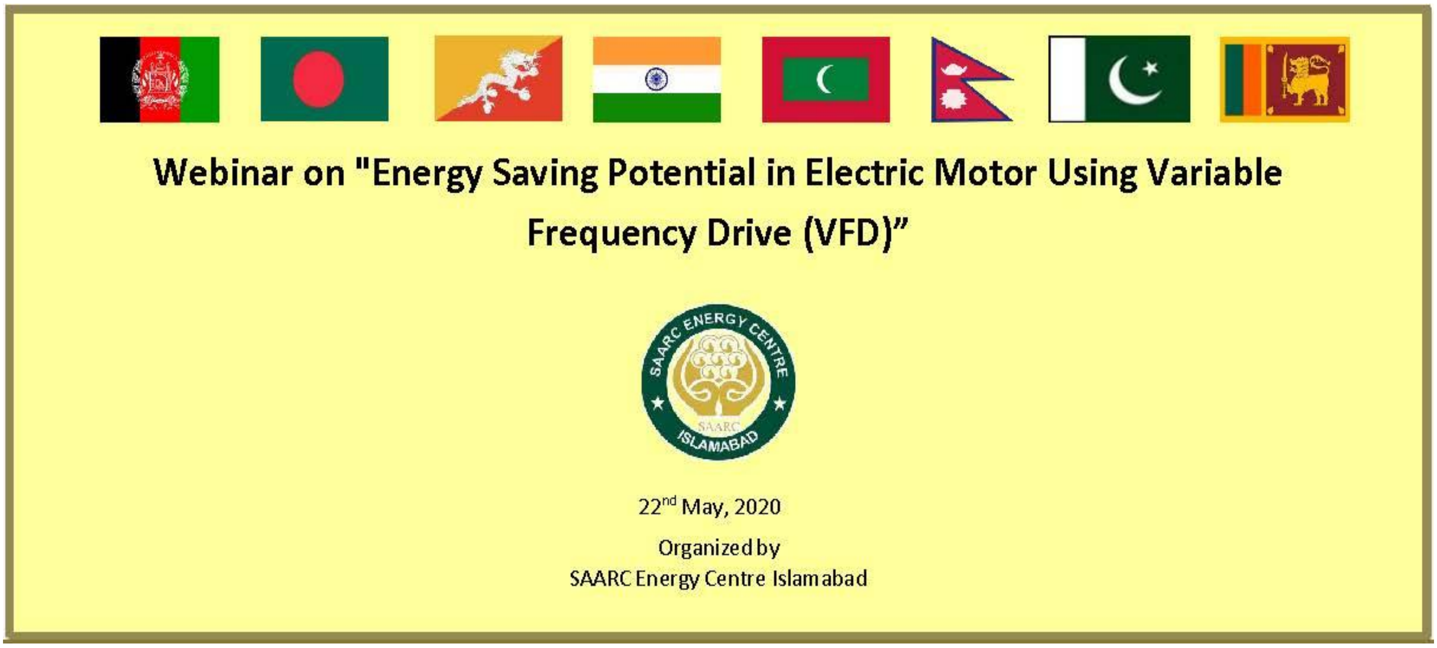
SAARC Energy Centre, Islamabad

Pakistan

# THE REPORT




**May 22, 2020**

**SAARC Energy Centre**
**697, Street 43, Sector E-11/4 (NPF),**
**Islamabad, Pakistan**
**www.saarcenergy.org**

## Introduction

1. SAARC Energy Centre (SEC), Islamabad successfully conducted a Webinar entitled "Energy Saving Potential in Electric Motor Using Variable Frequency Drive (VFD)" on Friday, 22nd May 2020. Webinar Agenda is available at Annexure -I.

2. Focus of the webinar was to share the information on energy saving opportunities in industrial processes that require the operation with electric motor. Areas discussed were: electric motor types, selection procedure and their wide range of application; Basis of energy saving potential in electric motor with VFD; case studies of industrial processes saving energy with VFD application.

## Participation

3. The webinar was attended by 40 participants representing public sector organizations, academia, industrial private sector, industrial professionals and other stakeholders within and outside SAARC region. The experts from USA and Sweden shared their knowledge ranging from the theoretical basis to the application side of electric motor and VFD systems focusing on energy saving aspects. Experts also presented the case studies of some VFD installations and exhibited the accompanied energy saving. The queries raised by participants during question answer session were addressed by respective speakers. The participants list is available at Annexure-II.

## Description

4. The webinar was started with introduction by Program Coordinator, Mr. Tula Ram Poudel, Research Fellow (Energy Trade) and welcome address by Mr. Shoaib Ahmad, Deputy Director (Coord), of SAARC Energy Centre. The technical session comprised of presentations by the expert speakers. Each presentation was followed by a brief Q & A session. The Program Coordinator read out conclusions, which were gathered during the webinar. Before closing

the webinar, the Program Coordinator from SEC offered remarks of appreciation to all the participants and presenters.

## Technical Proceedings

5. Two resource persons from USA and Sweden shared their knowledge in the webinar. All the presentations delivered during the webinar are available at SEC's website (https://www.saarcenergy.org/wp-content/uploads/2020/06/). Details of Resource Persons are available at Annexure-III and their Presentations at Annexure-IV. A brief information on the content of the delivered presentations is as follows:

## Presentation 1 – Motor and VFD for HVC Application

*Mr. Deepak Singh, Electric Machine Expert, National Electric Vehicle Company, Sweden.*

6. Dr. Deepak Singh received the M. Sc. (Tech.) degrees and the D. Sc. (Tech.) degree from Aalto University, Finland, in 2011 and 2017, respectively. His research interest includes measurement and modelling of magnetic properties of the electrical steel sheets under externally applied stress and multi-physics (Electromagnetics, Mechanics and Thermal) Finite Element Modelling of electrical machines to study the effect of stress on the core loss.

7. Since December 2017, Dr. Singh has been working as Electrical Machine Specialist for National Electric Vehicle Sweden AB (NEVS) where he is responsible for electric powertrain architecture definition, concept/technology/product selection. He is also the Work Package Leader from NEVS for EU-Horizon 2020 project DRIVEMODE. Dr. Singh is also involved in actuator development for steer-by-wire and brake-by-wire for autonomous vehicle.

## Presentation 2 – Energy Saving Potential Using Variable Speed Drive

*Dr. Ghanashyam Shrestha, Senior Scientist, ABB, USA.*

8. Dr. Ghanshyam Shrestha joined ABB Corporate Research Centre, Raleigh in 2012. He is Senior Principal Scientist focused on research and development of electrical machines. He has led several technology developments projects which includes large MW class generator to drivetrain integration. He holds several patents as well as publications in leading journals in his trade. Prior to joining ABB, he worked at Danotek Motion Technologies as a development engineer on MW class permanent magnet generators for wind turbines. His interests are in the field of motor topologies, drivetrain integration and transportation and industrial electrification.

9. Ghanshyam Shrestha holds a Ph.D. degree from Delft University of Technology, Netherland, and a Master's Degree from University of Siegen, Germany and a Bachelor's in electrical and electronic engineering from Kathmandu University, Nepal

## Conclusion and recommendation

*Mr. Tula Ram Poudel, Research Fellow (Energy Trade), SAARC Energy Centre*

10. Mr. Poudel thanked everyone for attending the event. He informed the participants that there is scope for the VFD to save the energy in industrial installation. Following are the main conclusions:

a. VFD can save significant amount of energy in industrial process.
b. There is a growing trend of using VFD in industry because of its ease of installation, efficient operation, intelligence and improved safety.
c. Tailored solutions complying the grid codes of respective member of SAARC countries are recommended to get the optimum performance with VFD installations.
d. VFDs are superior over valves, vents and dampers as they eliminate high starting currents, reduces stress to gearbox, brakes and provide the desired speed to industrial process.
e. Because of technical challenges and limitations, retrofitting of home AC unit is difficult.

11. It is important that all SAARC Member States take necessary action to regulate and operate the industrial process efficiently, intelligently and safely. SAARC Energy Centre has always played its role to facilitate the stakeholders to make aware of energy efficient technologies and encourage to apply these technologies for better performance.

## Closing of Webinar

*Mr. Tula Ram Poudel, Research Fellow (Energy Trade), SAARC Energy Centre*

12. Mr. Poudel, informed all the participants that the presentations and recording of the webinar proceedings will be available on SAARC Energy Centre's website (www.saarcenergy.org). He requested the participants to submit suggestions/comments for any further improvement of these webinars and suggest topics to SEC. He closed the webinar with a thank you note to everyone attending the Webinar.

# Annexures

# Webinar Agenda

**Webinar on**

**"Energy Saving Potential in Electric Motor Using Variable Frequency Drive (VFD)"**

**Friday, 22nd May, 2020**

| | |
|---|---|
| 02:00-02:10 | Introduction |
| 02:10-02:20 | Address with Objective of the seminar (By: DD(Coord), SAARC Energy Centre. |
| 02:20-03:00 | Construction and working principle of electric motor and VFD. Their range, types, size, price. Air compressor system and energy saving potential with inverter type Air conditioner and possibility Of retrofitting in old A/C<br>(**By Dr: Deepak Singh**, Electric Machine Expert, National Electric Vehicle Company, Sweden) |
| 03:00-03:20 | Q&A |
| 03:20-04:10 | Basis of energy savings in motor systems with installation of VFD. Case studies of VFD applications and accompanying energy. savings. Existing areas of energy savings potential with installation of VFD Installation requirement and safety assurance to the consumer concerned with VFD.<br>**(BY Dr. Ghanshyam Shrestha**, Senior Principle Scientist, ABB, USA) |
| 04:10-04:25 | Q&A |
| 04:25-04:30 | Conclusions, Recommendations and closing of Webinar |

**Information for the participants:**

1. All times mentioned in agenda are according to Pakistan Standard Time (PKT). The participants from other Member States may attend Webinar by following their own national time. The time conversion for all Member States is given below for reference:

| **Country** | Afghanistan | Bangladesh | Bhutan | India | Maldives | Nepal | Sri Lanka |
|---|---|---|---|---|---|---|---|
| **Local time** | (PKT-00:30) | (PKT+01:00) | (PKT+01:00) | (PKT+00:30) | PKT | (PKT+00:45) | (PKT+00:30) |

2. The participants can ask questions to presenters by typing questions or clicking to the raised hand option into the Attendees pane of the main window of GotoWebinar software. You may send in your questions at any time during the presentations; we will collect these and address them during the Q&A session at the end of each presentation.

3. All participants can also submit comments/views and/or observations on the draft study report to Mr. Tula Ram Poudel, Research Fellow (Energy Trade) (rfet@saarcenergy.org) before 22nd May, 2020.

## List of Participants

| Sr. No. | Last Name | First Name | Email address |
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| 40. | Poudel | Tula | rfet@saarcenergy.org |

## List of Presenters/Resource Persons

| Sr. No. | Name | Designation | Organization | Email address |
|---|---|---|---|---|
| 1. | Dr. Ghanashyam Shrestha | Senior Scientist | ABB, USA | ghanshyam.shrestha@us.abb.com |
| 2. | Dr. Deepak Singh | Electric Machine Expert | National Electric Vehicle Company, Sweden | deepaksingh.311@outlook.com |

## Presentations Delivered During the Webinar

4. “Basis of energy savings in motor systems with installation of VFD. Case studies of VFD applications and accompanying energy savings. Existing areas of energy savings potential with installation of VFD Installation requirement and safety assurance to the consumer concerned with VFD” by Mr. Ghanashyam Shrestha, Senior Principle Scientist, ABB, USA


### 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

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## 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™ —

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

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SIEMENS
WEG
WOLONG
Motors

ABB Global #1

ABB
SIEMENS
Danfoss
Rockwell Automation
Drives

Our key differentiators

1

Pioneering technology leader

2

Domain expertise

3

Global scale and coverage

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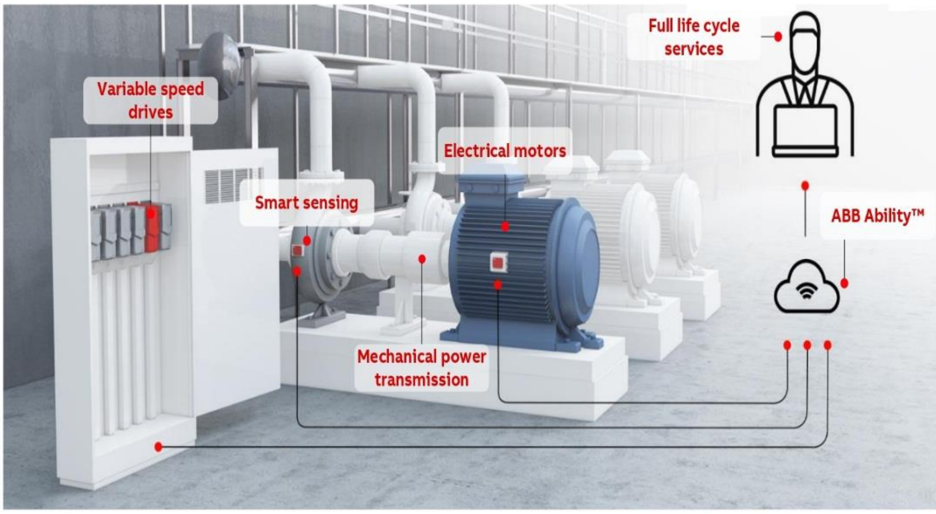
## Motion offering





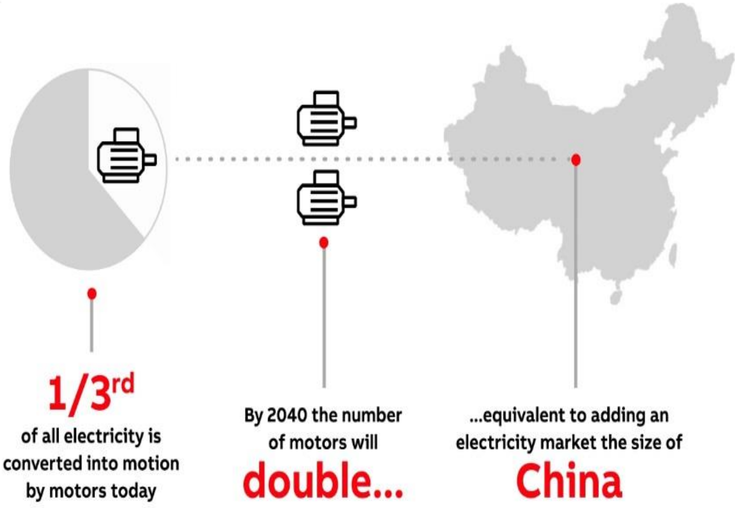


## Content

- 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

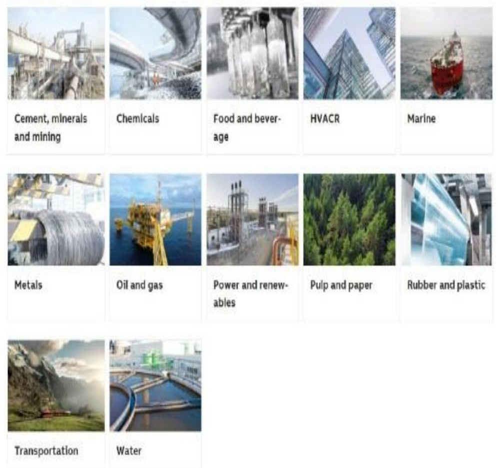



Improved energy efficiency is a must and we - the 20,000 people behind the motion business - play a key role realizing it.

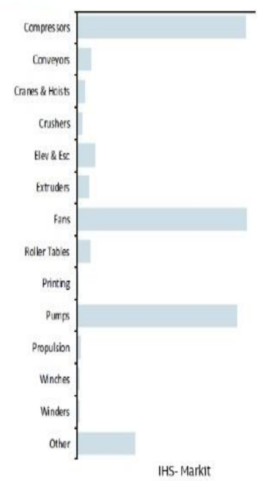


# Industries and Applications

## Industries




## Applications




**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**

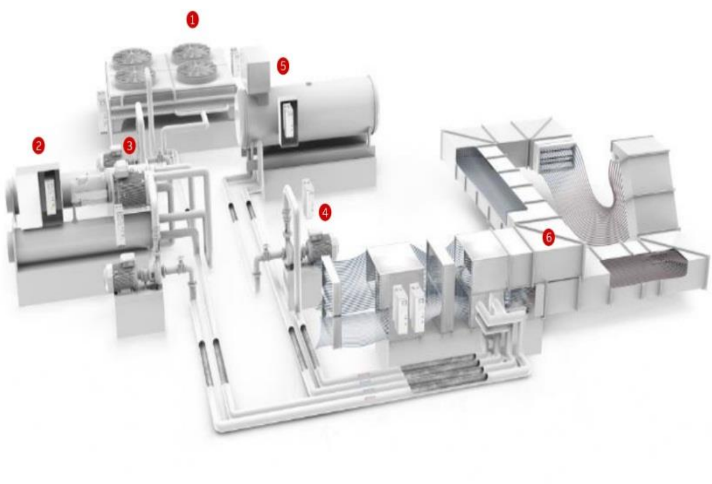
Chills water or other liquid to cool down and dehumidify the indoor air.

- 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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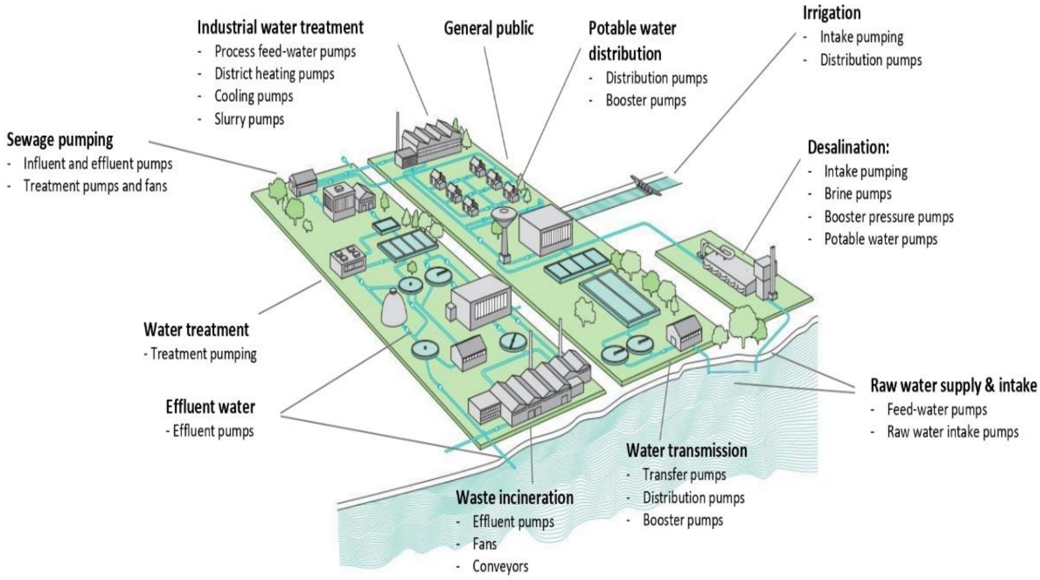
## Water and wastewater lifecycle

Municipality water supply, waste water treatment plant



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## 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**

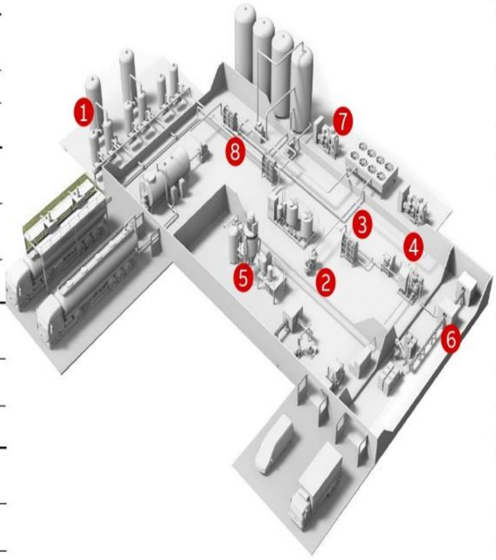
**Goal:** Milk is mixed with cream to get specified fat content levels correct

**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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## 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**

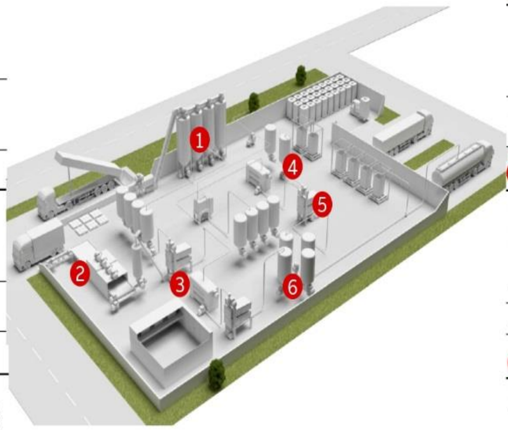
Grain is fed from intermediate silos by a feeder and moved on a screw conveyor to oven conveyor belt. Fans circulate oven air to keep temperature and moisture constant.

**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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# Basics of energy saving by VFD

Affinity Law

Centrifugal Fan, Pumps and Compressors

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

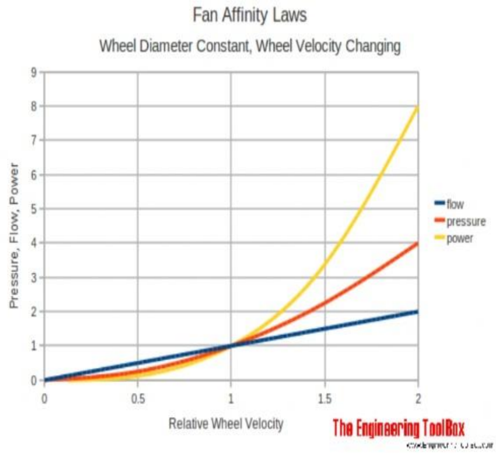
N= speed, Q= flow rate, H= head, P = power

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

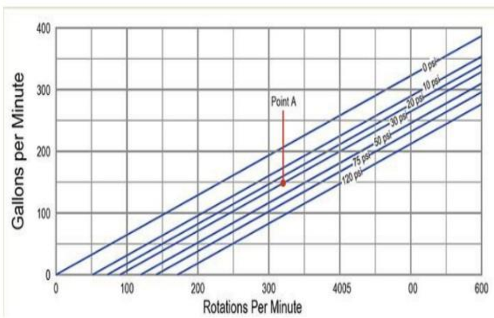
$$\frac{N_1}{N_2} = \frac{Q_1}{Q_2} = \frac{P_1}{P_2}$$

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 |
| | 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) |
| | 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

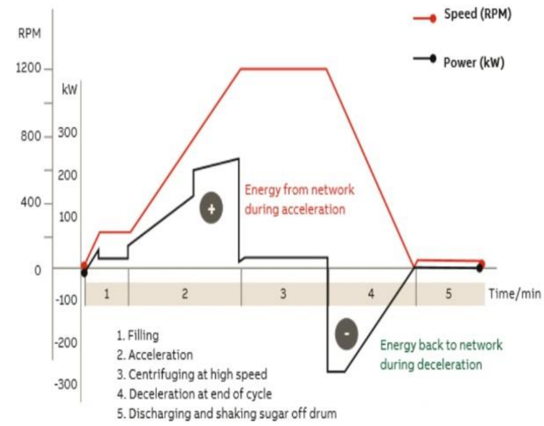
FA- SynRM Motor
IE5 and above

**Right motor selection enables additional energy savings.**

# Basics of energy saving by VFD

Regenerative braking

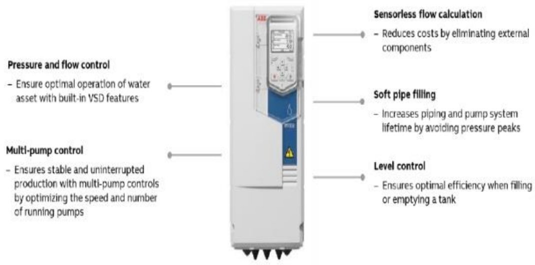
- Centrifuges application: Separation of crystalline sugar from syrup, Separation of cream from milk
- Mining hoists
- Cable cars and Ski lifts






# 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)

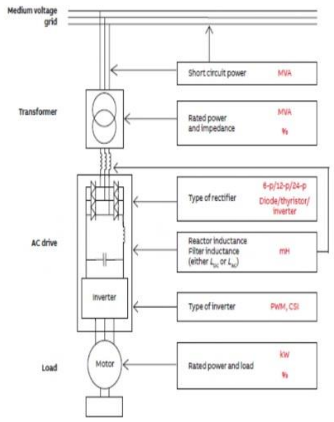
Sugar centrifuges fitted with ABB Motor and VFD at Al Khaleej sugar mills centrifuges

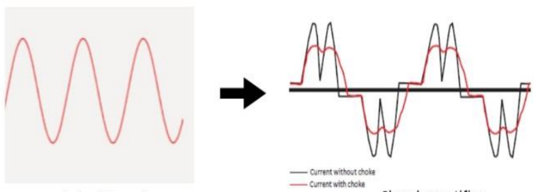


## Effects of VFD on the grid

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<br>no reactor/ choke | Six-pulse VFD<br>Low DC bus capacitance | Six-pulse VFD<br>+ 5% reactor/choke | 3-phase VFD<br>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.<br><br>Ability to boost output voltage during low-line conditions.<br><br>Unity fundamental power factor.<br><br>Can provide regenerative braking. |
| Cons | High harmonic content, not recommended for installations with higher quantities of drives. | Higher voltage distortion ($THD_u$), more than the six-pulse VFD with 5% reactor/ choke.<br><br>More succeptible to problems caused by poor power quality.<br><br>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<br>+ passive filter | Matrix technology drives | Multipulse VFD | Six-pulse VFD<br>+ active filter |
|---|---|---|---|---|
| Typical $THD_i$ | 5-10% | 5-13 % | 12-pulse: 10-12%<br>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.<br><br>Risk of resonances between the filter capacitors and other capacitors in the system. | Low harmonic mode (5% THD) does not allow full speed control throughout the entire frequency range, as it can only modulate up to 93% voltage.<br><br>No under voltage ride-through of power circuitry due to the lack of DC bus. | Very large footprint.<br><br>Significant number of points of failure.<br><br>Optimal harmonic performance requires perfectly balanced AC power feed with little background distortion.<br><br>Very difficult to retrofit in the field. | Typically the most expensive solution.<br><br>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. |

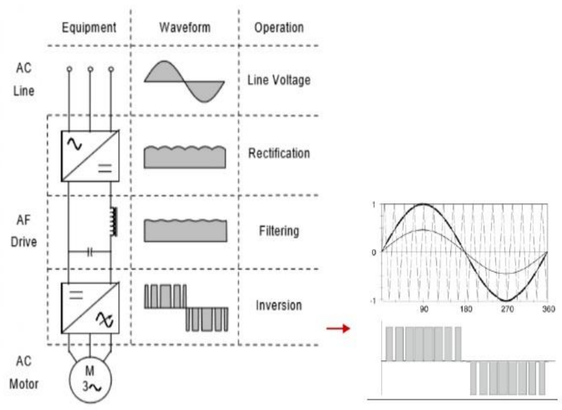
For most fan, pumps and compressors

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



# Effect of VFD on the motor

## Effect of pulse width modulation




**Insulation stress**

- Rise time for IGBT devices : 100us

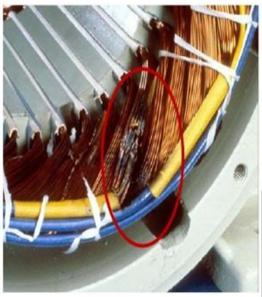
- Directly effects the insulation in the first turn of motor due to voltage overshoot
- Motor impedance is larger than cable impedance so voltage reflection occurs creating overvoltage at motor terminal.
- Overall voltage could be more than 2X the DC bus voltage.
- Partial discharge and premature failure 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

1. "Construction and working principle of electric motor and VFD. Their range, types, size, price. Air compressor system and energy saving potential with inverter type Air Conditioner Of retrofitting in old A/C." by Deepak Singh, Electric Machine Expert, National Electric Vehicle Company, Sweden.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# About Me

## Deepak Singh

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### PERSONAL INFORMATION

Nationality **Nepalese.**
Gender **Male.**

### WORK EXPERIENCE

DEC. 2017 TO DATE **Electrical Machine Specialist**, *National Electric Vehicle Sweden AB*, Trollhättan, Sweden.

MAY. 2017 OCT, 2017 **Postdoctoral Researcher**, *Tampere University of Technology Laboratory of Electrical Energy Engineering, Research Group of Electromechanics*, Tampere, Finland.

JAN. 2012 DEC. 2016 **Researcher**, *Aalto University School of Electrical Engineering, Department of Electrical Engineering and Automation*, Espoo, Finland.

JUN. 2010 DEC. 2011 **Research Assistant**, *Aalto University School of Electrical Engineering, Department of Electrical Engineering and Automation*, , Espoo, Finland.

### FORMAL EDUCATION

JAN. 2012 JAN. 2017 **Doctor of Science (Technology)** (Graduation: January 24, 2017), *Aalto University School of Electrical Engineering*, Espoo, Finland.

SEP. 2009 DEC. 2011 **Masters of Science (Technology)**, *Aalto University School of Electrical Engineering*, Espoo, Finland.

OCT. 2002 OCT. 2006 **Bachelor of Engineering (Electrical Engineering)**, *Tribhuvan University, Institute of Engineering, Pulchowk Campus*, Lalitpur, Nepal.

### PUBLICATIONS

Authored and co-authored 12+ journal articles and 20 conference papers and digests..
More Information: `https://scholar.google.fi/citations?user=GFA5WPMAAAAJ&hl=en`
`http://orcid.org/0000-0003-1629-0156`

NEVS

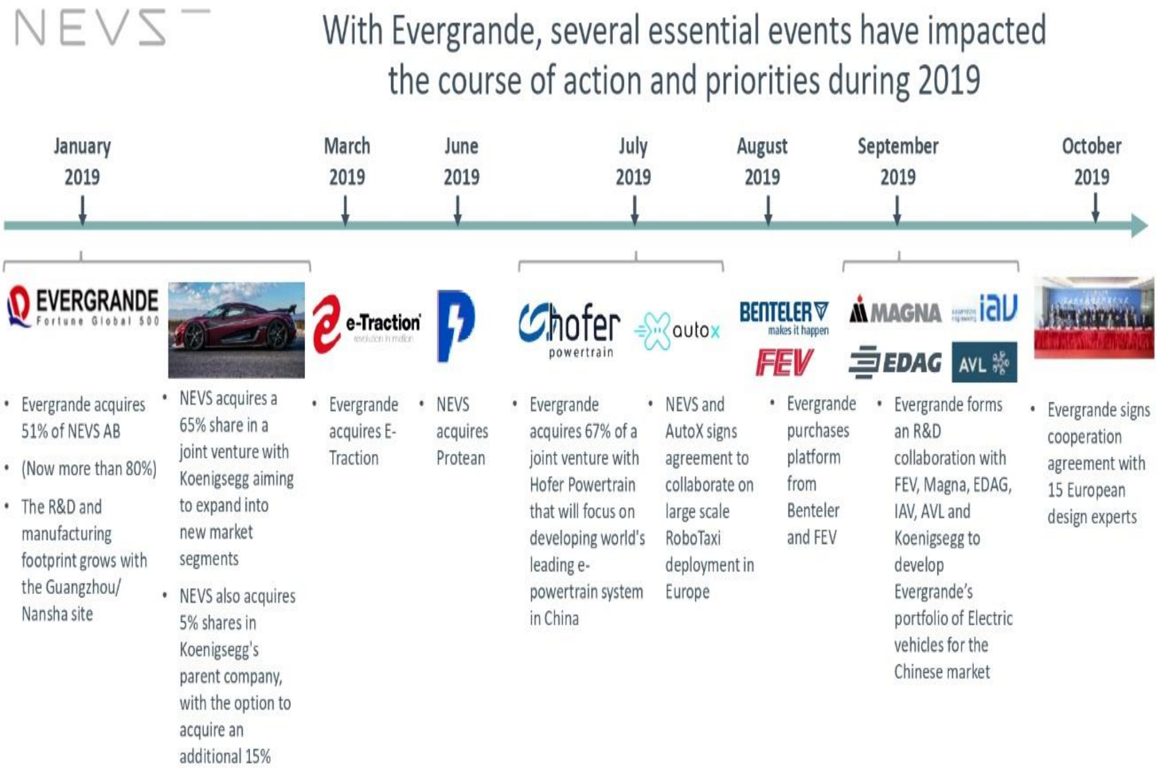
# NEVS was founded 2012, by Kai Johan Jiang

**Annexure-IV**


The reasons why NEVS exists
• Air pollution
• Climate change
• Congestion
NEVS


NEVS
A strong heritage – with 70 years of innovation
First Saab "Ursaaben"
Dual Brake Circuit
Side impact protection
Turbocharging
Saab Trionic
SAHR
NEVS Production of SAAB MY14
Tianjin factory
Partnership batteries & development


恒大集团
世 界 500 强
Evergrande Group
Real Estate
Health
Tourism/ culture
New Energy Vehicle
Chinese Evergrande Group now owns more than 80% of NEVS AB
Kai Johan Jiang's company National Modern Energy Holding less than 20%


NEVS
With Evergrande, several essential events have impacted the course of action and priorities during 2019
January 2019
March 2019
June 2019
July 2019
August 2019
September 2019
October 2019
EVERGRANDE Fortune Global 500
e-Traction
hofer powertrain
autox
BENTELER makes it happen
FEV
MAGNA
iav
EDAG
AVL
• Evergrande acquires 51% of NEVS AB
• (Now more than 80%)
• The R&D and manufacturing footprint grows with the Guangzhou/ Nansha site
• NEVS acquires a 65% share in a joint venture with Koenigsegg aiming to expand into new market segments
• NEVS also acquires 5% shares in Koenigsegg's parent company, with the option to acquire an additional 15%
• Evergrande acquires E-Traction
• NEVS acquires Protean
• Evergrande acquires 67% of a joint venture with Hofer Powertrain that will focus on developing world's leading e-powertrain system in China
• NEVS and AutoX signs agreement to collaborate on large scale RoboTaxi deployment in Europe
• Evergrande purchases platform from Benteler and FEV
• Evergrande forms an R&D collaboration with FEV, Magna, EDAG, IAV, AVL and Koenigsegg to develop Evergrande's portfolio of Electric vehicles for the Chinese market
• Evergrande signs cooperation agreement with 15 European design experts

NEVS

## NEVS/Evergrande has also acquired Protean Electric, word leading in-wheel electric motor developer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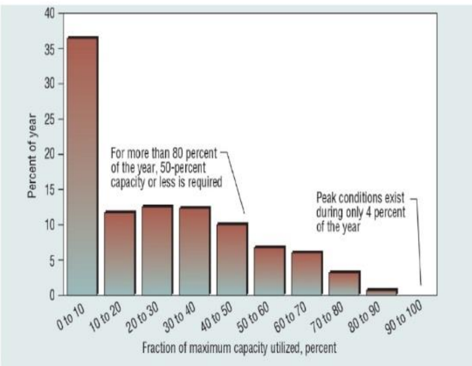
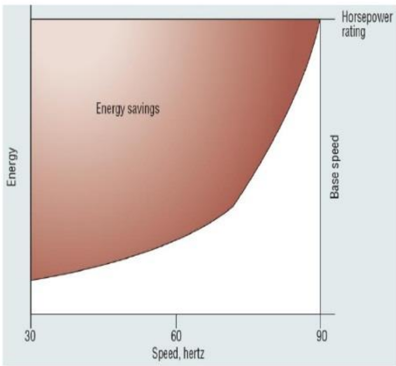
## WHY

- HVAC system with ON/OFF type compressor operates at max/zero speed (respectively)
- Compressors are modulated in two or multi stages for load matching, this leads to high energy consumption
- ON/OFF modulation of compressor draws high starting (inrush) current, causing mechanical, electrical and thermal strain on compressor components
- Similarly, fans (AHU and Exhaust unit) operating at max speed and the flow regulated by actuator controlled valves/vents/dampers etc... consumes high energy



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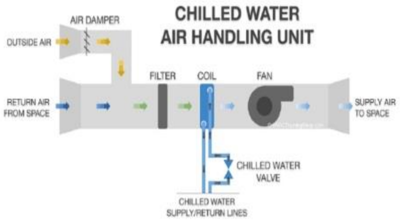
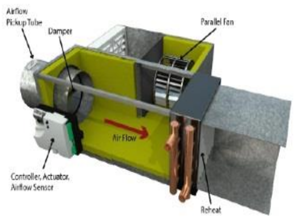
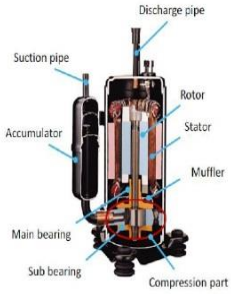



# Motor usage in HVAC

- Compressor for Refrigerant/water
- Fans (supply and return duct, cooling tower) and blower
- Pumps to circulate refrigerant/coolant

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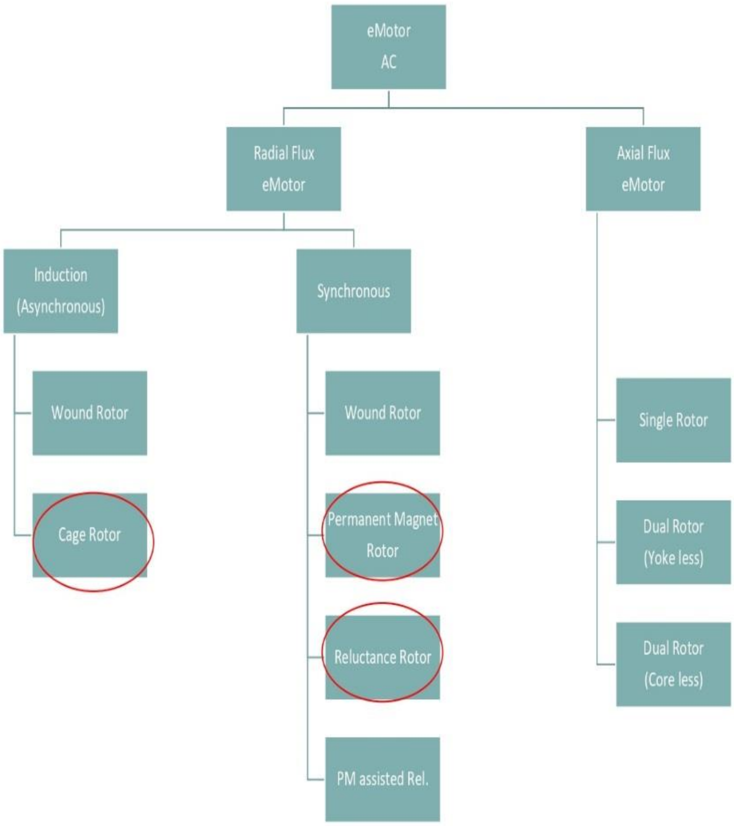
# AC Motor (Classification)



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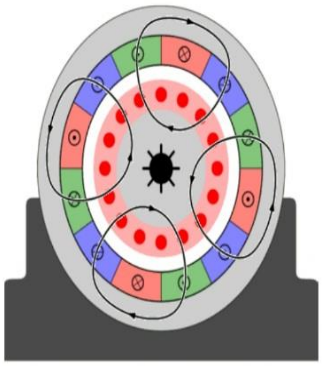
# Motor
## (Working Principle)



- All electric motors operate by opposing magnetic forces at the air gap causing the rotation motion
- Stator (Stationary) contains rotating magnetic field by virtue of AC current thru distributed coils
- Key difference is in **"How the Rotor gets its magnetic field"**
- **How Rotor gets its magnetic field**
  - Induction Motor – Induction effect (transformer principle) in short circuited coil or Cu/Al bars
  - PM motor – PM (special material), no current
  - Syn. Motor – Coil on rotor with DC
  - Syn. Reluctance – Flux from stator
  - Switched reluctance – Flux from stator and shape effect

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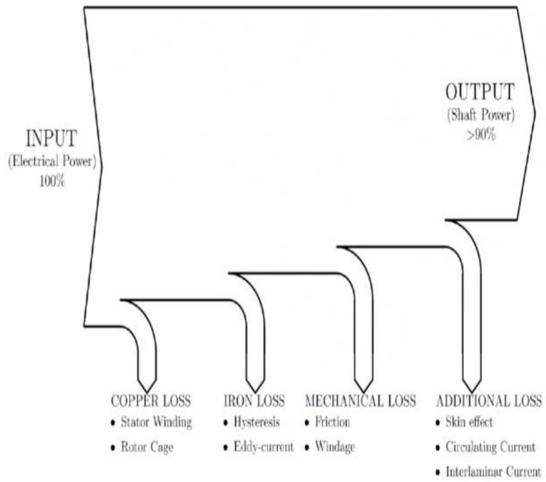
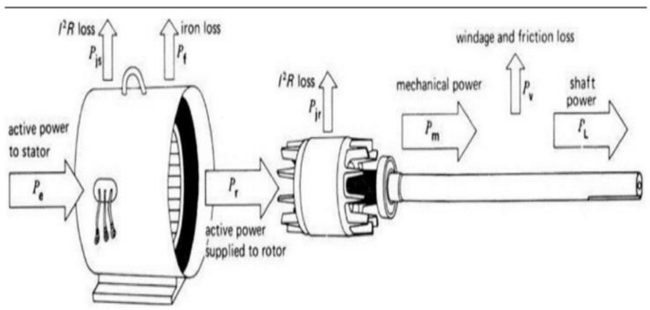
# Power Flow Diagram (General Motor)



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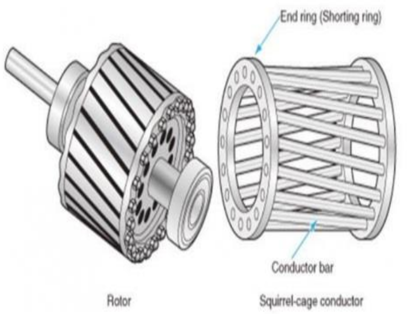
# Induction Motor (Cage)




- Mature technology, as IM are the most used industrial motor
- Controls, well developed
- Lower efficiency due to losses in rotor copper bars
- Reliable and very robust (better then PM motors)
- Cost: Cheap (no rear earth material)
- Possible to implement sensor-less control (reduces the sensor costs)
- ONLY motor capable of Line-Start

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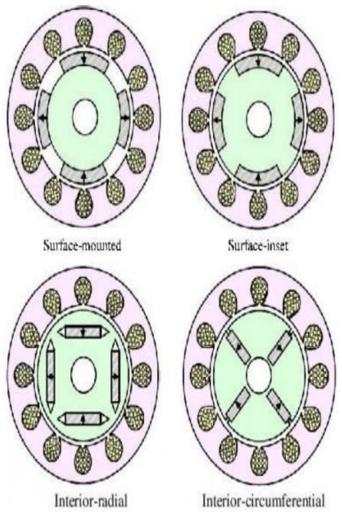
# PM Syn. Motor (PMSM)




- High torque density (compact motor for same application)
- Good technology maturity
- Controls, well developed
- High efficiency, no conductor in rotor, however considerable eddy current loss in PM at high speeds/switching frequency
- Less reliable (compared to IM and SyRM), risk of PM demagnetization due to overheating, over current and aging
- Relatively expensive due to use of rare earth material
- Possible to implement sensor-less control
- CANNOT line start, controller (inverter) required

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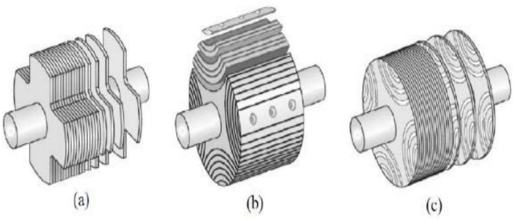
# Syn. Rel. Motor (SRM)

- Latest in the trend of Ultra Premium Efficiency (IE5)
- Controls, fairly developed
- Highest efficiency, no copper or magnet losses in rotor
- Reliable and very robust (better then IM motors)
- Cost: Cheap (no rear earth material or copper)
- Difficult to implement sensor-less control (research on going)
- CANNOT Line-Start, require controller to operate

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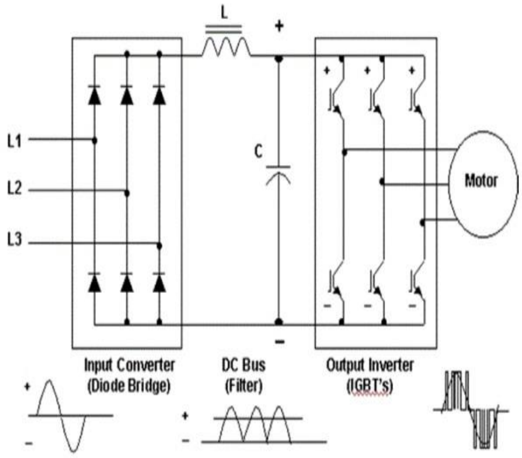
# VFD (working principal)




A VFD, delivers power from the source — AC mains — to a motor in three basic steps:

Step 1: A rectifier converts the AC power to DC
Step 2: A DC bus receives, smooths, and stores the power
Step 3: An inverter converts the DC power back into AC with the necessary frequency and voltage via pulse width modulation (PWM)

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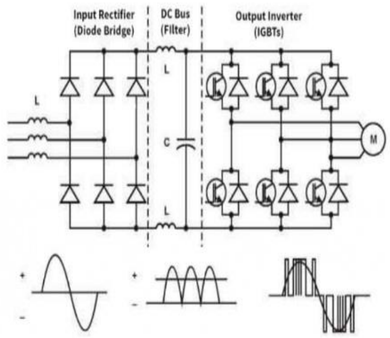
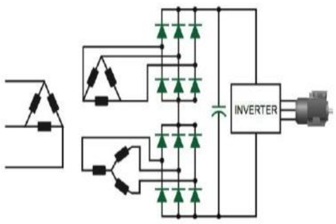
# VFD
## (Classification)

## Multi Pulse Front End VFDs

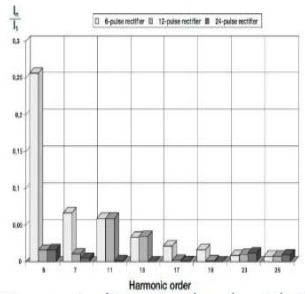
- 6 pulse VFD are the simplest and the cheapest, but has the worst THD
- THD can be reduced by implementing higher pulse rectifier (typically multiple of 6)
- 12 and 18 pulse VFD use 2 and 3, 6-pulse rectifier respectively
- Furthermore, they use multi-phase transformer with 30 and 20 deg phase shift in the supply respectively
- Added rectifier and other components for higher 12,18 and 24 pulse VFD push the cost up




VFD with 6 pulse rectifier




VFD with 12 pulse rectifier




Harmonic distortion levels with 6-, 12-, and 24-pulse rectifiers

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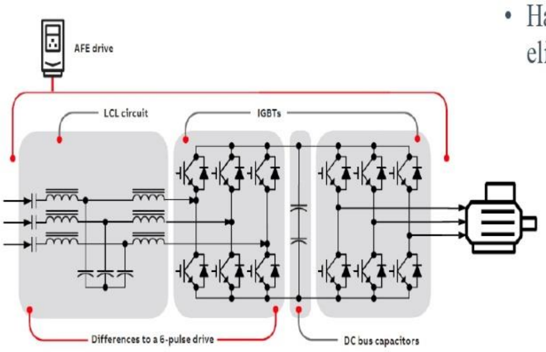
# VFD
## (Classification)

## Active Front End VFDs

- Input current waveform is monitored and shapes it to be sinusoidal, thereby SIGNIFICANTLY reducing the THD
- THD monitored for lower order harmonics only, thus require LCL filter to reduce higher order harmonics
- $PF = \frac{\cos\theta}{\sqrt{1+THD^2}}$: $\cos\theta$ is kept to near unity and THD significantly reduced, thus improving PF
- Handle regenerative power and put it back to the AC mains, thus eliminating the need of resistor bank to dump regenerative energy



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# VFDs
(Other issues)

- Additional heating in motor core and magnets (in PM Motors)
- Motor bearing current
- Voltage stresses ($^{dV}/_{dt}$) on motor insulation

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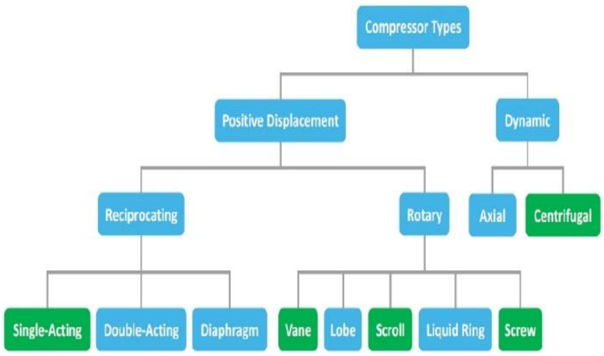
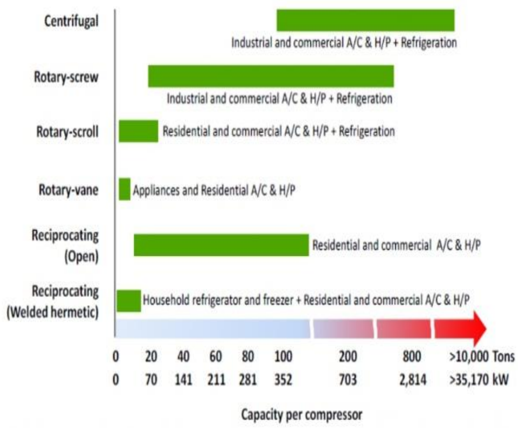
# Compressor
(Classification)

Typical Technical Classification




Capacity, size and usage



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# Compressor
(application of VFDs)

## Application of VFDs on fixed capacity compressors

- Typically use IM to operate in narrow frequency band 45-65 HZ
- Operation frequency band expanded to 35-75 Hz when used in conjuction with VFD, after ensuring proper lubrication and bearings
- NOT a pure variable speed application

## Application of VFDs with dedicated Variable Speed Compressor

- Each compressor is therefore paired, tuned, and optimized with a VFD
- Compressor protection and diagnostic features are built directly into the drive to ensure maximum reliability
- Dedicated oil pump to provide adequate lubrication across a broad speed range

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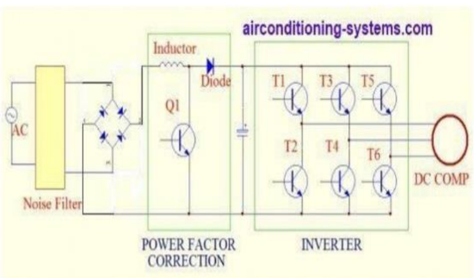
# Retrofitting of VFD
(considerations)




VFD to operate 3 phase motor from 1 phase source

## Commercial/residential building HVAC

- Compressor
  - Compatibility: lubrication and bearings
  - Safety: pressure build-up, over-heating and type of refrigerant
- Motor
  - 3 phase Induction Motors
  - Inverter duty rated: Winding insulation, bearing and cooling
  - Fan motors low torque application, careful in selecting VFD

## Home AC unit

- Compressor: Compatibility and safety
- Motor
  - Most cases its capacitor start/run induction motor; this type of IM will require special VFD
  - BLDC (Brush-less DC; don't get confused, it is still a PM motor with controller in the packaged product); variable speed application possible with incorporated controller

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# Conclusion

- VFDs have great energy saving potential especially in HVAC application
- VFD controlled compressor eliminate the need of multiple compressor setup required for modulation
- VFD controlled fans eliminate the need of many (not all) valves/vents/dampers...
- Active Front End – VFDs might be cost effective solution (both component and operational cost) compared to 12,18- pulse VFDs
- NOT ALL compressor are designed for variable speed application; careful when retrofitting old compressor with VFDs
- Retrofitting home AC unit – not feasible (give technical challenge and limited gains)

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