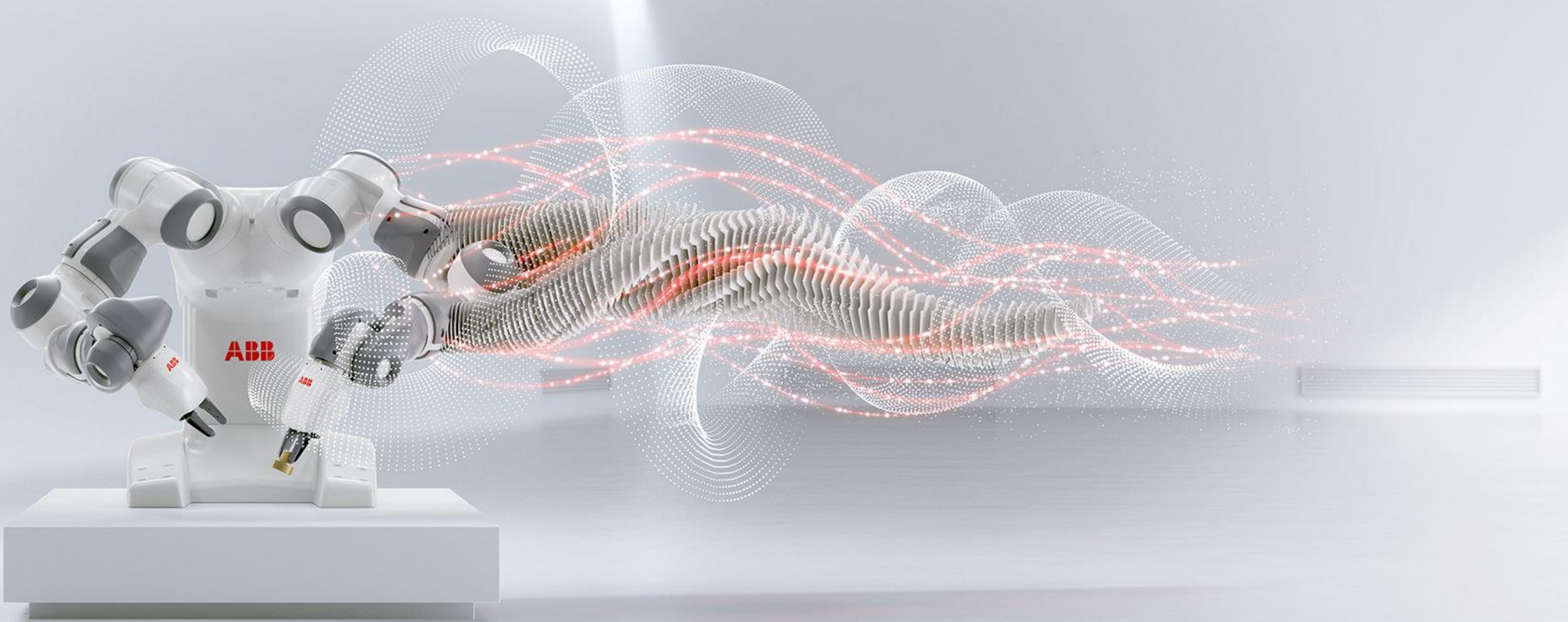


22ND MAY 2020

Energy saving potential using variable speed drive

Webinar for SAARC Energy Center

Ghanshyam Shrestha (PhD), Senior Principal Scientist, ABB INC.

About Me

- Ghanshyam Shrestha
- Nationality: Nepali
- Senior Principal Scientist at ABB INC, Raleigh, NC, USA
- At ABB since 2012
- Previously worked at Danotek Motion technologies in development of generators for wind turbines.
- PhD from Delft University of Technology, Netherlands
- Masters in Mechatronics Engineering from University of Siegen, Germany
- Bachelors in Electrical and Electronics Engineering from Kathmandu University, Nepal
- Interest in different motor topologies, drivetrain integration and transportation and industrial electrification
- Contact: ghanshyam.shrestha@us.abb.com, find me on Linkedin

Introduction

Operating through four leading businesses

	Electrification	Industrial Automation	Motion	Robotics & Discrete Automation
				
	Global #2	Global #2	Global #1	Global #2
2019 revenues	$12.7 bn	$6.3 bn	$6.5 bn	$3.3 bn
2019 Op. EBITA %	13.3%	11.7%	16.6%	11.9%
Employees	~53 k	~22 k	~20 k	~10 k

— Digitalization: ABB Ability™ —

ABB

Global #1 in motion industries – leading from a strong foundation

ABB
SIEMENS
WEG
WOLONG

Motors

ABB Global #1

Drives

ABB
SIEMENS
Danfoss
Rockwell Automation

Our key differentiators

1

Pioneering technology leader

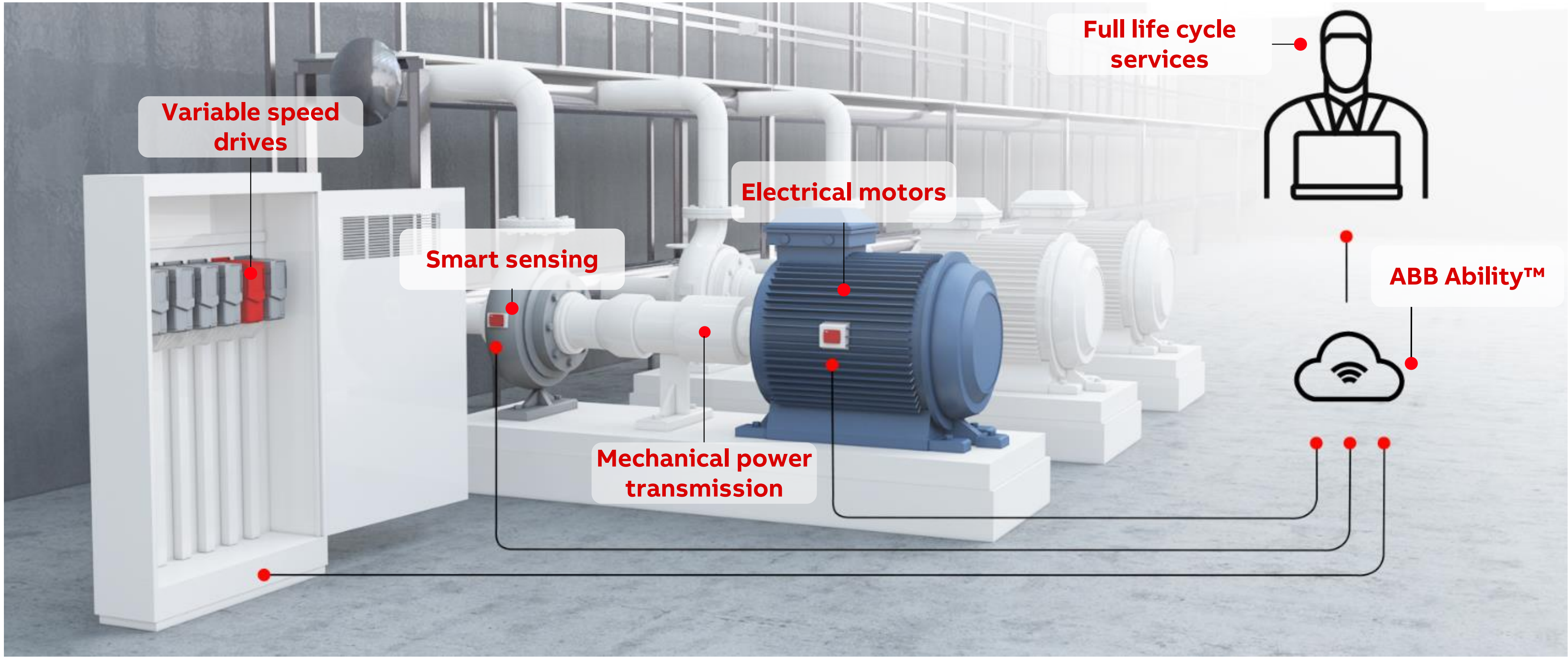
2

Domain expertise

3

Global scale and coverage

Motion offering

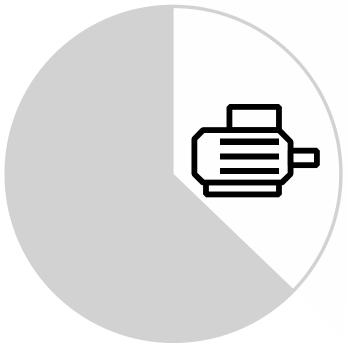


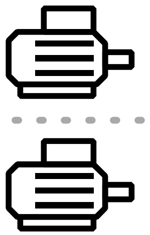
Content

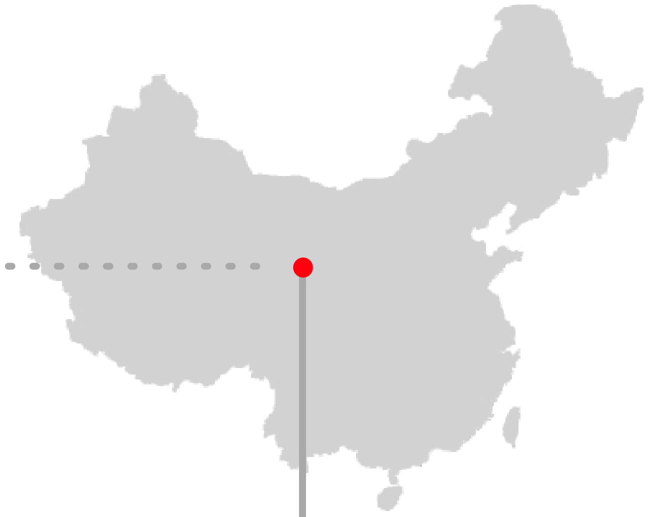
- Industries and Application benefitting from VFD
- Basics of energy saving with VFD and other benefits
- Effects of VFD on the grid
- Effect of VFD on the motor
- Summary

Global market and trends

The world is going electric







1/3rd

of all electricity is converted into motion by motors today

By 2040 the number of motors will

double...

...equivalent to adding an electricity market the size of

China

Improved energy efficiency is a must and we - the 20,000 people behind the motion business - play a key role realizing it.

Industries and Applications

Industries


Cement, minerals and mining


Chemicals


Food and bever-age


HVACR


Marine


Metals


Oil and gas


Power and renew-ables

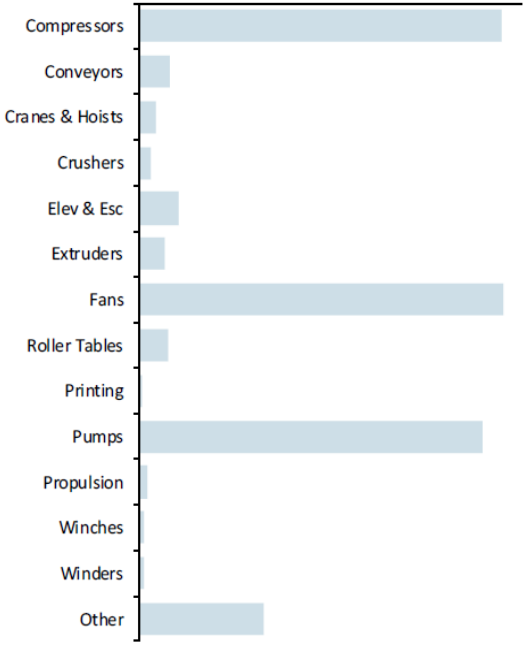

Pulp and paper


Rubber and plastic


Transportation


Water

Applications



IHS- Markit

Fan, Pumps and Compressor represent more than 75% application in different industries.

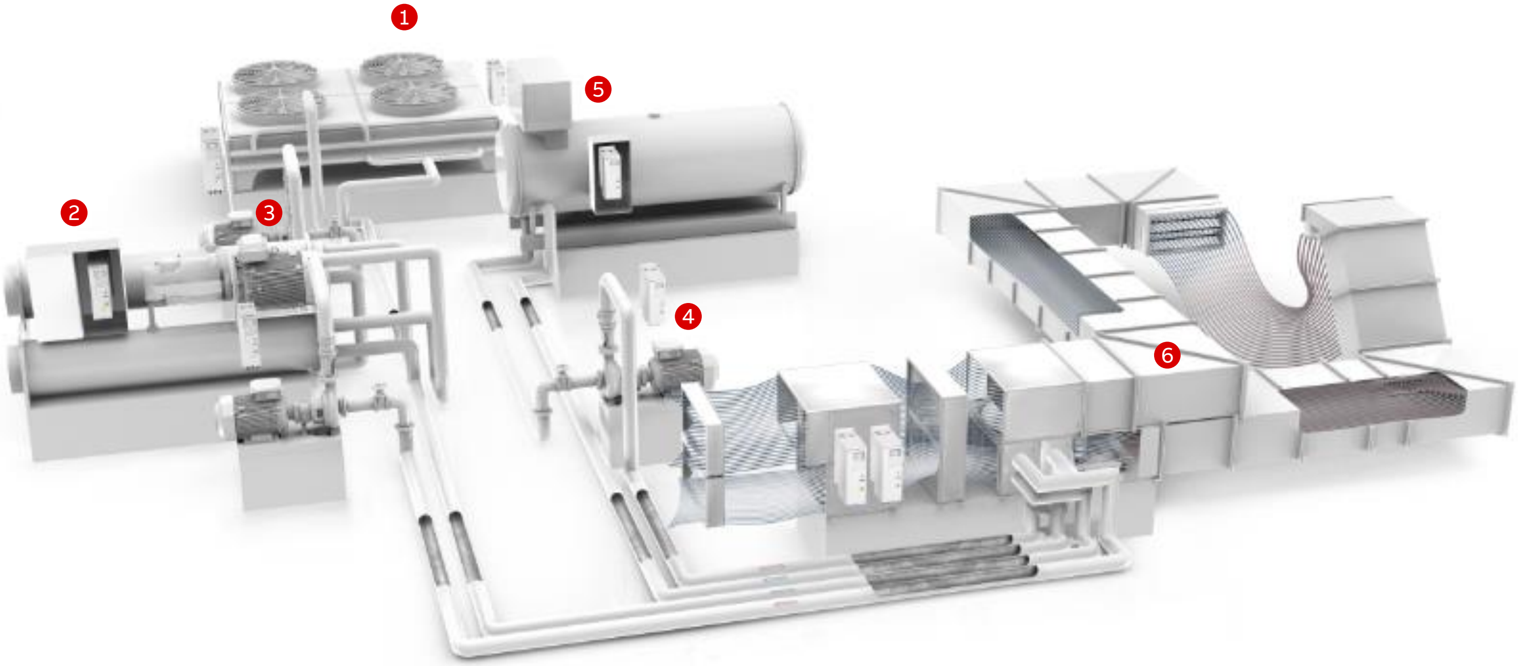
Air handling solution

Building, Hospitals, Malls..

1 Cooling tower
Cools down the condenser water.
- The drive controls the speed of multiple fans simultaneously to achieve high energy savings, while optimising the installation cost

2 Chiller
Chills water or other liquid to cool down and dehumidify the indoor air.
- The drive controls the speed of the compressor for better energy efficiency
- By-pass valves can be avoided
- Less mechanical stress as there are less starts and stops
- Mechanical resonance speeds can be avoided
- Maximum speed is not limited by nominal supply frequency
- Less stress to supply network as high inrush currents can be avoided with VFD controlled start

3 Condenser water pump
Circulates water between the cooling tower and the chiller.
- Energy savings can be achieved with variable frequency drives that adjust pump speed to the cooling load



4 Chilled and hot water circulator pumps
Circulate water (or other liquid) between heating coil and boiler or cooling coil and chiller.
- The cooling and heating loads vary a lot over time. Speed controlled circulator pumps make sure that an adequate amount of water or other liquid is distributed in the building.
- Soft start and stop of the pump reduces hydraulic stress on pipelines and valves

5 Boiler
Heats up the water for building heating.
- The drive controls the burner fan to adjust the amount of combustion air to the heating load

6 Air handling unit
Circulates, mixes, cleans, humidifies/dehumidifies, heats/cools air.
- Drives can be used to
  - control the speed of supply and return fans
  - eliminate mechanical stress of air duct system
  - avoid fan resonance speeds
  - control the speed and efficiency of the rotary heat exchangers
  - control the dampers
  - monitor AHU condition including filter clogging, fan belts and heating coil freeze
- ABB HVAC drives also have an override mode, which secures drive operation in emergency situations

Water and wastewater lifecycle

Municipality water supply, waste water treatment plant

Industrial water treatment
- Process feed-water pumps
- District heating pumps
- Cooling pumps
- Slurry pumps

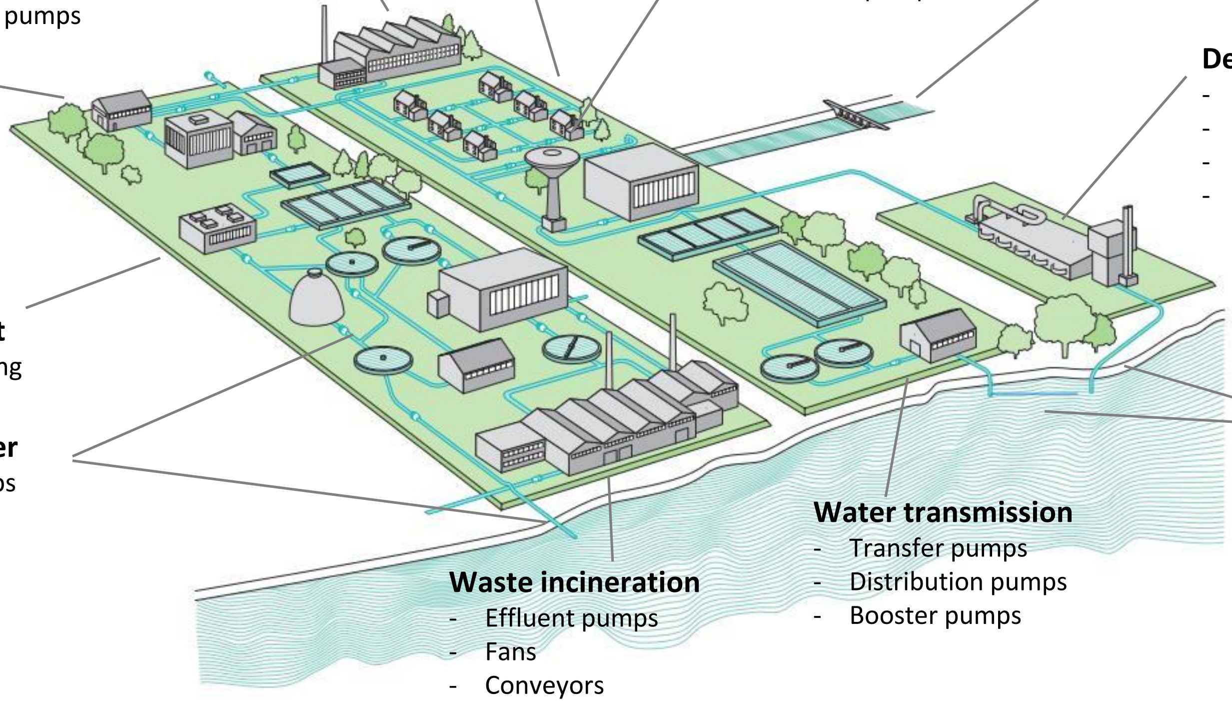
General public

Potable water distribution
- Distribution pumps
- Booster pumps

Irrigation
- Intake pumping
- Distribution pumps

Sewage pumping
- Influent and effluent pumps
- Treatment pumps and fans

Desalination:
- Intake pumping
- Brine pumps
- Booster pressure pumps
- Potable water pumps



Water treatment
- Treatment pumping

Effluent water
- Effluent pumps

Raw water supply & intake
- Feed-water pumps
- Raw water intake pumps

Water transmission
- Transfer pumps
- Distribution pumps
- Booster pumps

Waste incineration
- Effluent pumps
- Fans
- Conveyors

Dairy processes benefitting from motors and drives

Controlling the details boosts productivity

1 Raw milk handling

Goal: Milk is filtered, cooled and pumped to raw milk tank farm

Applications: Pumps

2 Separation

Goal: Fine control and precision necessary for separating cream from milk

Applications: Clarifiers or centrifugal separators

3 Pasteurization and standardization

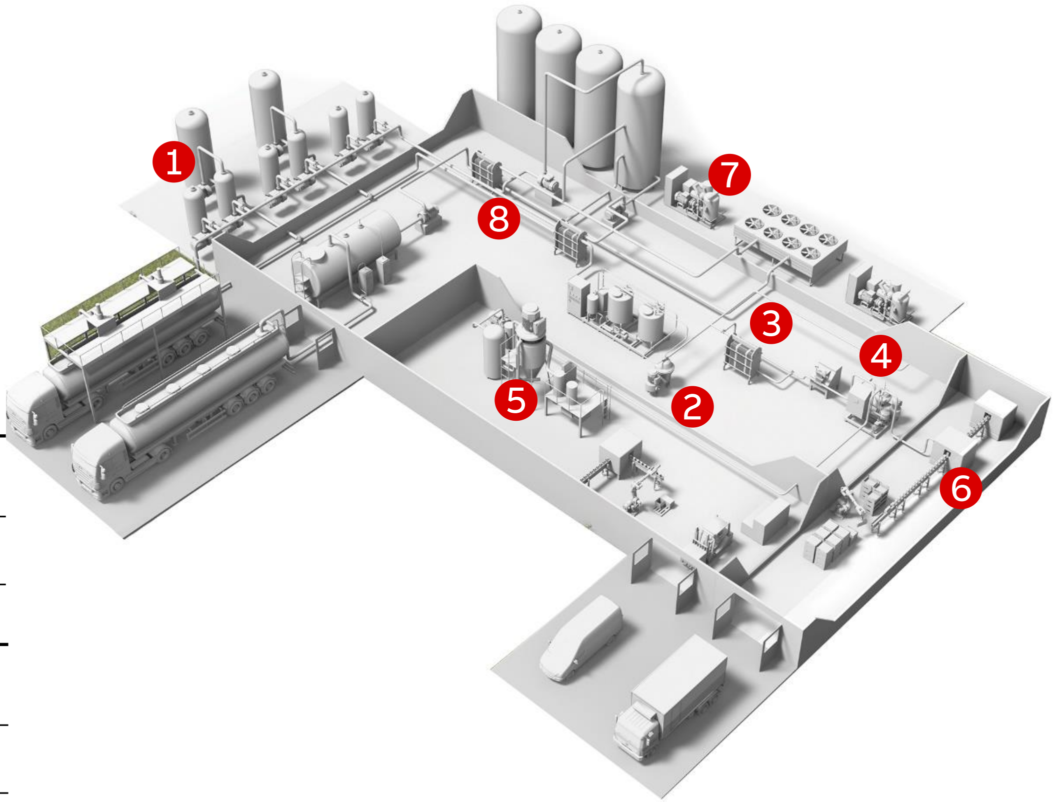
Goal: Milk is mixed with cream to get specified fat content levels correct

Applications: Pumps, heat exchangers, mixers

4 Homogenization

Goal: Breaking fat globules into small size to prevent natural separation from milk

Applications: Piston pumps



5 Milk powder production

Goal: Spray drying produces milk powders and stabilizes milk constituents

Applications: Milk powder spray tower comprising fan or air blower

6 Filling and packaging

Goal: Primary packaging and secondary packaging

Applications: Roll and belt conveyors

7 Refrigeration

Goal: Refrigerated storage is largest energy consumer, with compressors using the most

Applications: Compressors

8 Clean-in-place

Goal: Inner surfaces of process equipment and piping cleaned once a day

Applications: Pumps

Grain processing industry

Controlling the details boosts productivity

1 Grain received, cleaned and moved to silos

Grain is dropped through hopper onto a conveyor belt and moved to the main pipe system, where it is transferred by air from centrifugal blowers.

Applications: Drag flight conveyors, enclosed belt conveyors, screw conveyors, bucket elevators, centrifugal blowers

2 Grain roasting

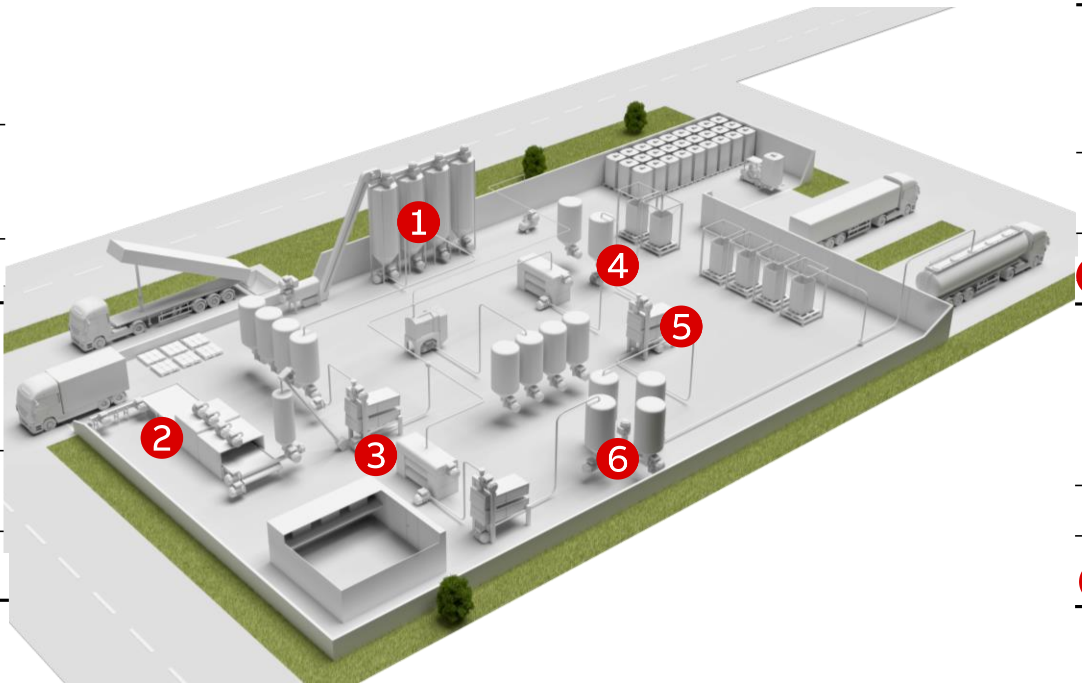
Grain is fed from intermediate silos by a feeder and moved on a screw conveyor to oven conveyor belt. Fans circulate oven air to keep temperature and moisture constant.

Applications: Feeders, centrifugal blowers, bucket/screw/belt conveyors, convection fans

3 Grain sieving

Sieves vibrate in horizontal and vertical directions. Grain is sorted by size. After sieving, grain of similar size is blown to peeling, mills or to intermediate silos prior to roasting.

Applications: Sieves, centrifugal blowers, compressors



4 Grain peeling

Grain skin can be partly or completely removed by peeling machine. Grain is passed between two milling stones which gently separate skin from grain. After peeling, grain is blown to mills.

Applications: Peeling machines, centrifugal blowers

5 Grain milling

Grain is blown to mills and flows through two milling rolls which crush grain to flour. After each milling phase, flour is blown back to sieving. Milling/sieving process can be repeated several times, depending on required flour purity.

Applications: Mills, centrifugal blowers, sieves

6 Mixing, packing and moving flour

Grain is blown to be packed or mixed. Different flours mixed by feeding measured amounts of each flour into intermediate silos. Flours are moved on a screw conveyor to mixer.

Applications: Feeders, screw conveyors, mixers, centrifugal blowers

Basics of energy saving by VFD

Affinity Law

Centrifugal Fan, Pumps and Compressors

$$\frac{N_1}{N_2} = \frac{Q_1}{Q_2} = \frac{\sqrt{H_1}}{\sqrt{H_2}} = \frac{\sqrt[3]{P_1}}{\sqrt[3]{P_2}}$$

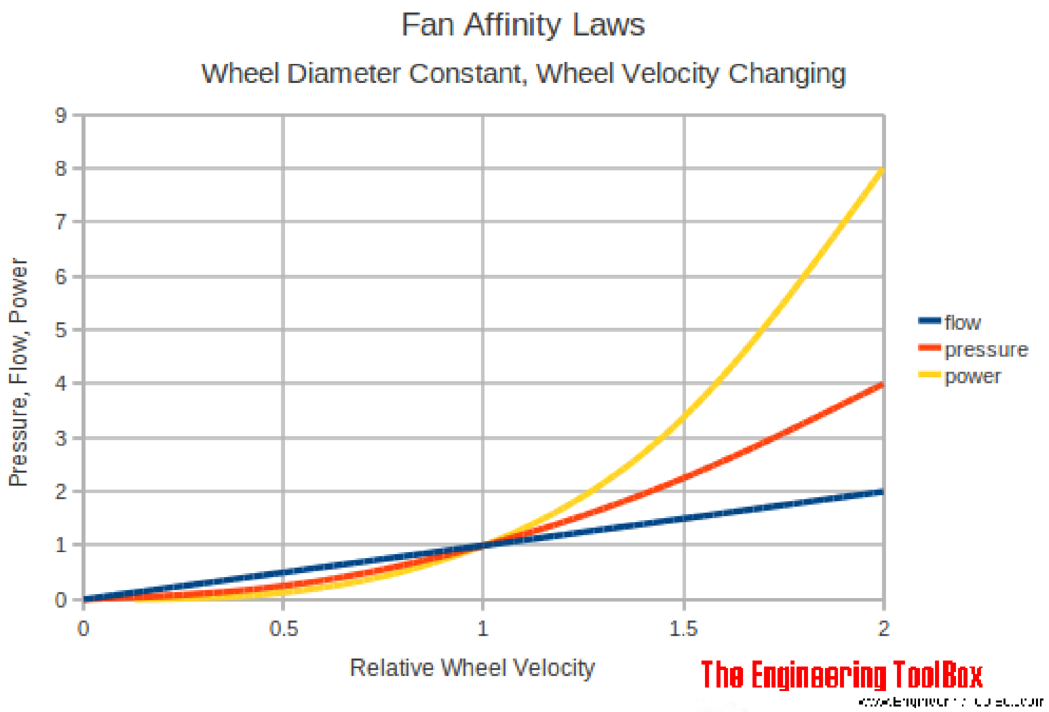
N= speed, Q= flow rate, H= head, P = power

20% increase in speed

20% increase in flow rate

44% increase pressure

73% increase in power consumption



Centrifugal fan and pumps has the highest value proposition for variable speed operation.

Basics of energy saving by VFD

Affinity Law

Positive displacement pumps, blowers

Screw and piston compressors

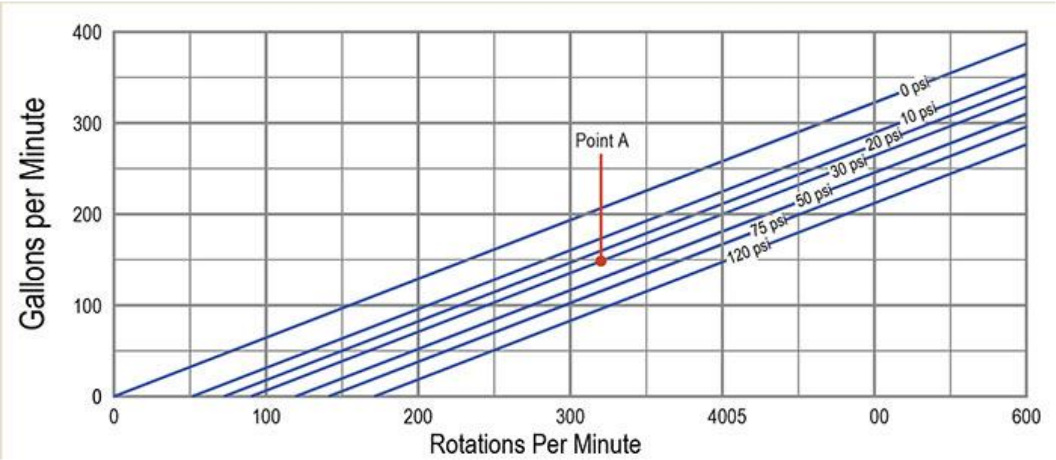
$$\frac{N_1}{N_2} = \frac{Q_1}{Q_2} = \frac{P_1}{P_2}$$

20% increase in speed

20% increase in flow rate

Pressure not affected by speed

20% increase in power consumption



https://www.pumpsandsystems.com/guide-reading-positive-displacement-pump-curve

Displacement pumps and compressors are also attractive for energy saving.

Basics of energy saving by VFD

Examples: DOL vs VFD fed pump and fan

Assume a city water pumping station with 3 pumps.

- Water demand at a certain time is 66.6% of total capacity.

Assume tunnel ventilation system during off peak hour

- Vehicle traffic is only 30% of designed traffic.

	Fixed speed/ no drive	Variable speed with VFD
Pump	2 pumps working @ ~1500 rpm, 1 switched off	3 pumps working @ 999 rpm
Pump	Power consumption is 66.6% of total power	Power consumption is 30.4% of total power consumption*
Fan	Fan operating @~ 1500 rpm all the time	Fan operating at 450 rpm speed (30% airflow)
Fan	Power consumption 100%	Power consumption 2.8%*

* Assuming drive efficiency of 97%

Energy saving can be tremendous based on the end use.

Basics of energy saving with VFD

Effect of motor topologies

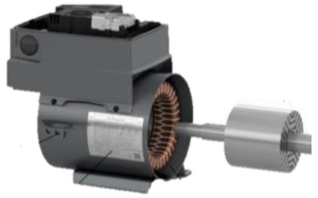
Type	Induction Motor with ACS 850 VFD (4 pole)	SyRM Motor with ACS 850 VFD (4 pole)	FA-SynRM with ACS 850 VFD (4 pole)
Power (kW)	11kW		
Motor eff. (%)	91.8	94.2	95.6
Power factor	0.845	0.737	0.953
Rated current (A)	21.8	24.2	18.4
Positive displacement pump			
Annual energy consumption (kWh)	55011	54027 (-984)	53274 (-1734)
Centrifugal pump (Quadratic head)			
Annual energy consumption (kWh)	44121	43366 (-755)	42803 (-1318)

*Assumption: Motor operates at 100%, 75%, 50%, 25%, 0% speed for 20%,40%, 30%, 8%, 2% time respectively.
All the motor works in sensorless mode, with automatic parameter identification by the VFD

ABB Motor Technologies

Induction Motor
IE2, IE3

SynRM Motor
IE4, IE5



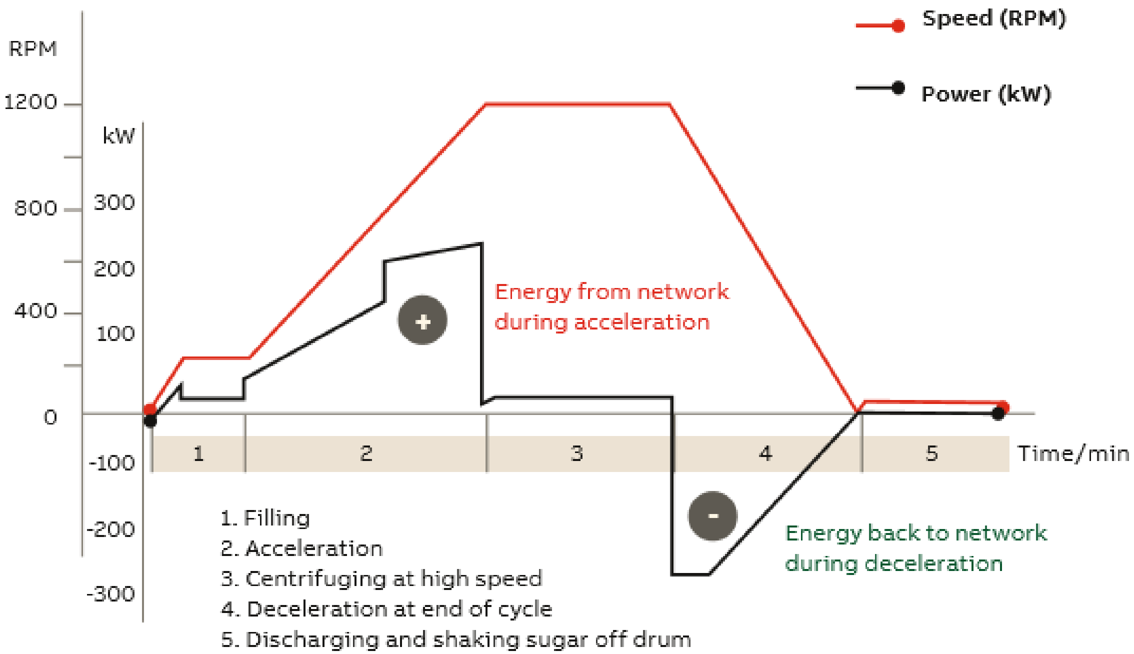
FA- SynRM Motor
IE5 and above

Right motor selection enables additional energy savings.

Basics of energy saving by VFD

Regenerative braking

- Centrifuges application: Separation of crystalline sugar from syrup, Separation of cream from milk
- Mining hoists
- Cable cars and Ski lifts



Other advantages of VFD

- Accurate speed and torque control. (leads into less waste and better quality, which means better usage of raw materials.)
- Can overspeed for emergency operations (if needed)
- Able to handle weak networks.
- Reduces maintenance related to frequent start and stop. (no high starting currents, reduces stress to gearbox, brakes..)
- Added intelligence and safety features for specific application (fireman override, pipe pressure detection..)

Examples

Al Khaleej Sugar Mill, UAE

- Centrifuge replaced by ABB motor and VFD
- Number of cycles increase from 24/ hour to 30/hour (25% increase in productivity)
- Energy usage reduce from 0.952kWh/ ton to 0.75kWh/ ton (22% energy saving)

Mirpurkhas Sugar Mills, Pakistan

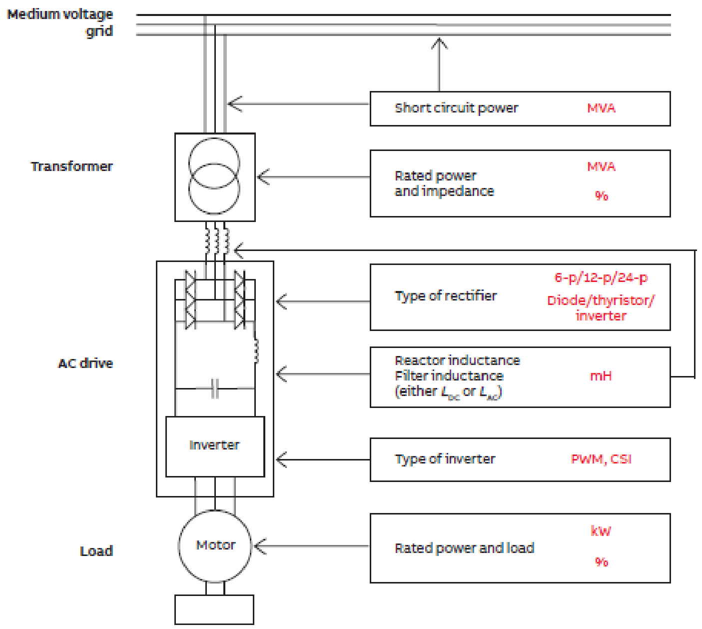
- ABB NRX motor with ACS800 drive replaced steam turbine for a crusher.
- Power usage reduced from 650-700kW to 350-400kW. (40% energy saving)

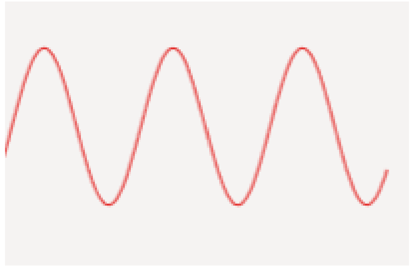

Sugar centrifuges fitted with ABB Motor and VFD at Al Khaleej sugar mills centrifuges

Effects of VFD on the grid

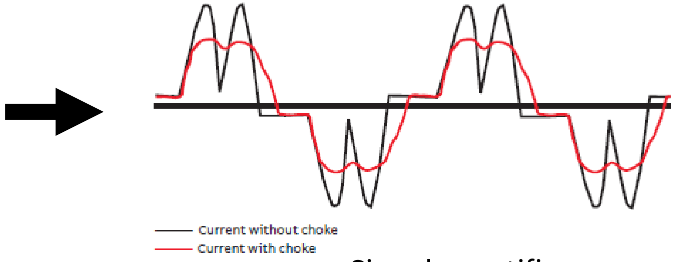
Line side harmonics

Basic diagram





Ideal grid supply current



Six pulse rectifier

Problems that could occur

- Overheating of transformers, cables, circuit breakers, other motors and fuses.
- Nuisance trips of breakers and fuses due to the added heat and harmonic loading.
- Unstable operation of sensitive electronics that require a pure sinusoidal AC waveform
- Flickering lights

Effect of VFD on the grid

Available mitigation techniques

	Six-pulse VFD no reactor/ choke	Six-pulse VFD Low DC bus capacitance	Six-pulse VFD + 5% reactor/choke	3-phase VFD Active front end drive*
Typical THD_i	90-120%	35-40%	35-45 %	3-5 %
VFD system price**	$	$	$$	$$$
Footprint	O	O	OO	OOO
Pros	Simple and low cost solution, acceptable for installations with low quantities of small drives.	Simple and low cost solution that results in some mitigation of current harmonics (THD_i).	Standard solution in HVAC applications.	Best harmonic performance of any of the solutions. Ability to boost output voltage during low-line conditions. Unity fundamental power factor. Can provide regenerative braking.
Cons	High harmonic content, not recommended for installations with higher quantities of drives.	Higher voltage distortion (THD_v), more than the six-pulse VFD with 5% reactor/ choke. More susceptible to problems caused by poor power quality. Almost no under voltage ride-through ability.	Systems with a large quantity or large sizes of drives, may require additional harmonic mitigation.	The drive itself generates slightly more heat than a standard six-pulse drive with reactor.

	Six-pulse VFD + passive filter	Matrix technology drives	Multipulse VFD	Six-pulse VFD + active filter
Typical THD_i	5-10%	5-13 %	12-pulse: 10-12% 18-pulse: 5-6 %	4-7%
VFD system price**	$$$	$$$$	$$$$	$$$$$
Footprint	OOOO	OOO	OOOOO	OOOO
Pros	Assuming physical space is available, a passive harmonic filter can be added after the drive is installed, if harmonics are determined to be a problem.	Includes regenerative braking.	Traditional harmonic mitigation method.	One active filter can clean up the harmonics from multiple drives/loads.
Cons	Leading power factor at light loads unless the filter's capacitors are switched out of the circuit. Risk of resonances between the filter capacitors and other capacitors in the system.	Low harmonic mode (5% THD_i) does not allow full speed control throughout the entire frequency range, as it can only modulate up to 93% voltage. No under voltage ride-through of power circuitry due to the lack of DC bus.	Very large footprint. Significant number of points of failure. Optimal harmonic performance requires perfectly balanced AC power feed with little background distortion. Very difficult to retrofit in the field.	Typically the most expensive solution. The filter becomes a single point of failure for harmonic mitigation. A filter failure could result in significant/ immediate harmonic related issues within the system.

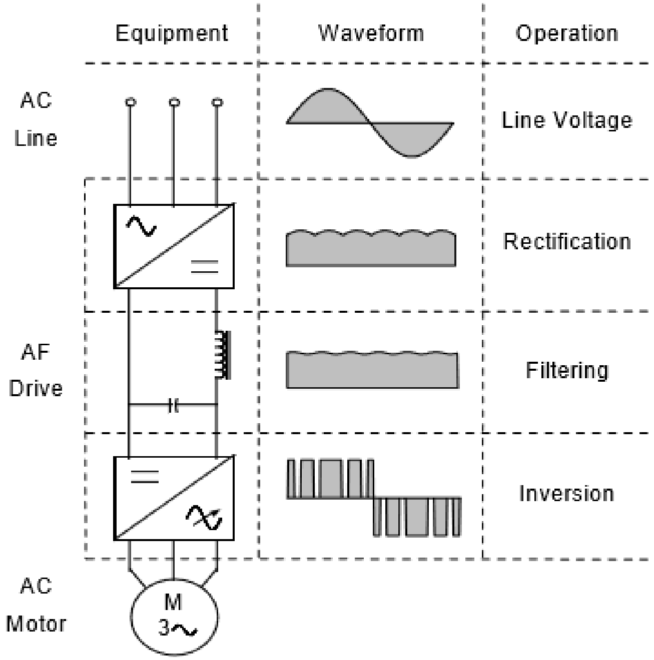
For most fan, pumps and compressors

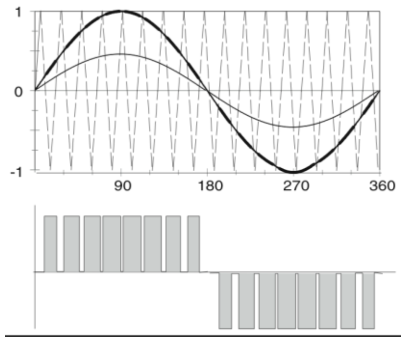
Mitigation technique depend on the application, number of installation, grid code requirement etc..

ABB

Effect of VFD on the motor

Effect of pulse width modulation





Insulation stress

- Rise time for IGBT devices : 100us

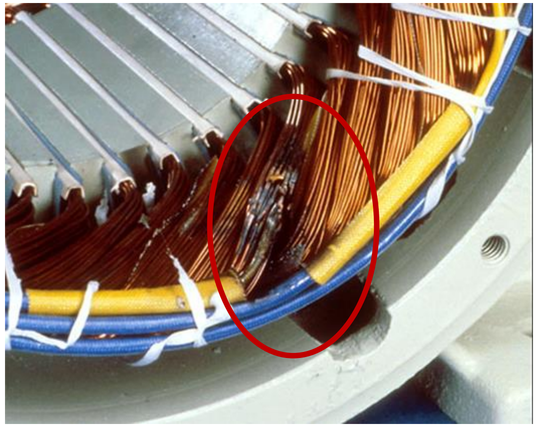
- Directly effects the insulation in the first turn of motor due to voltage overshoot
- Motor impedance is larger than cable impedance so voltage reflection occurs creating overvoltage at motor terminal.
- Overall voltage could be more than 2X the DC bus voltage.
- Partial discharge and premature failure of motor insulation if the motor is not insulated properly. (Inverter ready motors)

Bearing currents

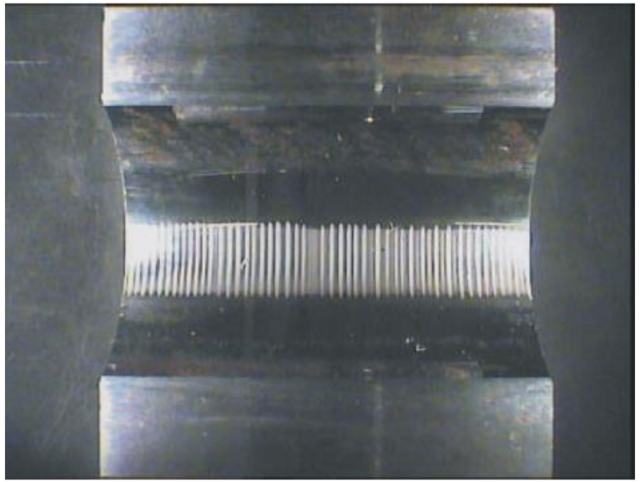
- Common mode voltage in PMW drives (vector sum of instantaneous voltage is not zero)
- High frequency capacitive current can flow to the shaft, bearing to cause premature failure of bearings

Effect of VFD on the motor

Effect of pulse width modulation



Insulation breakdown
due to partial discharge [1]



Fluting of bearing race due
to bearing current (EDM) [2]

Some common mitigation techniques

Supply voltage	Motor framesize	Winding insulation	Motor bearings	Drive filters
≤ 500 V	≤ IEC 250	ABB standard insulation	Standard bearing	No filter needed
	IEC 280 - 315	ABB standard insulation	Insulated non-drive end bearing	No filter needed
	IEC 355 - 450	ABB standard insulation	Insulated non-drive end bearing	Common mode filter
≤ 600 V	≤ IEC 250	ABB standard insulation	Standard bearing	du/dt filter
		ABB special insulation (variant code 405)	Standard bearing	No filter needed
	IEC 280 - 315	ABB standard insulation	Insulated non-drive end bearing	du/dt filter
		ABB special insulation (variant code 405)	Insulated non-drive end bearing	No filter needed
	IEC 355 - 450	ABB standard insulation	Insulated non-drive end bearing	du/dt filter, common mode filter
		ABB special insulation (variant code 405)	Insulated non-drive end bearing	Common mode filter
≤ 690 V	≤ IEC 250	ABB special insulation (variant code 405)	Standard bearing	du/dt filter
	IEC 280 - 315	ABB special insulation (variant code 405)	Insulated non-drive end bearing	du/dt filter
	IEC 355 - 450	ABB special insulation (variant code 405)	Insulated non-drive end bearing	du/dt filter, common mode filter
600 V - 690 V with cable length over 150 m	Any frame size	ABB special insulation (variant code 405)	Standard bearing	No filter needed

1. https://electrical-engineering-portal.com/2-most-common-contributing-factors-in-insulation-failure
2. A. Muetze: " Bearing currents in inverter fed AC motor", PhD dissertation 2004

Summary

- Using VFD can save significant amount of energy attributing to variable speed operation, reduced maintenance and better quality and increased productivity.
- There is a growing trend of using VFD in industry. About 50% of new installations used VFD with motors.
- Modern VFD provides ease of installation, intelligence and improved safety.
- Tailored solutions for different industries so that it meets grid codes, country standards and provides required interfaces for provides optimum performance.
- Trend towards integration of motor and VFD.

ABB EC Titanium Integrated Motor drive

Thank You

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