead
  – Motor end turn
  – Motor bearing
  – Sensor
  – Broken shafts

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Lessons from other industries

- NEMA MG 10-2017 states that usual conditions for a motor or generator (MG) is:
  - a voltage unbalance of 1% or LESS, and the motor should operate successfully within those specifications.
  - 3.5% voltage unbalance causes 20% increase in motor losses (incremental heat).
- Norm Christopherson is an accredited & published HVAC Technician and Electrical Instructor:
  - His ratios are consistent with the NEMA calculation: 2.987% Voltage Imbalance → 17.84% increase in motor winding temp rise (he provides an example, pp. 3-4)
- Pumps & Systems Article by Thomas H. Bishop, P.E, EASA:
  - A 1% voltage imbalance yields a 6-10% current imbalance which yields as much as a 21% motor temp rise increase as determined by Power = I^2R → (1.10)^2 = 1.21.
- A 10 deg motor temperature rise can have potential life of motor

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Common problems

Best Practices for VFD Grounding

Minimize the damage caused by common mode noise.
by Jay Marchi

A good grounding system is an integral part of any electrical system. Older, linear systems were designed around the linear relationships between voltage and current. However, the proliferation of solid-state power supplies that take in incoming alternating current (AC) power, rectify it to direct current (DC), then reconstitute it at varying voltage and current ratios at different frequencies, called nonlinear systems, presents some new challenges for a typical ground scheme. The byproducts of these nonlinear systems are the production of significant harmonic distortions, voltages and currents on a system and, when referenced to ground, are described as common mode noise (CMN). CMN can have deleterious effects on some mechanical components such as bearings and electrical and control systems on the same ground bus.

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Downhole power quality specifcation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ADVANCED MANUFACTURING OFFICE

Energy Tips: MOTOR SYSTEMS

Motor Systems Tip Sheet #14

When Should Inverter-Duty Motors Be Specified?

Electronic adjustable speed drives, known as variable frequency drives (VFD), used to be marketed as "usable with any standard motor." However, premature failures of motor insulation systems began to occur as fast-switching, pulse-width-modulated (PWM) VFDs were introduced. The switching rates of modern power semiconductors can lead to voltage overshoots. These voltage spikes can rapidly damage a motor's insulation system, resulting in premature motor failure.

Effects of VFDs on Induction Motors

The nonsinusoidal variable frequency output of PWM drives has several effects, including increased motor losses, inadequate ventilation at lower speeds, increased dielectric stresses on motor windings, magnetic noise, and shaft currents. These effects can combine to damage a motor's insulation and severely shorten its useful operating life.

High switching rates of modern power semiconductors lead to rapid changes in voltage in relatively short periods of time. (dV/dt, quantified in units of volts per microsecond). Steep-fronted waves with large dV/dt or very fast rise times lead to voltage overshoots and other power supply problems.

Suggested Actions

- Obtain information from motor and drive manufacturers about inverter rise times and effects of cable length. Use this information to evaluate the capacity of existing motors to withstand drive-induced voltage stresses.
- Damaging reflected waves are generally not a problem when the distance between the motor and the drive is less than 15 feet.
- Voltage overshoots are more likely to occur with smaller motors and drives with faster rise times.

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Lessons from other industries

Electrical Construction and Maintenance

By Philip M. Gonski, P.E., Keystone Engineering Group, Inc.

Aug 17, 2012

Understanding the risk factors behind bearing current development associated with variable-frequency drives (VFDs)

In the age of energy efficiency, engineers are often excited about the potential cost savings associated with variable-frequency drives (VFDs) and their ability to operate motors to match demand loads. While VFDs can significantly alleviate electricity costs, they can also dramatically reduce a motor's lifespan. Shaft voltages generated from the common-mode output of VFDs lead to arcing across a motor bearing. Over a short period of time, this can lead to audible noise, not to mention subsequent motor failure.

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Lessons from other industries

Electrical Construction and Maintenance
By Philip M. Gonski, P.E., Keystone Engineering Group, Inc.
Aug 17, 2012

Understanding the risk factors behind bearing current development associated with variable-frequency drives (VFDs)

Motor frame size — Motor bearing currents have a direct relationship to motor size. Specifically, motors above 450 hp have been found to be the greatest candidates for bearing currents, due to the higher likelihood of magnetic asymmetry in the construction of the motor windings. While large motors will experience some amount of bearing currents, motors powered from VFDs introduce additional magnetic asymmetry from common-mode voltage.

Rough handling — Motors are at an increased risk of shaft voltage if they were handled roughly during shipment. Oftentimes, damage can occur in the factory, in transit, or when the motor is being lifted onto its pedestal. Minor motor damage during shipment may not cause noticeable problems with motor performance; however, it increases the likelihood of magnetic asymmetry leading to bearing current development.

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Best practices for downhole ESP

- Limit or reduce harmonics
- Always use SWF on PWM
- Measure harmonics to make sure SWF working properly
- Place surge suppression so protects downhole ESP (and VSD).
- Ensure properly grounded
- Use filter to remove common mode (line to ground) current

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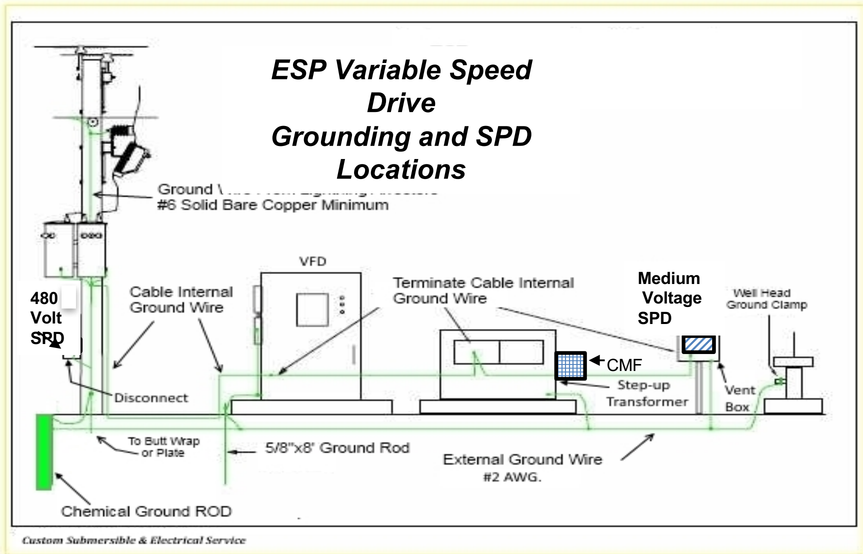
Best practices for downhole ESP



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Best practices for downhole ESP

- Why don't we have a specification or guideline?
- IEE519 only covers harmonics to utility
- There is no downhole equivalent

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- Atika
- Ibrahim
- David Shipp
- Michael Rommer
- John Graham
- Mark Turland
- Hany
- Kenneth
- Sal
- Richard Delayoye
- Tom van Akkeren

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Thank You / Questions

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