

COURSE NAME | Session No.2

# ELECTRICAL ENERGY Motors, Pumps & Drives



Learning Facilitator: ENGR. JAY A. ESCORIAL, REE, CEM, CEA

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## SESSION OBJECTIVES

- ❑ To obtain understanding on the operating principles and assessment of the performance of motor, pumps, drives & associated systems
- ❑ Identify different types of electric motors commonly used in industrial applications, such as induction & synchronous motors, and compare their characteristics and performance.
- ❑ To gain insights on emerging, cost-effective electrical technologies & efficient operating practices for enterprises to increase efficiency, reduce energy waste & carbon emission for a sustainable business growth



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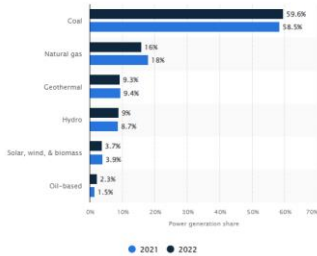
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## PH Power Generation Mix, 2021 & 2022 by Fuel Source



The energy sector in the **Philippines** is confronted with a significant challenge arising from the escalating power demand owing to population growth, rapid economic expansion, and a strong emphasis on digitalization. Despite efforts to **increase the utilization of renewable energy sources**, **fossil fuels, primarily coal**, continue to take up most of the power generation mix.



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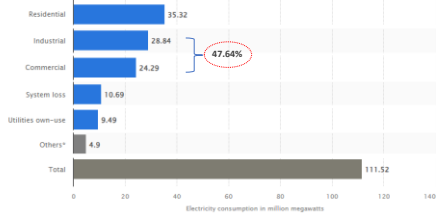
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**Total electricity consumption in the Philippines in 2022,**  
(in million megawatts)



<https://www.statista.com/statistics/1266853/philippines-electricity-consumption-by-sector/>

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**Top Energy Consuming devices**

The top energy-consuming devices in the world vary across sectors, but some of the notable contributors include:

- Data Centers
- Air Conditioning and Heating Systems
- Industrial Machineries
- Transportation
- Household Appliances
- Lighting
- Consumer Electronics
- Water heating systems



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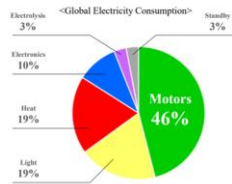
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**Electric Motors are the World's Biggest Energy Consumers**

Electric motors are the single biggest consumer of electricity. They account for about two thirds of industrial power consumption and, as stated above, about 46% of global power consumption, according to a new analysis by the International Energy Agency.



Source: IEA Energy Efficiency Series, Paul Walde and Conrad U. Brunner, et al., 2011

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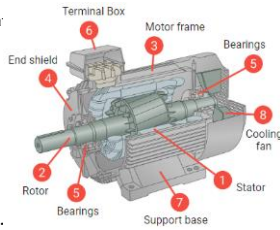
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## Electric Motor

An electric motor is a device that converts electrical energy into mechanical energy. It operates based on the principle of electromagnetic induction, discovered by Michael Faraday. The basic components of an electric motor include a coil of wire (usually wrapped around a core), a current-carrying conductor, and a magnetic field.



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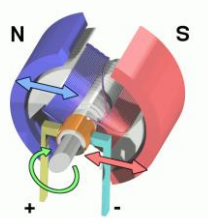
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## Electric Motor Working Principle

- The electric motor working principle mainly depends on the interaction between electric current and magnetic field or the Faraday's first law of electromagnetic induction.
- "Whenever a current-carrying conductor is placed in the magnetic field, flux is induced in the circuit, due to which a current starts to flow which is called induced current".
- In simple words, when the electric current is passed through a coil it generates a magnetic field that allows the coil to rotate its own axis.



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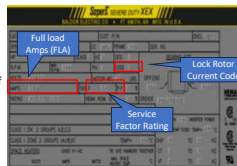
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## Glossary of Frequently Occurring Motor Terms

- Full Load Amps**
  - The amount of current the motor can be expected to draw under full load (torque) conditions
  - It is also known as nameplate amps
- Locked Rotor Amps**
  - Also known as starting inrush, this is the amount of current the motor can be expected to draw under starting conditions when full voltage is applied.
- Service Factor Amps**
  - This is the amount of current the motor will draw when it is subjected to a percentage of overload equal to the service factor on the nameplate of the motor.
  - For example, a motor having a service factor of 1.15, means that it can safely handle a 15% intermittent overload beyond its nameplate rating.



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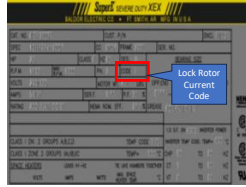
## Glossary of Frequently Occurring Motor Terms

### CODE

The code letter is an indication of the amount of inrush current or locked rotor current that is required by a motor when it is started. Motor code letters usually applied to ratings of motors normally started on full voltage (chart below)

Code letter	Locked rotor* kVA per horsepower	Horsepower Single-phase	Horsepower Three-phase
F	5.0 to 5.6	5	15 up
G	5.6 to 6.3	5	7.5 to 10
H	6.3 to 7.1	5	5
J	7.1 to 8.0	1.5 to 2	5
K	8.0 to 9.0	0.75 to 1.00	1.5 to 2
L	9.0 to 10.0	0.5	1

\*Locked rotor kVA is equal to the product of the line voltage times motor current divided by 1000 when the motor is not allowed to rotate. This corresponds to the first power range required to start the motor. Locked rotor kVA per horsepower range includes the lower figure up to but not including the higher figure.



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## Formulas for computing the LRA (Locked Rotor Amps)

### For single-phase AC motors

For single-phase motors, when KW is known:

$$LRC = \frac{P_{kw} \times 1341 \times (KVA/HP)}{Voltage}$$

For single-phase motors, when HP is known:

$$LRC = \frac{P_{hp} \times 1000 \times (KVA/HP)}{Voltage}$$

Where,

- **Voltage:** The phase-to-phase voltage for a 3-phase supply.
- **Rating:** The power rating of the motor in kW.
- **KVA/HP:** Maximum value corresponding to the NEMA code.

### For Three-phase AC motors

For three-phase motors, when KW is known:

$$LRC = \frac{P_{kw} \times 774 \times (KVA/HP)}{Voltage}$$

For Three-phase motors, when HP is known:

$$LRC = \frac{P_{hp} \times 577 \times (KVA/HP)}{Voltage}$$

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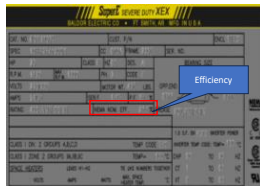
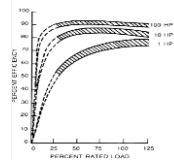
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## Glossary of Frequently Occurring Motor Terms

Efficiency is the percentage of the input power that is actually converted to work output from the motor shaft.



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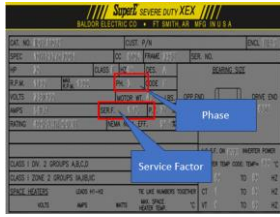
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## Glossary of Frequently Occurring Motor Terms

### Phase

Phase is the indication of the type of power supply for which the motor is designed. Two major categories exist: single phase and three phase.



### Service Factor

The service factor is a multiplier that indicates the amount of overload a motor can be/are expected to handle.

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## Example:

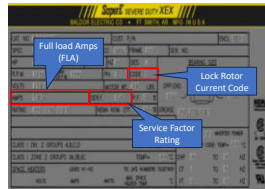
Based on the sample motor nameplate:

Full Load Amps: 54 Amps for 230V or 27 Amps for 460V

Code: H (locked rotor KVA/HP is 6.3 - 7.1)  
HP: 20 HP, Voltage: 460 V, Phase: 3

Locked Rotor Amp:  
=  $(1000 \times (6.3-7.1) \text{KVA/HP} \times 20 \text{HP}) / (1.732 \times 460 \text{V})$   
= 158.15 Amps to 178.23 Amps

Service Factor Amps:  
Service Factor Rating: 1.15  
= FLA x 1.15  
= 54 A x 1.15 or 62.1 Amps for 230 V  
= 27 A x 1.15 of 31.05 Amps for 460 V




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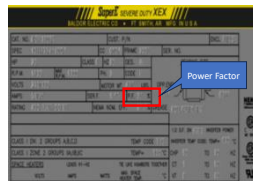
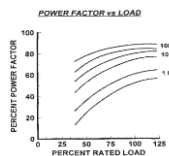
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## Glossary of Frequently Occurring Motor Terms

Power factor is the measure of a particular motor's requirements for magnetizing amperage. The formula "watts = amps x volts" must be altered when inductance is introduced to the load to include power factor. Thus, the new formula for single phase loads becomes "watts = amps x volts x pf".

$$\text{Power Factor (3 phase)} = \text{pf} = \frac{\text{Watts Input}}{\text{Volts} \times \text{Amps} \times 1.73}$$




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### Power Factor Characteristics of Induction Motors

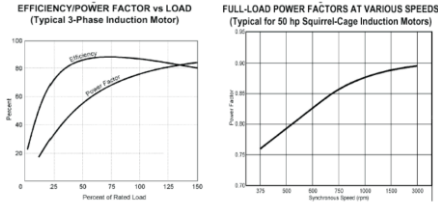


Figure 2.1 % Load vs. Power factor, Efficiency

Figure 2.2 Speed vs. Power factor

Bureau of Energy Efficiency

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### When Should I Consider Buying an Energy-Efficient Motor?

Energy-efficient motors should be considered in the following circumstances:

- For all new installations
- When purchasing equipment packages, such as compressors, HVAC systems, and pumps
- When major modifications are made to facilities or processes
- Instead of rewinding older, standard efficiency units
- To replace oversized and underloaded motors
- As part of a preventive maintenance or energy conservation program.




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### Pumps

Pumps are mechanical devices used to move fluids (liquids or gases) from one place to another. They work by applying mechanical force (usually through the action of a motor) to increase the pressure of the fluid, thereby causing it to flow. Pumps are widely used in various industries and applications, including:

Water supply and distribution, Wastewater treatment, Chemical processing, Oil and gas extraction, HVAC (Heating, Ventilation, and Air Conditioning) systems.

Pumps come in various types and designs, including centrifugal pumps, positive displacement pumps, diaphragm pumps, and reciprocating pumps, each suited for specific applications and fluid-handling requirements.




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## Pumps Performance Terms & Definitions

**Pump capacity, Q** = Volume of liquid delivered by pump per unit time, m<sup>3</sup>/s

**Total developed head, H** = The difference of discharge pressure and suction pressure

**Pump efficiency** = (Hydraulic power / Power input to the pump shaft) x 100

Hydraulic power (kW) = (Q \* (hd - hs) \* P \* g) / 1000

Q = volume flow rate (m<sup>3</sup>/s),

P = density of fluid (kg/m<sup>3</sup>),

g = acceleration due to gravity (m/s<sup>2</sup>),

(Discharge head, hd - Suction head, hs) = Total head (m)




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## Energy Savings Opps in Pumping Systems

Symptoms that Indicate Opportunity for Energy Saving		
Symptom	Likely Reason	Best Solutions
Throttle valve-controlled system	Oversized pump	Variable speed drive, trim impeller, small impeller, two speed drive, lower rpm
Bypass line (partially or completely) open	Oversized pump	Variable speed drive, trim impeller, small impeller, two speed drive, lower rpm
Multiple parallel pump system with the same number of pumps always operating	Pump use not monitored or controlled	Install controls
Constant pump operation in a batch environment	Wrong system design	On-off controls
High maintenance cost (seals, bearings)	Pump operated far away from Best efficiency point	Match pump capacity with system requirement




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## Common Motor Loads in Industrial & Commercial Bldg.

- Air-Cooled/Water-Cooled Chillers
- Cooling Towers & Air Compressors
- Chilled Water Pumps & Transfer Pumps
- Airconditioning Units
- Air Handling Units & Fans
- Power Mixers & Conveyor System




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### Air-Cooled & Water-Cooled Chillers



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### Cooling Towers



### Air Compressors



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### Industrial Pumps



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### Air Conditioning Units



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### AHU's and Fans Systems



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### Power Mixers & Conveyor System



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### Common Motor Loads in Industrial & Commercial Bldg.




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### Affinity Laws

The affinity laws, also known as the "fan laws" or "pump laws," are a set of engineering principles that describe the relationship between the variables involved in the performance of centrifugal pumps or fans.

There are typically **three (3) affinity laws**:

- 1. Flow Rate (Q) Affinity Law:** This law states that the flow rate through a pump or fan is directly proportional to its speed.
- 2. Head (H) Affinity Law:** This law states that the head, or pressure generated by the pump or fan, is proportional to the square of its speed.
- 3. Power (P) Affinity Law:** This law states that the power consumption of the pump or fan is proportional to the cube of its speed.




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### Affinity Law



The flow rate, **Q**, of a pump or fan is proportional to its speed:

$$\frac{Q_2}{Q_1} = \frac{RPM_2}{RPM_1}$$



The pressure, **P**, in a system is proportional to the square of the motor speed:

$$\frac{P_2}{P_1} = \left(\frac{RPM_2}{RPM_1}\right)^2$$



The motor power, **HP**, is proportional to the cube of the motor speed:

$$\frac{HP_2}{HP_1} = \left(\frac{RPM_2}{RPM_1}\right)^3$$




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### Affinity Law

For example, if the power demand of a fan at full speed is 10kW, then slowing the speed to 80% would reduce the power demand this way:

$$\frac{HP_2}{HP_1} = \left(\frac{RPM_2}{RPM_1}\right)^3$$

$$\frac{HP_2}{10} = \frac{0.83^3}{1} = 10 \times 0.512 = 5.12 \text{ kW}$$



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### Affinity Law

**Sample problem:** If speed of pump is reduced from 3500 rpm to 1750 rpm, its effect on flow head and power is calculated below.

$Q_1/Q_2 = (N_1/N_2)$     Where:  
 $H_1/H_2 = (N_1/N_2)^2$      $Q$  = Flow rate,  
 $P_1/P_2 = (N_1/N_2)^3$      $H$  = Head,  
 $P$  = Power absorbed,  
 $N$  = Rotating speed

**Head is proportional to the square of speed**

$$H_1/H_2 = (N_1/N_2)^2, \text{ where } H_1=100m$$

$$\text{Example: } 100/H_2 = 1750^2/3500^2$$

$$H_2 = 400m$$

**Flow is proportional to the speed**

$$Q_1/Q_2 = (N_1/N_2), \text{ where } Q_2=100 \text{ m}^3/\text{hr}$$

$$100/Q_2 = 1750/3500$$

$$Q_2 = 200 \text{ m}^3/\text{hr}$$

**Power is proportional to the cube of speed**

$$P_1/P_2 = (N_1/N_2)^3, \text{ where } P_1=5 \text{ kW}$$

$$5/P_2 = 1750^3/3500^3$$

$$P_2 = 40 \text{ kW}$$

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### Application of Affinity Law Utilizing a VSD/VFD

Variable Speed Drives allow motors to *operate at varying speeds, matching them precisely to the workload*, and thus *offering significant energy-saving potential*.



Instead of running at full capacity continuously, motors equipped with VSDs can be precisely controlled to *operate at the optimal speed required for each task*. By reducing motor speed during low-demand periods, businesses can realize substantial *energy savings* and VSD's can *reduce energy consumption by up to 50%* in various industrial applications.




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### Application of Affinity Law Utilizing a VSD/VFD

Sample problem:

An air handling unit (AHU) with a 60Hz, 4-pole inductive motor with a power input of 33,570 watts (45Hp) having a frequency inverter installed to it, is limited to run at only 50Hz for a year. What is the energy savings in kWh if the AHU unit doesn't have a frequency inverter or VSD controlling it?



Poles	60 Hertz
2	3600
4	1800

$N_s = \frac{120 \times f}{P}$   
 N<sub>s</sub> : Synchronous Speed (rpm)  
 f : Power Supply Frequency (Hz)  
 P : Number of Poles (each of our motors have four poles.)

Table 1 Induction Motor Synchronous Speeds




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### Application of Affinity Law Utilizing a VSD/VFD

Solution:

$$\frac{HP_2}{HP_1} = \left(\frac{RPM_2}{RPM_1}\right)^3$$

$$HP_2 = \frac{(1500)^3}{(1800)^3} \times 33.57 \text{ kW} = 19.43 \text{ kW}$$

$$kWh_{\text{savings}} = (P_1 - P_2) \times 24 \text{ Hr} \times 365 \text{ Days/Year}$$

$$kWh_{\text{savings}} = 14.14 \text{ kW} \times 24 \times 365 = 123,866.4 \text{ kWh}$$

On average energy rate of Php10.5/kWh  
**Php 1,300,597.20**




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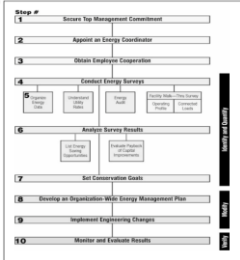
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## Elements of a Successful Energy Mgmt. Program

Figure 1-2 Steps in an Energy Management Program



Energy-management consists of a well structured team effort to create energy awareness: collect and organize energy cost and consumption data; identify, analyze and implement energy conservation opportunities; and monitor results.

These ten "Key Elements" are crucial to success of an energy management program.



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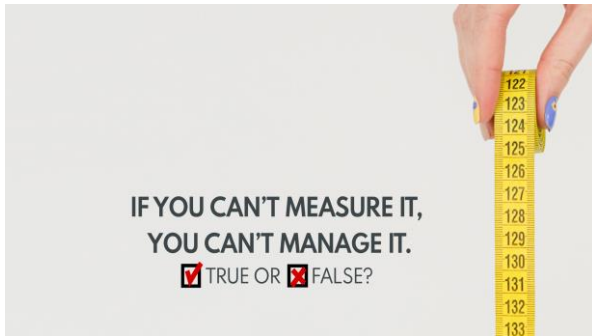
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## Instruments Used to Gather (Energy) Data

### Power/Energy Meters & Submeters

Used to measure several relevant electrical energy data such as but not limited to the following:

- kWh, kW, kVA
- Voltage levels
- Current (amps)
- THD
- Power Factor, etc.

Ideally, significant load groups should be sub-metered separately from other load groups such as for Compressed dry air system, HVAC systems, production equipment, & lighting system, etc.



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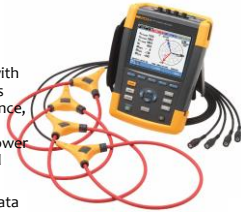
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### Instruments Used to Gather & Analyze Electrical Data

#### Power Quality Analyzer (PQA)

Power quality analyzers identify issues with power quality which typically manifest as dips, swells, harmonic distortion, unbalance, flicker, and transients. Power quality determines the suitability of electrical power to drive motors, machines and other end user devices.

This can also be used as power/energy data logger.



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### Instruments Used to Gather & Analyze Electrical Data

#### Thermal Imager / Thermal Scanner

Infrared thermography is a quick and reliable method for identifying and measuring temperatures of components operating at unreasonably elevated temperatures. High temperatures are a strong indication of both energy wastage and pending failure.



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### Instruments Used to Gather & Analyze Data

#### Tachometer

Measures the working speed of a motor, typically in revolutions per minute (RPM).



#### Digital Multimeter & Clamp Meter

Portable instrument that is used to measure electrical data at the site:

- Voltage levels
- Current (amps)
- Resistance
- Continuity



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### Key Points

- Power factor correction (PFC) aims to improve power factor, and therefore power quality. It **reduces the load on the electrical distribution system**, **increases energy efficiency** and **reduces electricity costs**.
- Energy-efficient motors are constructed with improved manufacturing techniques and superior materials; thus, they have **higher service factors, longer insulation and bearing lives, lower waste heat output**, and **less vibration**, all of which **increase reliability**.



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### Key Points

Motor systems fitted with VSDs can bring other benefits, including:

- i. reduced maximum power demand.
- ii. reduced stress on system components.
- iii. accurate control of pressure, flow and temperature.
- iv. improved safety and amenity, through reduced heat and noise levels.
- v. integration of VSD control with building management systems (BMS).



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## KNOWLEDGE REVIEW

1. The amount of current the motor can be expected to draw under full load (torque) conditions.
  - a. Full Load Amps
  - b. Locked Rotor Amps
  - c. Service Factor Amps
2. \_\_\_\_\_ is also known as "Fan Laws" and "Pump Laws"
  - a. 1<sup>st</sup> Law of Thermodynamics
  - b. Ohm's Law
  - c. Affinity Law



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### KNOWLEDGE REVIEW

3. \_\_\_\_\_ is a device that converts electrical energy into a mechanical energy.
- a. Capacitor
  - b. Conveyor
  - c. Electric Motor
4. Which device listed below, used to measure electric current?
- a. Voltmeter
  - b. Ammeter
  - c. Tachometer



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### KNOWLEDGE REVIEW

5. \_\_\_\_\_ is a multiplier that indicates the amount of overload a motor can be/are expected to handle.
- a. Full Load Speed
  - b. Frequency
  - c. Service Factor
6. \_\_\_\_\_ is the percentage of the input power that is converted to work output from the motor shaft.
- a. Power Factor
  - b. Efficiency
  - c. Frequency



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**THANK YOU!**



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