IPPTA
Workshop cum Seminar 2019

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Trends in Drives and Motors - Ultra-low Harmonic Drives, Energy efficiency and Digital ready

Prasanna Deshpande , Vice President, ABB India Limited

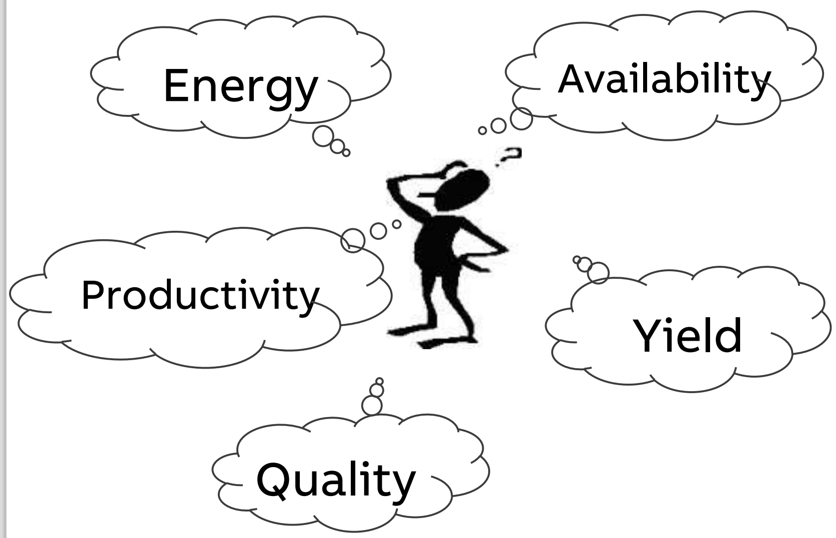
Indian Industry - Changing Priorities

The things that really count

Key aspects

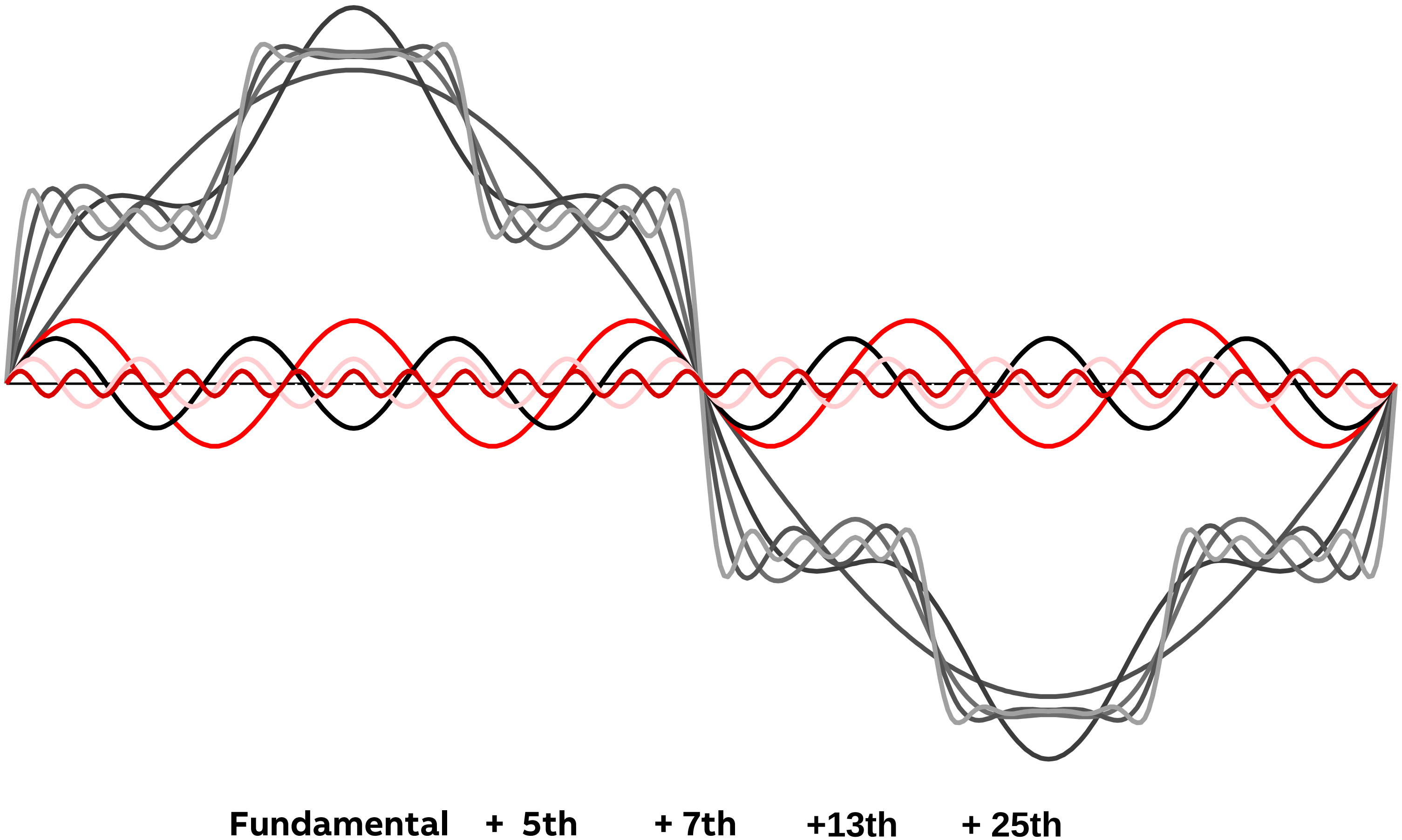
- Energy Efficiency
- Carbon Footprint
- Productivity
- Availability
- Safety
- Sustainability
- Compliance to changing regulations

Motivation



Harmonics - Concept

What are harmonics



Recommended harmonic limit

IEEE STD 519-2014

Focusing on Point of Common Coupling (PCC)

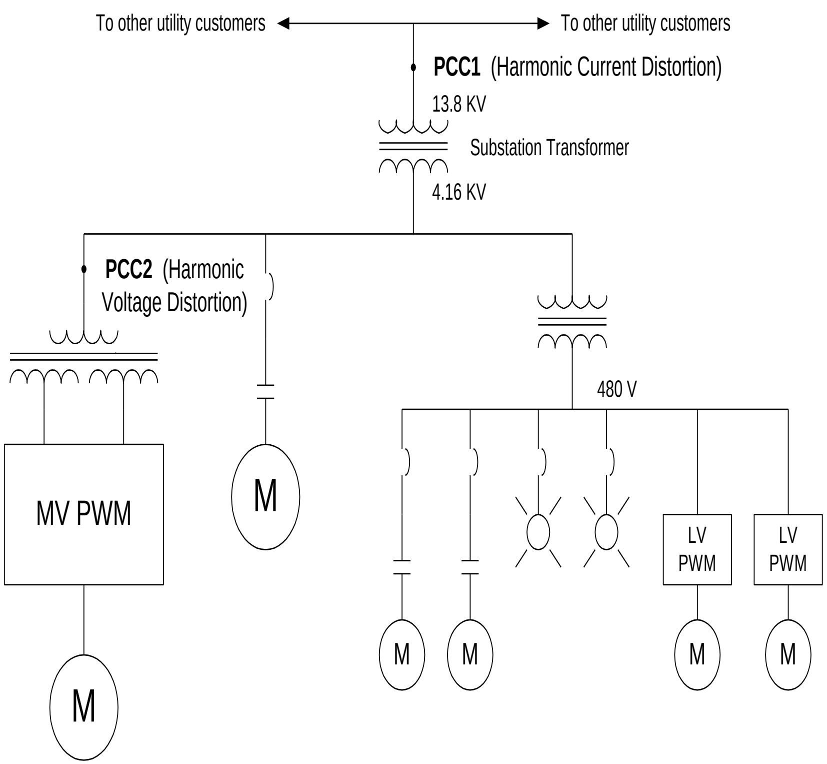


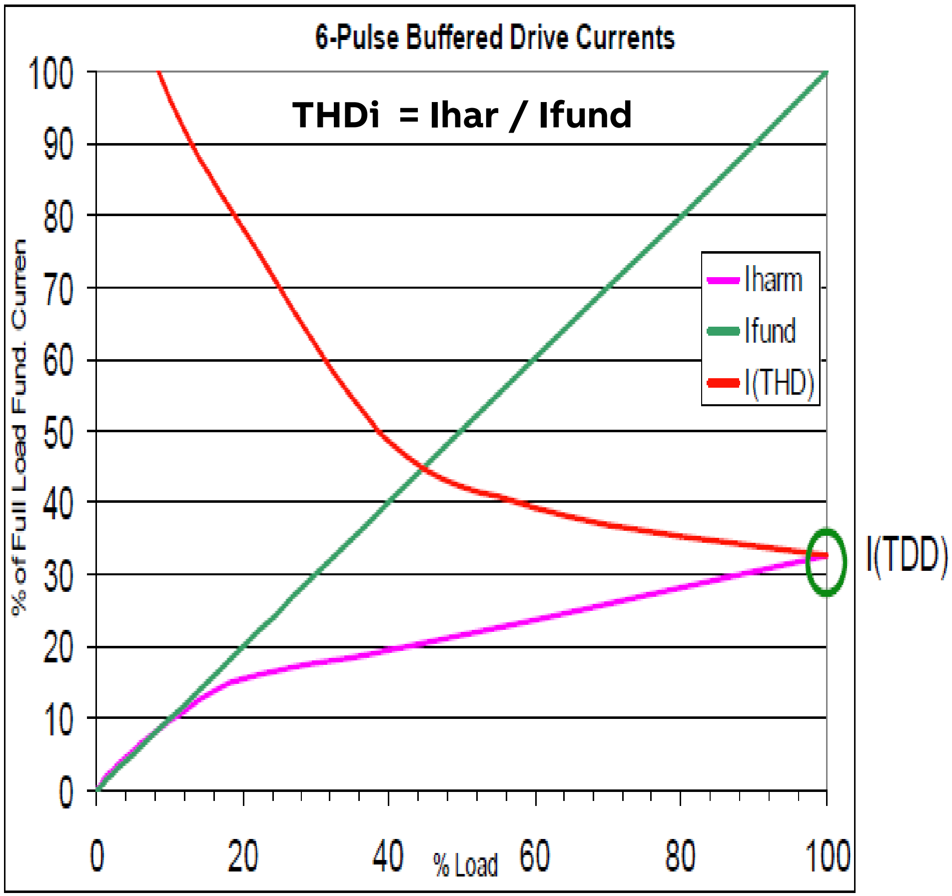
Table 1—Voltage distortion limits

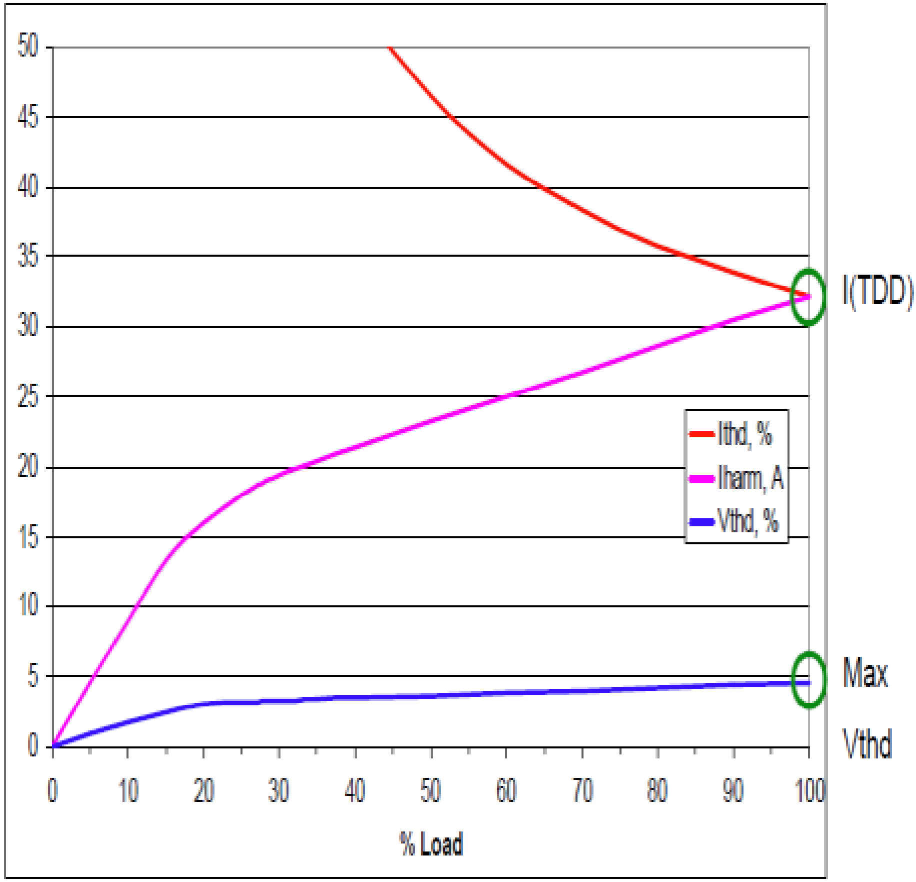
Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV $< V \leq$ 69 kV	3.0	5.0
69 kV $< V \leq$ 161 kV	1.5	2.5
161 kV $< V$	1.0	1.5[a]

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
< 20[c]	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

Effect of motor loading on a VFD driven system

How does motor load affect I(THD) and V(THD)





Ultra-low harmonic drives

Solutions to mitigate harmonics

Solutions to reduce harmonics in drive applications

Choke	Correctly sized choke in a drive with a 6-pulse diode supply unit
Passive or active filters	Active filter with a drive - cancelation of harmonics by equal and opposite harmonic generation Passive filter with a drive - low impedance path for harmonics
Multipulse drives	Increasing pulse number of the drives: 6-pulse -> 12-pulse -> 18-pulse -> 24-pulse
Ultra-low harmonic drives	Ultra-low harmonic drives

Harmonics can be suppressed with the correct measures.

Ultra-low harmonic drives

Comparison of harmonics reduction solutions

	6-pulse rectifier without choke	6-pulse rectifier with large choke	6-pulse drive and passive filter	6-pulse drive and active filter	Multipulse drive	IGBT supplied drive / low harmonic drive
Typical THDI% at nominal load	>100%	40%	<10%	<5%	6 to 10% (12-pulse) <6% (18-pulse)	<5%
Drive system efficiency (excluding motor and supply), typical value at rated power	~98%	~97%	~96.5%	~96.5%	~ 96%	~96.5%
Motor voltage (4	~0.96 × supply voltage	~0.95 × supply voltage	~0.95 × supply voltage	~0.95 × supply voltage	~0.95 × supply voltage	Full motor voltage
True power factor	~0.7 at nominal load only	~0.98 at nominal load only	~0.98 at nominal load only	~0.99 at nominal load only	~0.98 at nominal load only	1.0 at all load conditions
Simplicity of the installation	One single component	One single component or two separate components	Two separate components	Two separate components	Multiple separate components	One single component
Installation footprint	100%	110%	250%	250%	300%	120%
Equipment cost of all required components	100%	120%	190%	230%	200%	190%

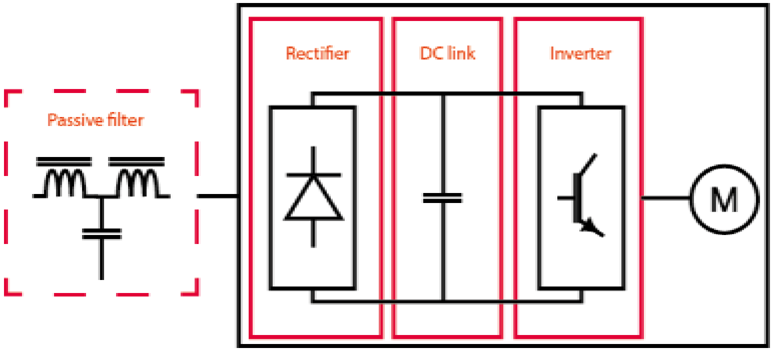
Data is based on a 100 kW installation. Results may vary depending on equipment types and their dimensioning.
For IGBT supplied drive, evaluations are based on ABB ultra-low harmonic drives.

Ultra-low harmonic drives

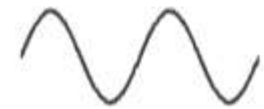
Passive filter versus ultra-low harmonic drive

Passive filter with drive

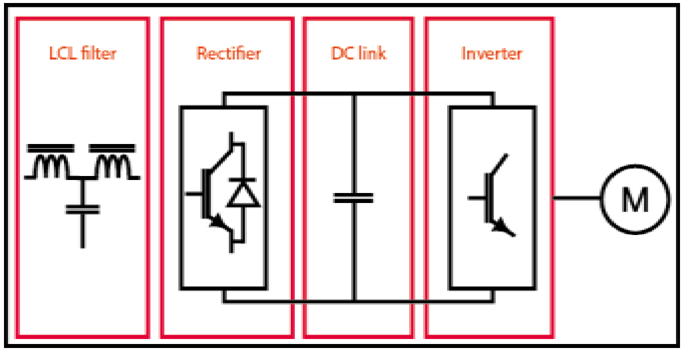
- THDI typically 5 to 10% (depends on filter type)
- Requires additional filter and cabling
- Leading power factor at no load
- Risk of resonance
- Load dependent voltage drop over the filter
- On partial loads DC voltage can rise even by 10%, creating the possibility of an overvoltage fault



Ultra-low harmonic drive



- THDI typically 3%, i.e. current harmonics are below limits set by harmonic standards like IEEE519 and G5/4
- Does not require any external parts or cabinets
- Power factor unity at any load point
- Full motor voltage
- No risk for resonance

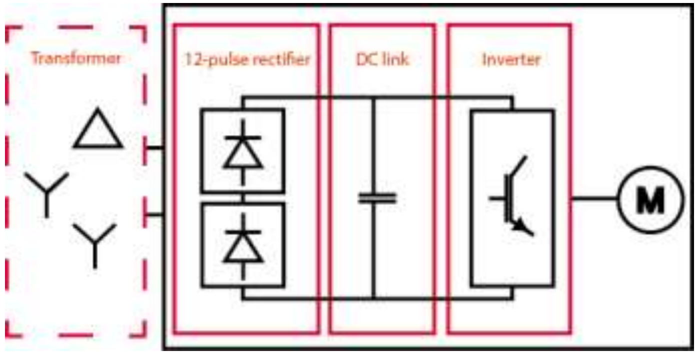


Ultra-low harmonic drives

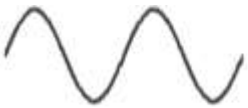
Multipulse drive versus ultra-low harmonic drive

12-pulse drive

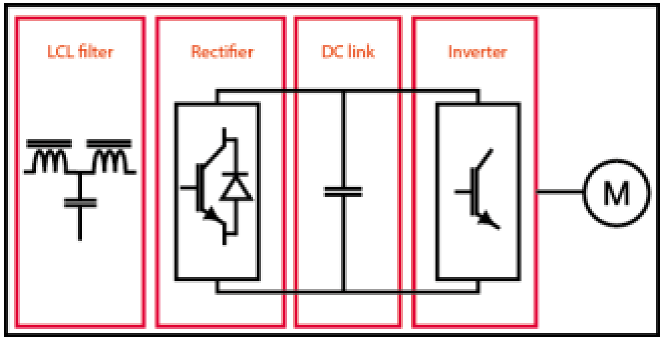
- THDI typically 12%
- Requires a special transformer
- Lower power losses in the drive and lower power factor
- Effectiveness depends on line imbalance and transformer windings balance
- Higher cabling and installation cost
- Space and weight demand



Ultra-low harmonic drive



- THDI typically 3%, complies with IEEE519, G5/4
- No need for special transformer and filters
- Lower transformer losses compensates overall efficiency
- Power factor 1.0
- Harmonic performance is robust against supply and transformer variations
- Compact design

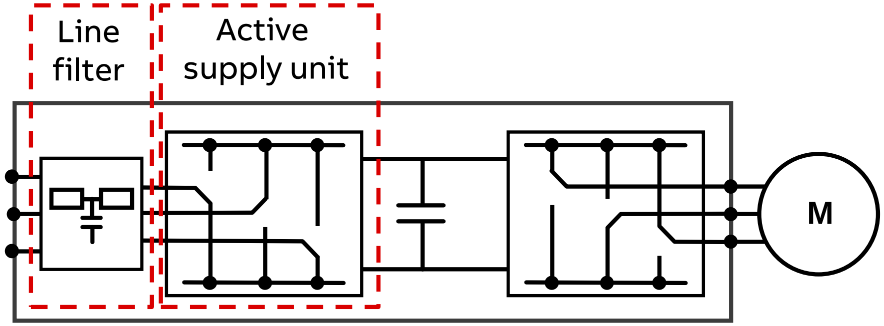


Ultra-low harmonic drives

Harmonic mitigation built-in

Operation principle

- ABB's ultra-low harmonic drives have harmonics mitigation built into the drive
  - Drive has an active supply unit (= IGBT supply unit) and in-built line filter



- Active supply unit is controlled to eliminate low order harmonics in the current.
- Line filter suppresses components above the switching frequency of the active supply unit IGBTs.

Total harmonic distortion, THDI, is typically 3%.
Exceeds requirements set by low harmonic standards.

Ultra-low harmonic drives

Harmonic mitigation built-in

Low harmonic content, 3% THDI

- ABB ultra-ow harmonic drives can help you to overcome the challenges created by harmonics
- With harmonics mitigation built into the drive, the ultra-low harmonic drive produces exceptionally low harmonic content

Standard 6-pulse drive

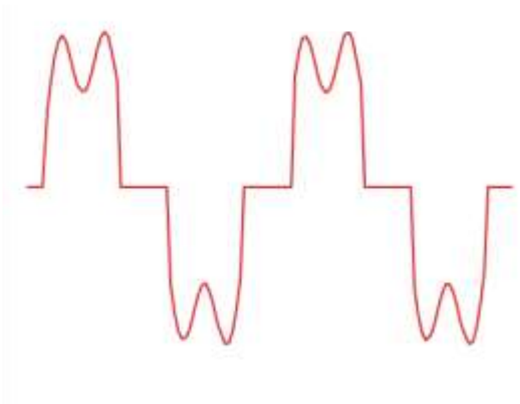
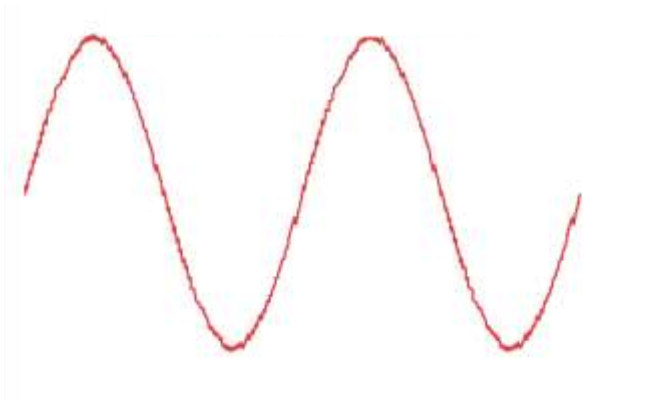


ABB ultra-low harmonic drive



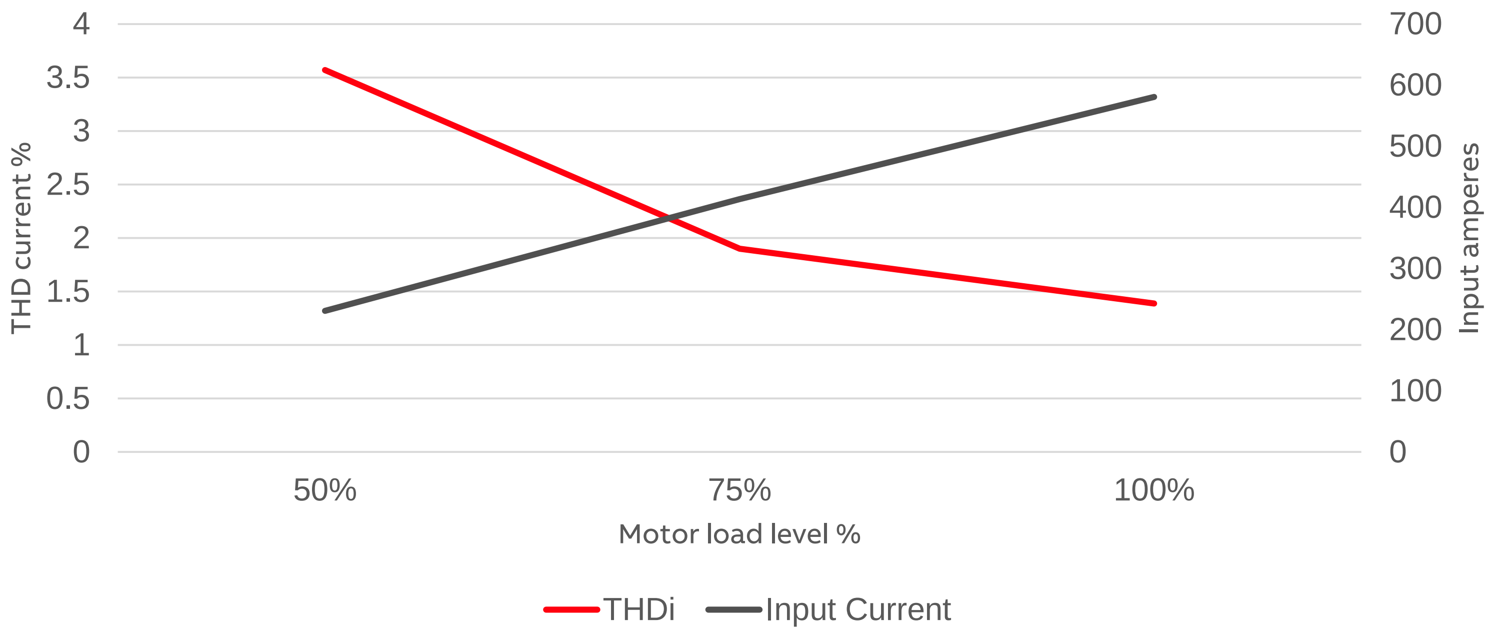
THDI is typically 3%. Exceeds requirements set by low harmonic standards.

Ultra-low harmonic drives

Excellent harmonic performance at all load levels

Harmonic mitigation performance

- Excellent harmonic performance at light load level
  Harmonics are below the limits defined in IEEE519, IEC61000-3-12 and G5/4 standards



Values in example are measured in on 400V Network with ~ 20 RSC using a 650 ampere /400V motor. Drive used was an ACS880-34-650A-3 Ultra Low Harmonic drive

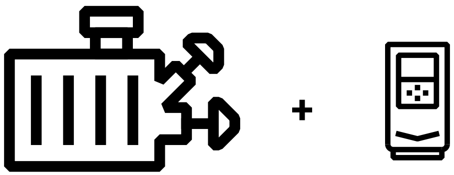
Ultra-low harmonic drives

Benefit to optimize transformer sizing

Transformer sizing

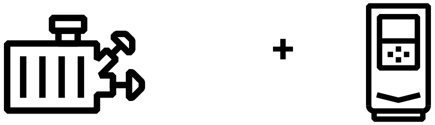
- When using 6-pulse drives, the transformer is selected using a factor of 1.35 x motor kVA to take into account power factor and harmonic distortion
- When using low harmonic drives the factor used is 1.1 x motor kVA. For example:
  - Motor load = 1000 kVA
  - 6-pulse system requires 1.35 MVA transformer
  - Ultra-low harmonic solution requires only 1.1 MVA transformer

* See next slide for more detailed example and explanation.



1.35 MVA

6-pulse drive

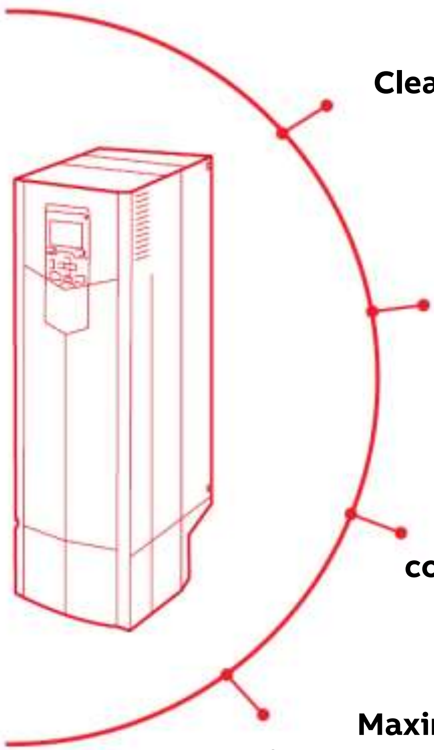


1.1 MVA

Ultra-low harmonic drive

Ultra-low harmonic drives

Value proposition



Clean supply network

- Low harmonic content and unity power factor at all loads decrease system losses and minimize energy consumption.
- Meets IEEE519, IEC61000-3-12 and G5/4 harmonic standards under all load conditions.

Minimized downtime

- Immunity to network disturbances – the drive will not interrupt the process or affect its quality in unstable supply network conditions.
- Drives' active supply unit is able to boost the output voltage, which guarantees full motor voltage even when the supply voltage is below nominal.

Optimized cost and space

- The drive comes in one single, compact package, which helps to reduce equipment costs and required space. Installation is fast and easy.
- Advantage in motor dimensioning since the motor voltage can be boosted to a higher value. With a higher voltage, the same power can be achieved with less current, which may allow a smaller motor to be used.

Maximized motor performance and efficiency

- Full motor voltage in all conditions.
- ABB's direct torque control (DTC) provides precise speed and torque control for maximum motor performance and motor efficiency.

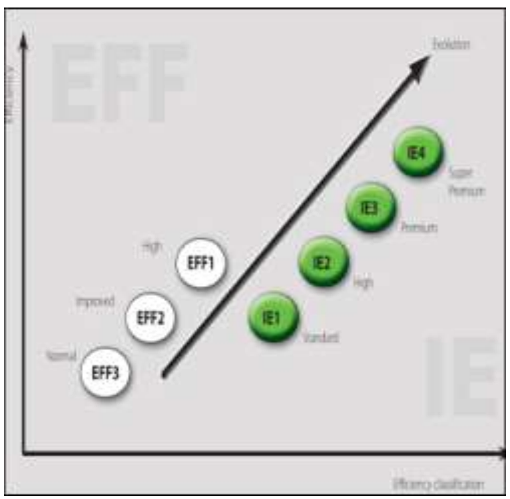
Energy Efficient motors

Energy Efficient Motors

Regulation and Efficiency comparison

GOI Gazette wef Jan 2018

- Min IE2 efficiency
- Motors complying to IS 12615 (2011)
- Testing and marking by BIS
- Motors complying to IS 12615:2018 from Feb 2019



Efficiency comparison

KW	Pole	IE2	IE3	IE4
11	4	89.8	91.4	93.3
22	4	91.6	93	94.5
30	4	92.3	93.6	94.9
37	4	92.7	93.9	95.2
11	6	88.7	90.3	92.3
22	6	90.9	92.2	93.7
30	6	91.7	92.9	94.2
37	6	92.2	93.3	94.5
11	2	89.4	91.2	92.6
22	2	91.3	92.7	94

The art of efficient energy conversion

Comparing motor technologies

Induction motor

- Starts DOL
- Robust
- Familiar and well-proven technology
- Torque only in asynchronous operation
- High speed accuracy is difficult without sensors
- Slip losses in rotor heats up bearings

Typical PM

- High energy efficiency
- Compact
- Synchronous speed
- Low bearing temperature & longer bearing life
- Only for VSD operation
- Rare-earth magnets, Uncertain cost variation
- Demagnetization risk
- Service challenges due to magnet forces

SynRM

- High energy efficiency
- Accurate speed control even without sensors
- Low bearing temperatures
- Safer fault behavior since unexcited in idling mode
- Mainly for VSD operation (DOL option for serial OEM)
- Lower power factor and higher current demand (handled by VSD)

Synchronous Reluctance motor

Concept and offering

Cage Induction motor

Cage Induction motor

Losses

- I^2R Rotor
- Other
- I^2R Stator

SynRM Std Output

Losses

- Other
- I^2R Stator

IE4 SynRM motor

Elimination of rotor losses

SynRM High Output

Losses

- Other
- I^2R Stator

IE3 High Output SynRM motor

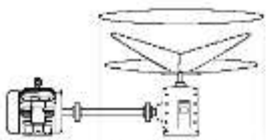
Compact frame for standard output

High output for given frame

Permanent Magnet Motors

Cooling tower drives : Conventional control vs New direct drive technology

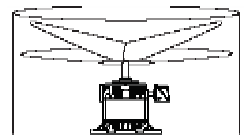
Conventional control



Key Points

- High Mechanical Maintenance - More components to fail over time:
  - Gearbox failures
  - Oil leaks & contamination
  - Failed & misaligned drive shafts
  - Excessive vibration
  - Additional replacement time due to large mounting frame
- Conventional Cooling Tower Control
  - Lightly loaded majority of the time
  - Peak load for short durations
  - Started across the line
  - High inrush currents
  - Mechanical stresses

New direct drive technology



Key Points

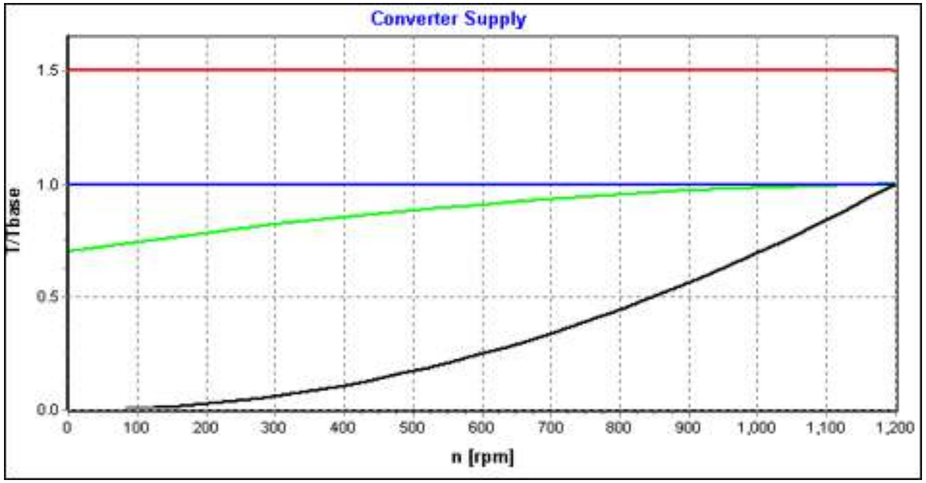
- IP56 Protection.
- Encapsulated winding.
- Permanent Magnet Finned Laminated Yoke motor
- Online Greasing once in a year.
- Improved power factor.
- Reduced Current.
- 12% Guaranteed Savings at Full Speed.
- Upto 50% Energy savings at Low rpm.
- No Oil Leakages and contamination.
- No Bearing failures and shaft breakages.

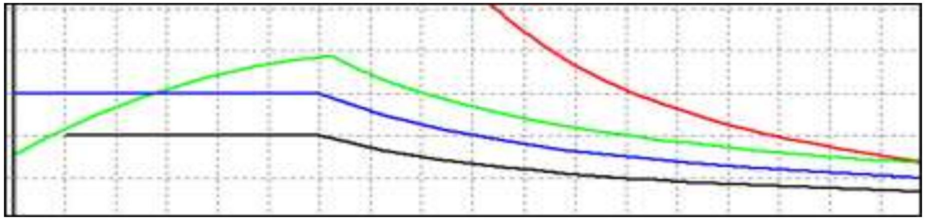
Motors for Variable frequency drives

Factors to be accounted for VFD motors

Lower cooling

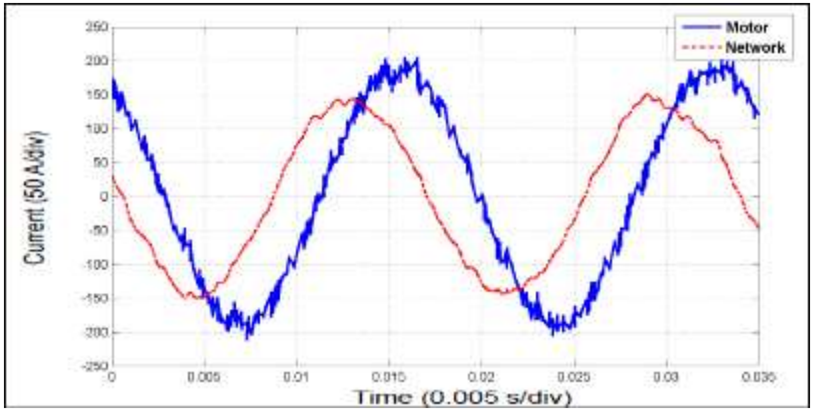
For self-cooled (IC 411, 611, 81W) motors, the cooling air flow may be inadequate at low speeds.

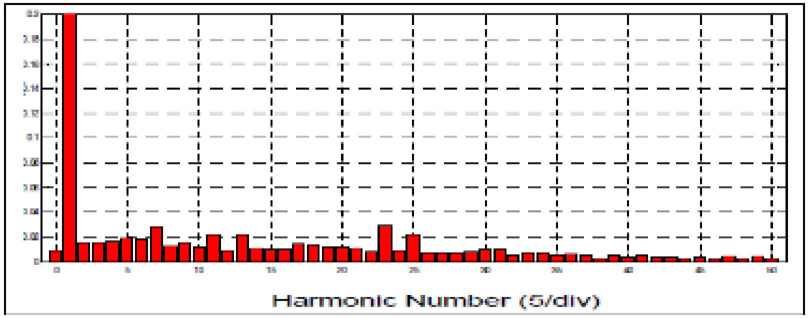




Harmonics – Temperature rise

Harmonics created by the converter supply mean the temperature rise is higher than with the sinusoidal supply.



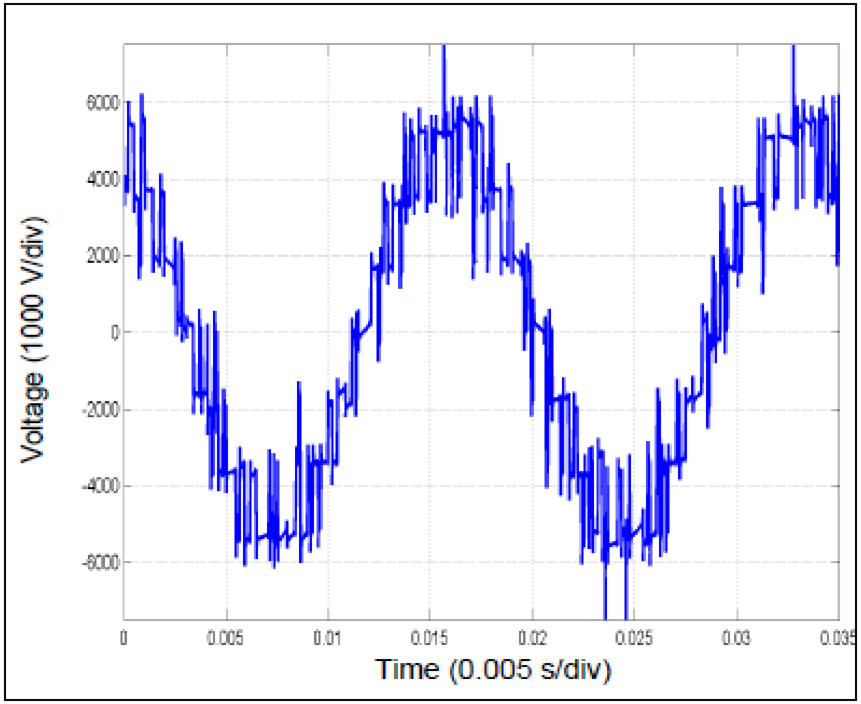


Motors for Variable frequency drives

Factors to be accounted for VFD motors

Higher voltage Stress – peak voltages

Due to steep voltage pulses compared to the smooth sinusoidal wave.



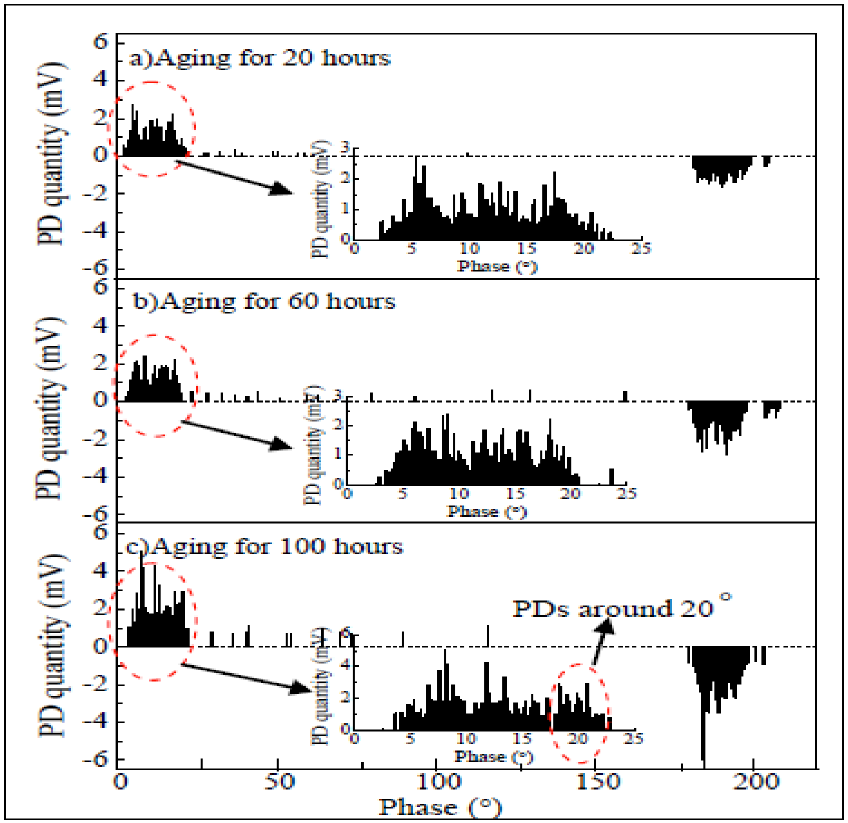
Some cases of failures

Source - Pictures from IEEE paper

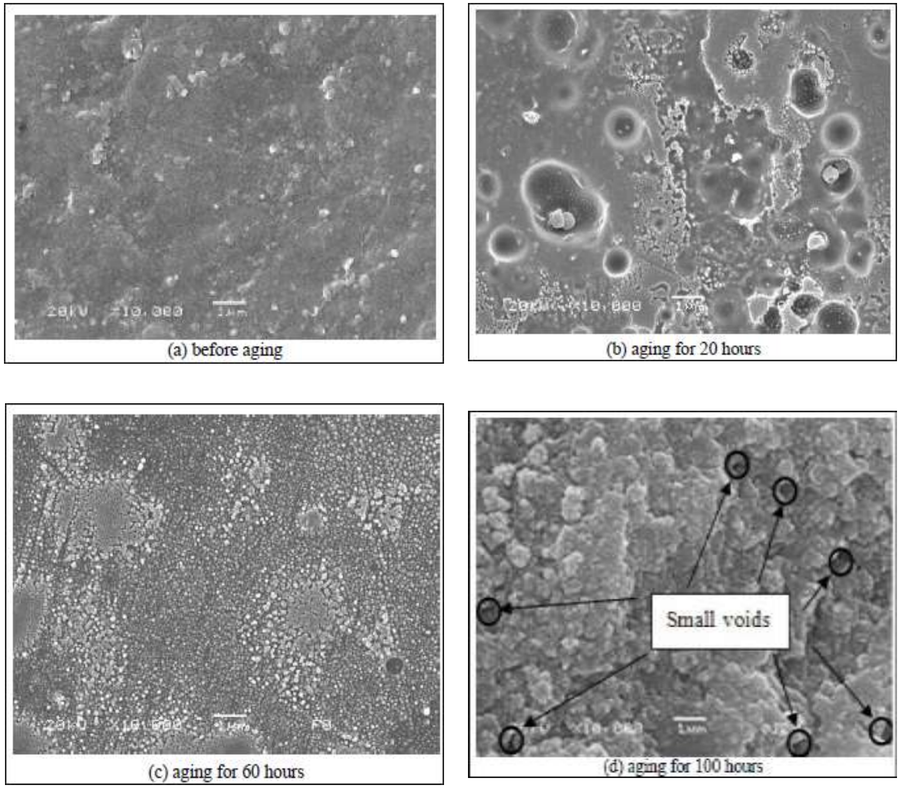
Motors for Variable frequency drives

Factors to be accounted for VFD motors

Higher voltage Stress – PD effect



Inter turn insulation surface



(a) before aging

(b) aging for 20 hours

(c) aging for 60 hours

(d) aging for 100 hours

Source - Pictures from IEEE paper

Cost of ownership of motors

Repair or replace ?

According to the life cycle approach

Ten new 15KW motors were independently tested and purposely damaged and sent to nine different repair companies

Every failure even if repaired, generally reduces the overall reliability of motor.

Results of tests carried out on 15-kW motors rewound at nine different repair companies

Motor	Efficiency change %
1	– 3.4
2	– 0.9
3	– 0.6
4	– 0.3
5	– 1.0
6	– 0.7
7	– 0.4
8	– 0.9
9	– 1.5
Average	– 1.1

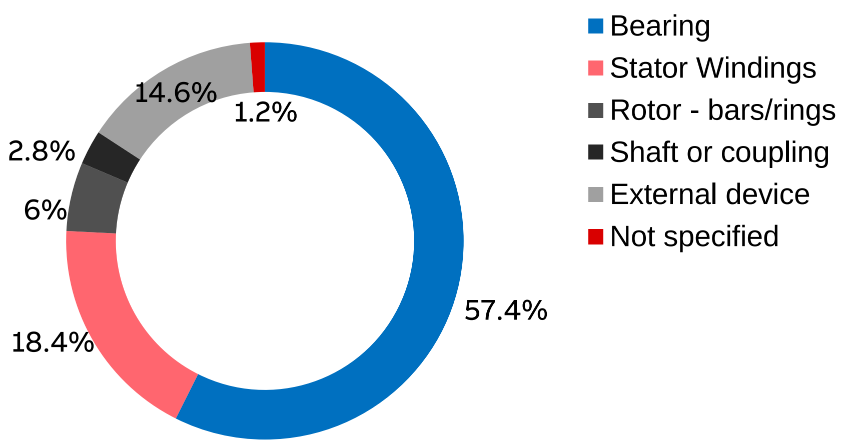
Efficiency loss varied from 0.3 to 3.4%

Failure statistics

Specific industry segment

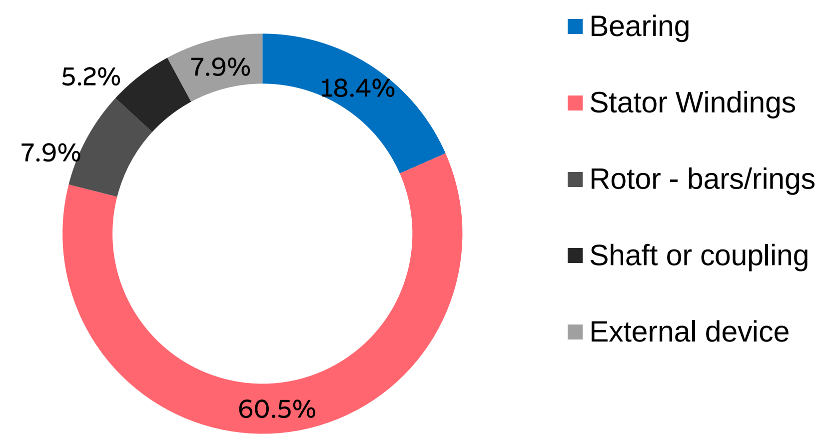
Motors below 2 MW

Motors below 2 MW commonly use anti-friction bearings, which are more likely to fail.



Motors above 2 MW

Motors above 2 MW often use sleeve bearings, which are less likely to fail.



IEEE transactions on industry applications . vol. 35. no. 4. july/august 1999

Digitalization and IIoT Ready

Will motors be included in the IoT?

If a large number of motors delivered status information…

If monitoring equipment were affordable and easy to install...

If competent data analysis with a large volume of information were readily available...

… then service engineers could provide advanced plant optimization at affordable costs

… and plant operators could save operating costs and increase productivity.

Monitoring and maintenance of LV motors today

Prioritizing the maintenance and monitoring cost – A challenge

Better monitoring & maintenance can boost plant performance

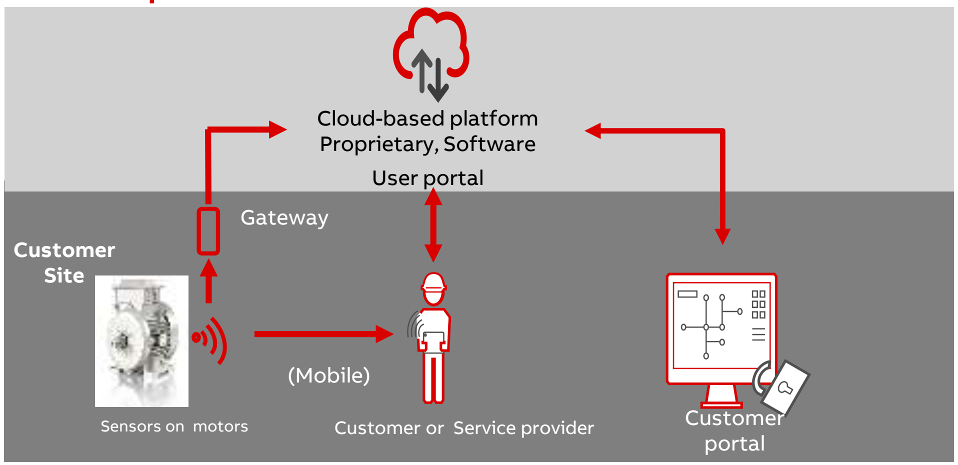
Most LV motors are not monitored, and serviced only reactively.

- A significant infrastructure is required, which typically costs more than the motors themselves
- Specialist personnel are needed to install and maintain the monitoring equipment
- Without correctly installed infrastructure, the maintenance team does not have sufficient data to carry out optimizations

Condition monitoring for LV motors

Some concepts and KPIs

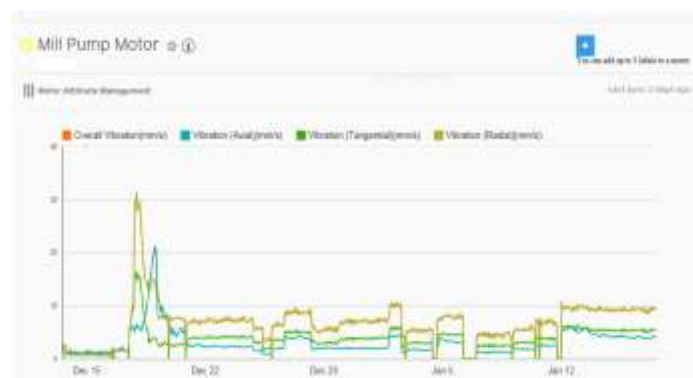
Concepts – 1



Other Concepts

Some Parameters monitored to bring value

- Vibration: Axial, Radial and Tangential
- Vibration overall
- Bearing condition
- Skin temperature
- Operating hours
- Number of starts
- Speed
- Energy consumption
- Operating Power / Loading

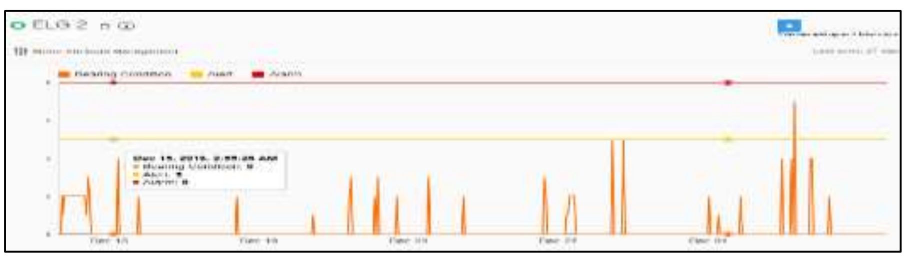


A game changer in condition monitoring for LV motors

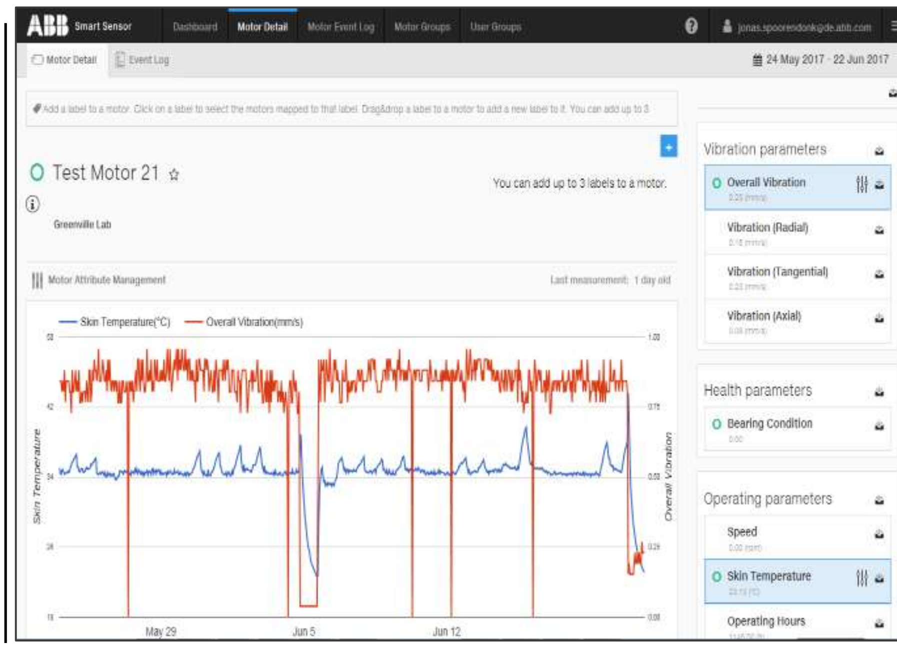
Example of Dashboard views

Types of maintenance & end results

Thresholds



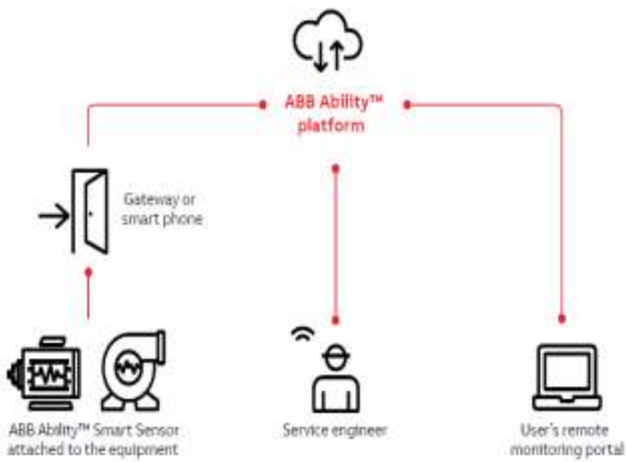
Overall Dashboard



Monitoring and maintenance of Driven Powertrain

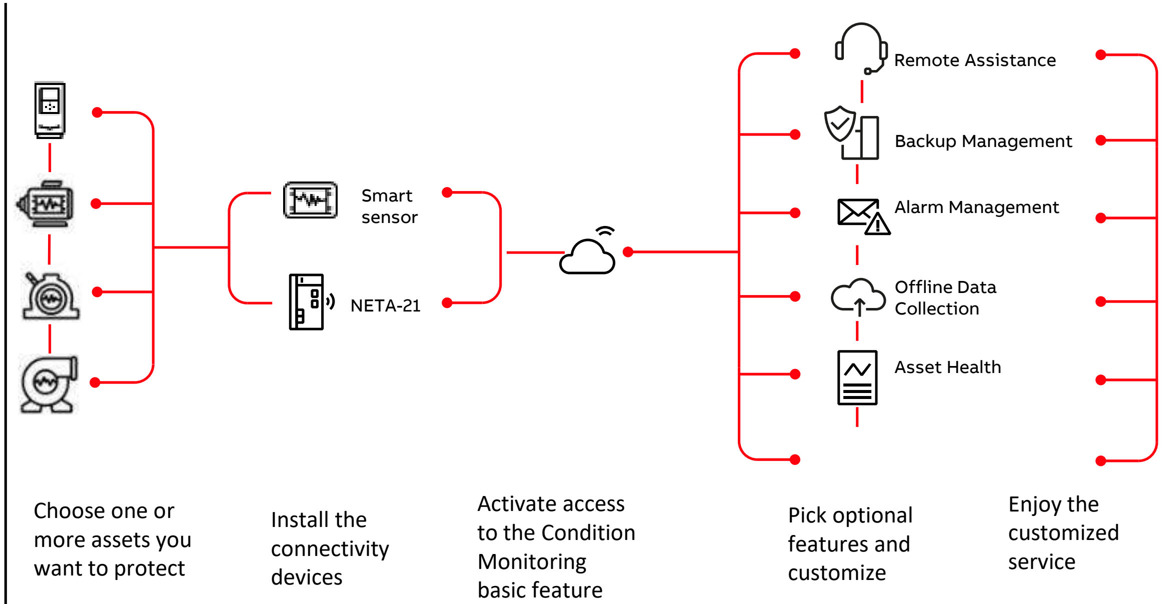
Eg - Smart Sensor for pumps and

Together with motor sensor can provide significant value



- Monitored parameters : Vibration and temperature
- Performance indicators e.g. : Rotating speed of the pump, Operating hours, Blade problems , Looseness, misalignment, unbalance

Configurable powertrains and customizable digital service



Finding the right Value

Remote Services provide clear value with substantial benefits

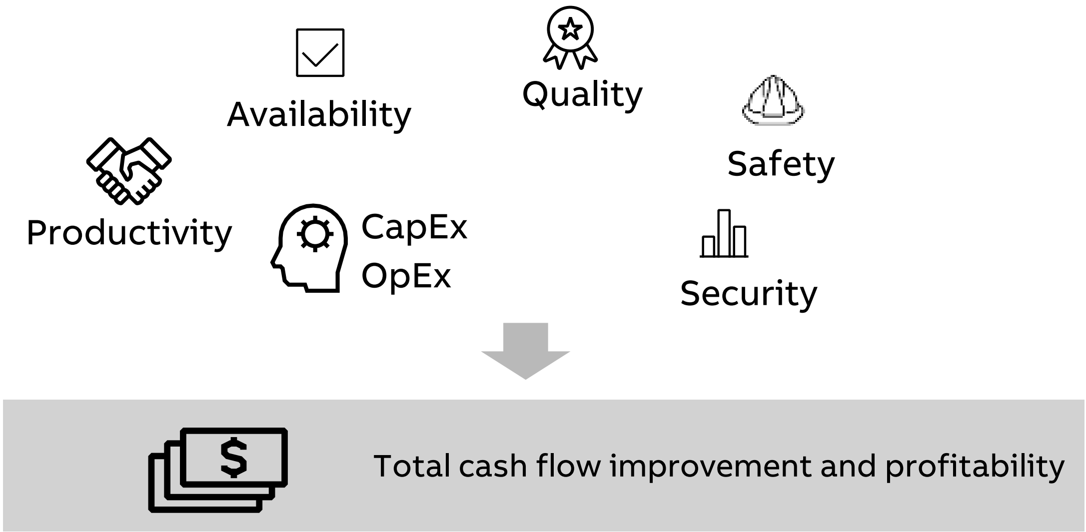
Value Perception may differ

Industry

Applications

Ability to apply data for gaining benefits

- Parameter Backups
- Fleet Benchmarking & Maintenance Benchmarking
- Enhanced and Efficiente Maintenance
- Human Safety (Virtual site Visit)
- IoT & Industry 4.0
- Peace of mind & Resourcing



ABB