GE Power Conversion

MV Motor Designs & Specifications

IEEE/IAS Atlanta Chapter
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Syllabus

Part 1 – MV Motor Designs

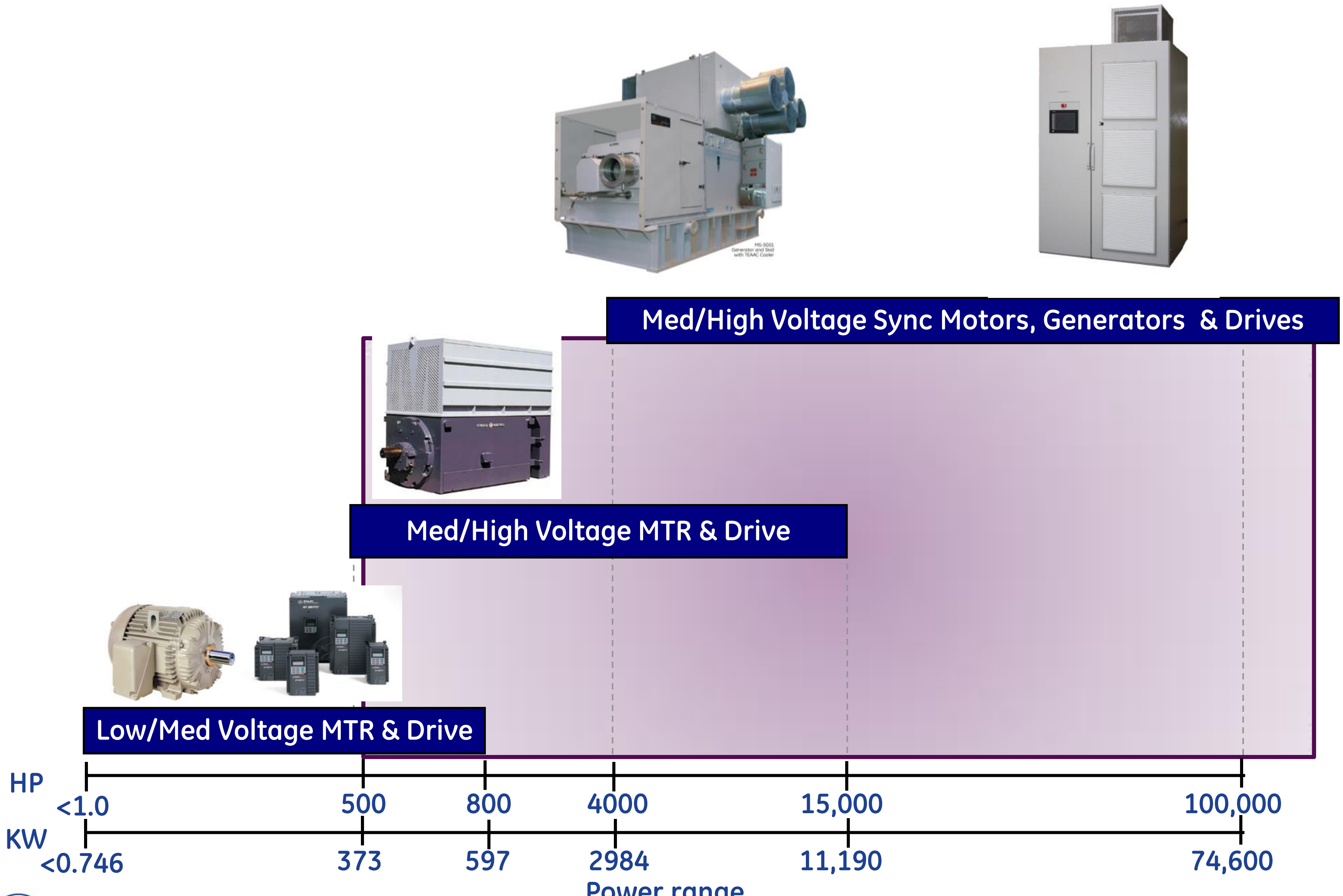
- Motor Designs
- Construction

Part 2 – Standards (brief outline)

- Industry Standards
- Data Sheets

Part 1 Motor Designs

Medium (M&H) Voltage Motor Range



imagination at work

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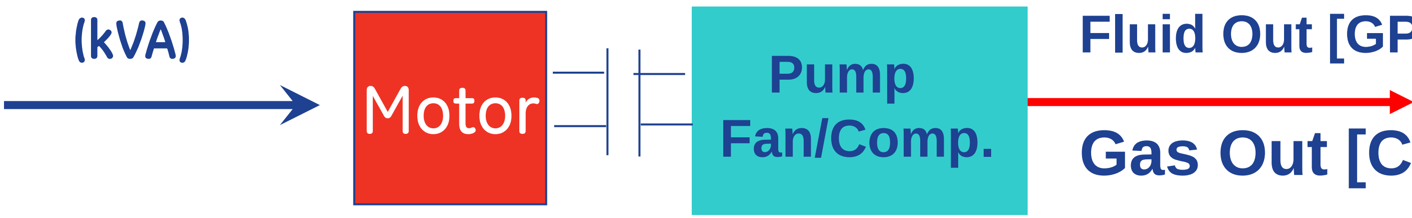
Basics

What is a Motor?

It is an Electrical Machine that converts Electrical energy to Mechanical energy very efficiently!

Electrical Energy In

(kVA)



Fluid Out [GPM or LPS]

Gas Out [CFM]

Conversion of Energy is as high as 98%

Maxwell's Equations

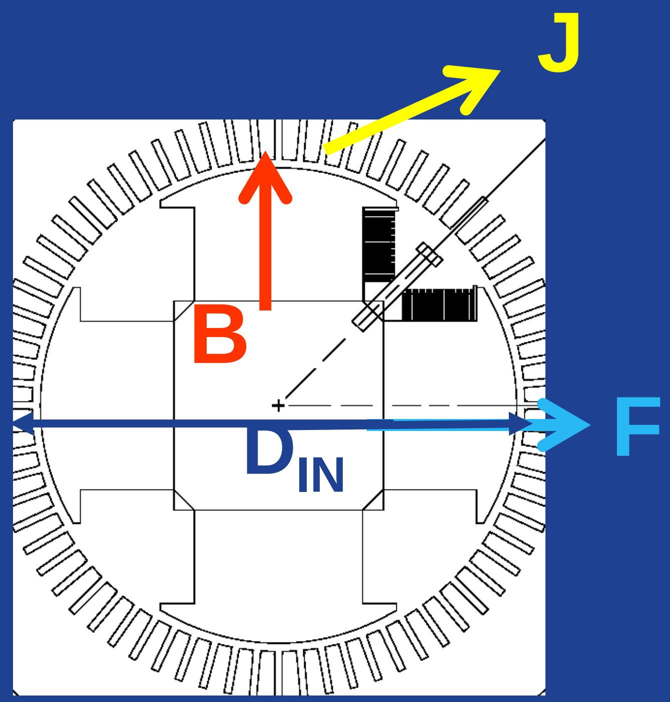
I. Gauss's Law for Electricity $$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_0}$$

II. Gauss's Law for Magnetism $$\oint \vec{B} \cdot d\vec{A} = 0$$

III. Faraday's Law for Induction $$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

IV. Ampere's Law $$\oint \vec{B} \cdot d\vec{s} = \mu_0 i + \frac{1}{c^2}\frac{\partial}{\partial t}\int \vec{E} \cdot d\vec{A}$$

Lorentz Force



Force = Φ x J

Where:

Φ = Total Air Gap Flux

= B x Π x D_{IN} x L

J = Specific Current

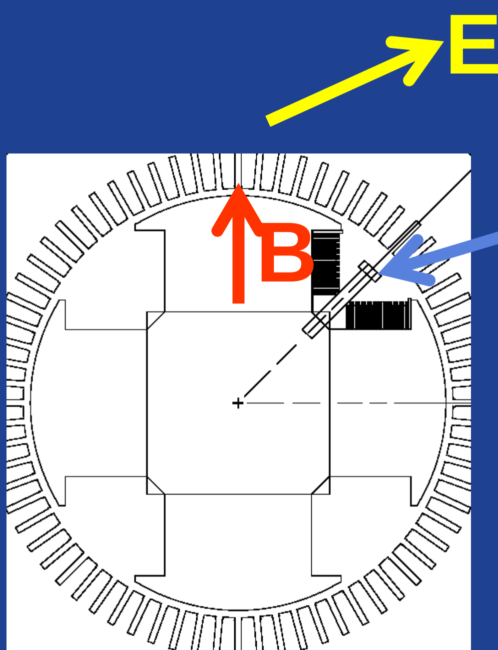
(Amp. Turns/Meter)

Torque = F x D_{INSIDE} /2

$\propto$ B x J x $D_{IN}{}^{2}$ x L

Power = Torque x Speed

Faraday's Law



A Moving Field (B) Generates a Voltage (E) on a Stationary Conductor.

N = No. of Turns

BA = Magnetic Flux

$$\text{Voltage}_{\text{Generated}} = -N \frac{\Delta BA}{\Delta t}$$

A Few Useful Equations

Amps (3 ph.) = Hp *0.746 / (1.732 * kV * Eff. * PF)

Hp (shaft) = [kVA * PF * Efficiency] / 0.746 or

Hp = kW/0.746

kVA (motor) = [1.732 * L-L Volts * Amps] / 1000

kW= Hp* 0.746

Speed (Synchronous) = RPM_{sync} = 120 * Hz / # Poles

Temperature = ^{0}C = (^{0}F-32) * 0.555 or ^{0}F = (^{0}C * 1.8) +32

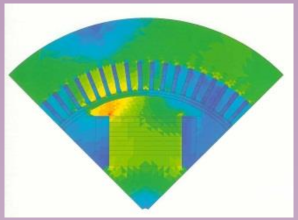
Torque (ft-lbs) = HP * 5252 / RPM

Torque (N-m) = kW * 9545 / RPM

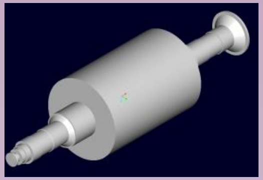
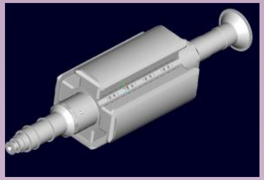
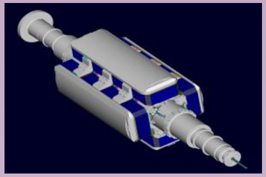
Design Tools

Design Tools

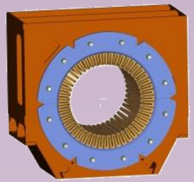
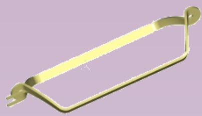
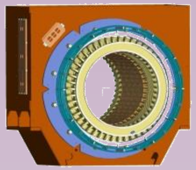
- Electromagnetic Finite Element Analysis



- 3 D Solid Modeling
  - ✓ 4 Pole Rotor

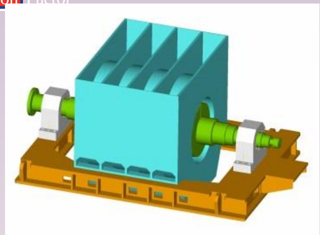
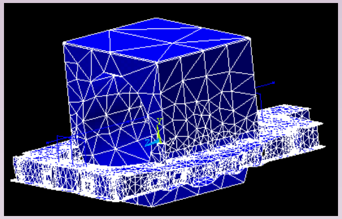




  - ✓ Wound Stator Model

- Stress Analysis

- Dynamic Modal Analysis

Base Design Modification Increased Natural Frequency From 33 Hz to 40 Hz

Where Are They Used?

By Industry

- Petroleum
- Chemical
- Pulp and Paper
- Mining
- Metals
- Cement
- Utility
- Marine

By Application

- Centrifugal Compressor
- Reciprocating Compressor
- Pulpwood Refiner
- Chippers
- Grinding Mill
- Axial Compressor
- Pumps
- Fan / Blower
- Steel Rolling
- Propulsion

A Few Pictures…

Pulpwood Refiner

Mining -Grinding Mill

Many Applications…

Metal Rolling

Ship Propulsion

imagination at work

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Driving Compressors

On a Pipeline

At a Refinery

More Compressors…

Reciprocating Compressor

Centrifugal Compressor

Types of Motors

Induction Vs. Synchronous

Induction

- Lower capital cost (except 'big' machines)
- Simpler construction
- Self excited

Synchronous

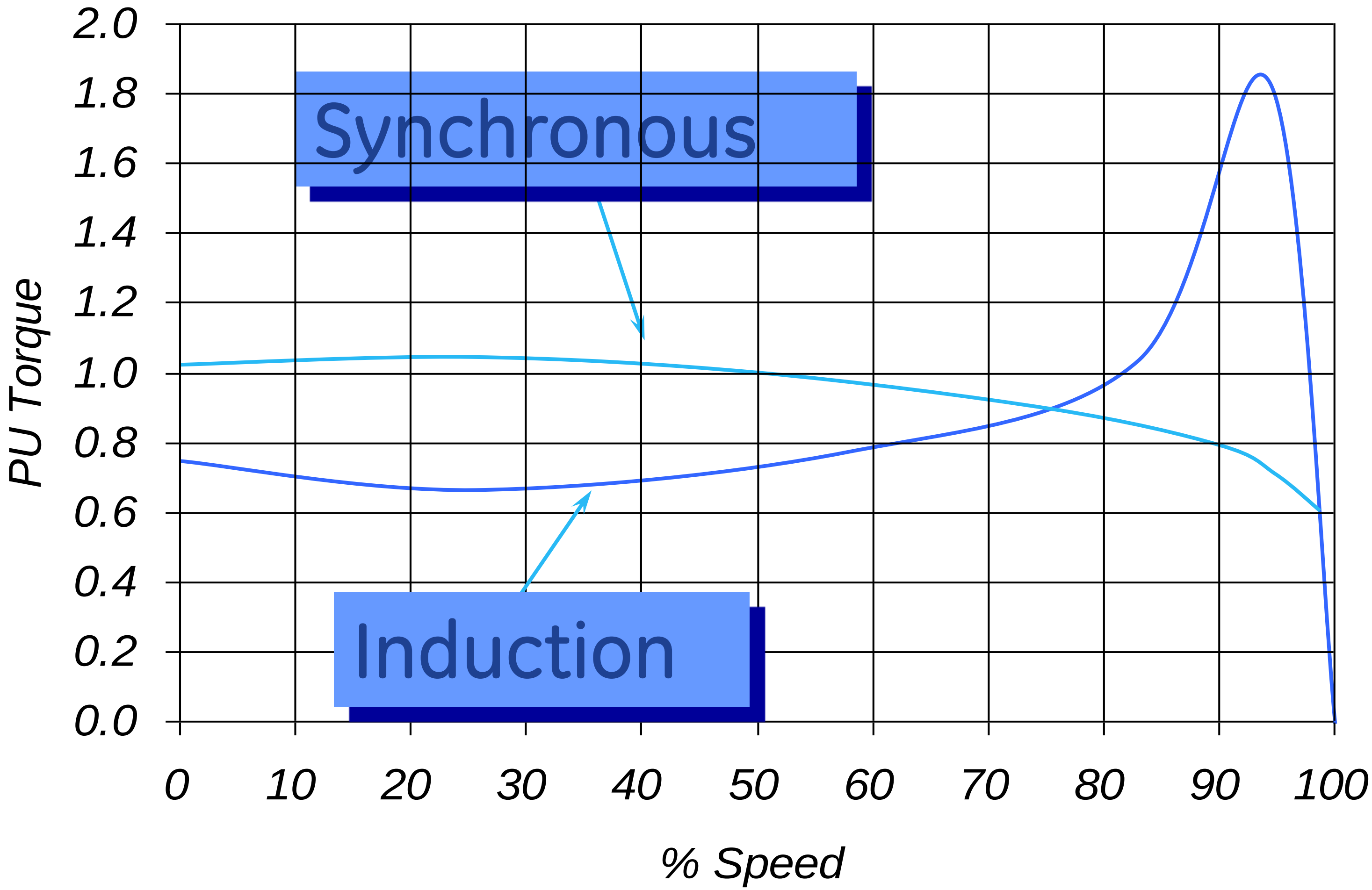
- High efficiency
- Power system support (unity and leading PF designs)
- Starting & operating performance are independent (low inrush designs)
- Constant speed (no slippage)
- Large power output available

	Synchronous	Induction
Horsepower	15,000	15,000
Voltage	13,800	13,200**
Power Factor	1.0	0.88
RPM	1,800	1,780
Full load current	476	561
Full load efficiency	98.4%	97.0%
Full load losses	182kW	*346kW

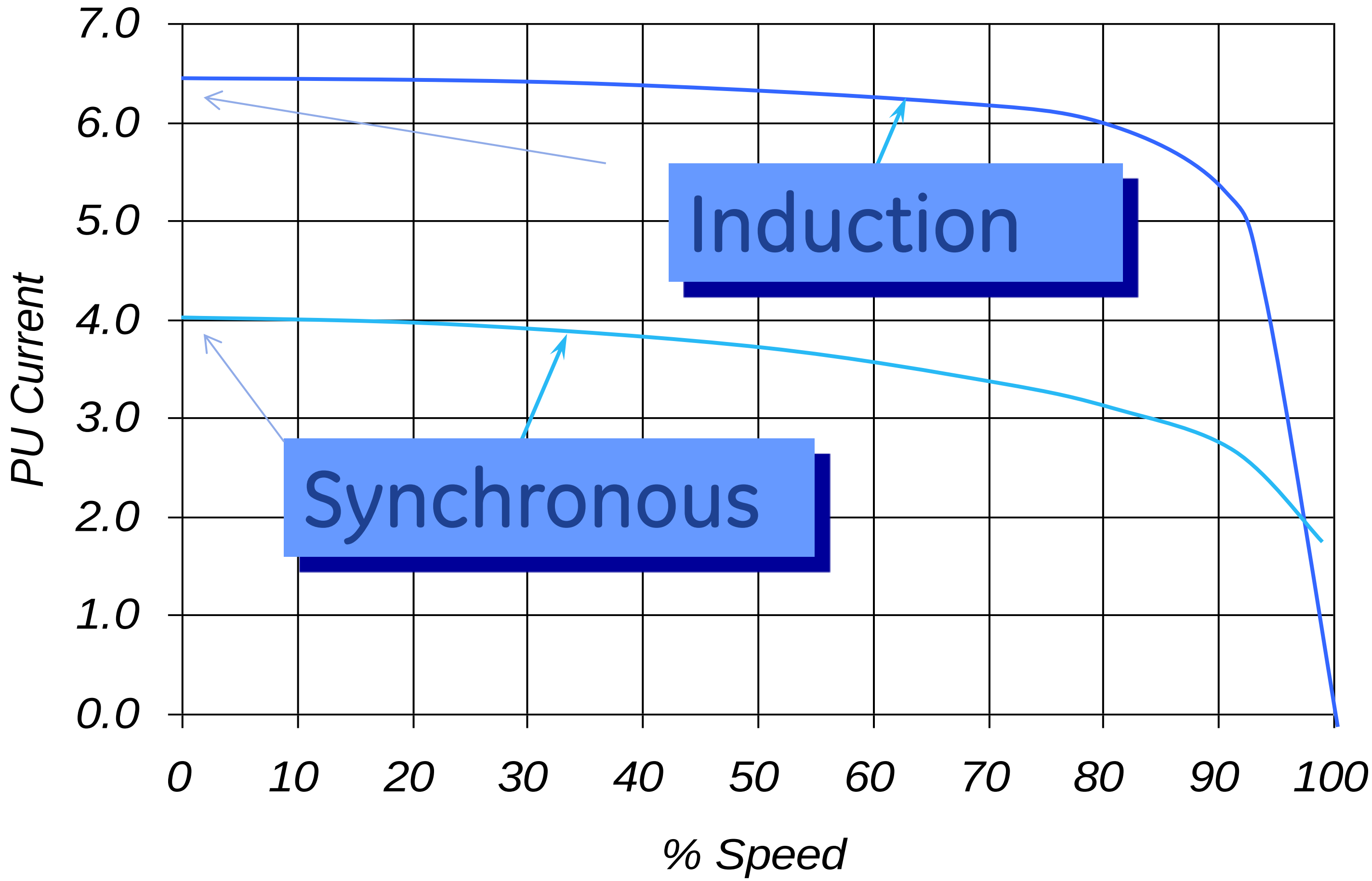
- Additional annual operating cost (@5¢/kW-Hr) = $72,000
- 20 Year operating savings using a synchronous motor = $ 1,436,600.

** API 546 3rd Edition states bus voltage = motor voltage

Typical Torque/Speed – 4 Pole



Typical Current/Speed - 4 Pole



Motor Design Considerations & Construction

Motor Design Considerations

Electrical Requirements

1) **Application**
2) **Power (hp or kw) & Speed**
3) **Torque**
   1. Variable
   2. Constant
   3. Low, Medium, High
4) **Motor Voltage** 2300, 2400, 3000, 3300, 4000, 4160, 6000, 6900, 10000, 11000, 12470, 13200, 13800
5) **Volt Drop at Motor Terminals**
6) **Voltage Drop at Utility**
7) **Power Factor** : Lag (-0.88) to Leading (+0.80)
8) **Frequency** 50, 60, or higher
9) **Inrush** 650%, 500, 450, 400, 350, or less

Starting Arrangement

1. **DOL**
2. **Reactor**
3. **Auto-Transformer**
4. **Reactor Capacitor**
5. **Soft Starter VVFF**
6. **Soft Starter VVVF**
7. **Adj. Freq. Drive (VVVF)**

Load

1. **Unloaded, Partial, or Fully Loaded**
2. **NEMA Load Inertia ½, 1 x, 2 x, 3x, or more**
3. **Service Factor 1.00, 1.15, 1.25, or greater**

Site Conditions

1. **Ambient 40^0C, 45^0C,50^0C, or higher**
2. **Elevation 0-3300 ft., or higher**

Enclosures

1. **ODP**
2. **WP1**
3. **WP2**
4. **TEWAC**
5. **TEAAC**
6. **TEFC**
7. **TEFV/TEPV**

Special Conditions

1. **No. of Starts: 2 cold/ 1 hot, 3 /2, or more**
2. **Acceleration/Safe Stall time**
3. **Vibration Limit**
4. **C Factor**
5. **OEM, EPC, End User Spec and/or Industry Specs**

Inputs

- Electrical Req'ts
- Site Conditions
- Starting Req'ts
- Load Conditions
- Special Req'ts

Motor Design & Construction

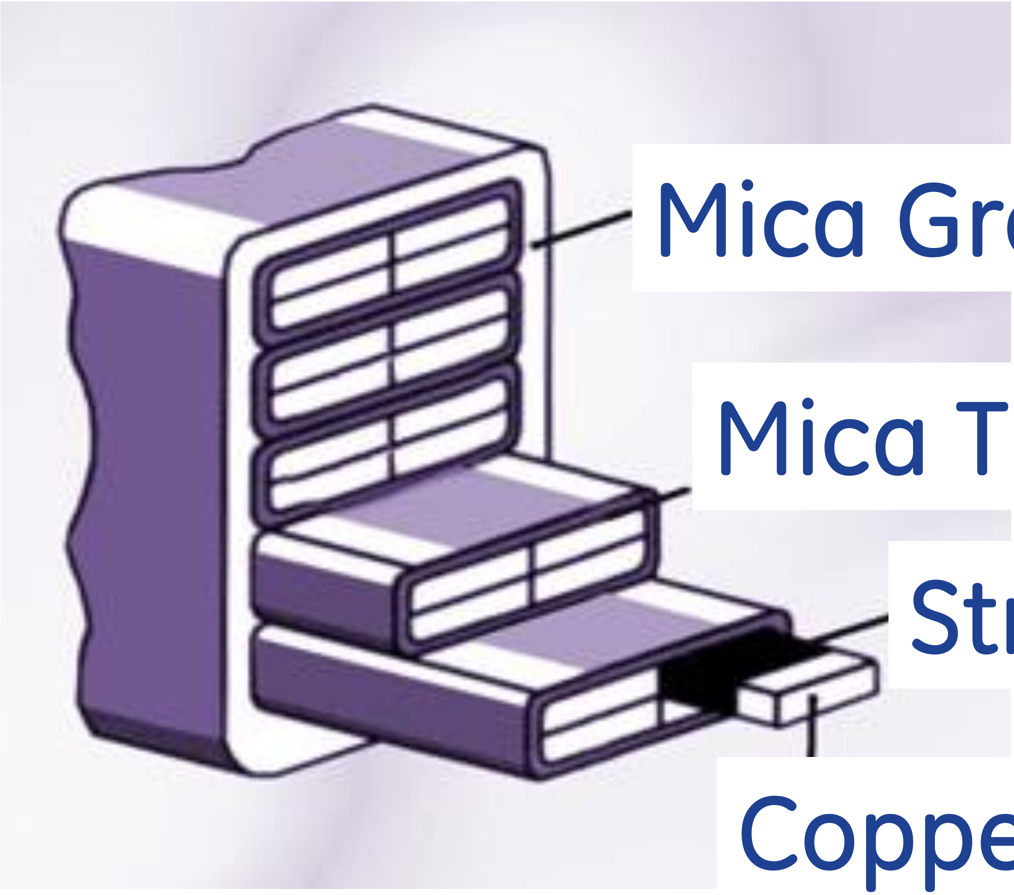
Common Components

- Stator
- Rotor
- Bearings
- Enclosures (TEWAC & TEAAC preferred)
- Protection Devices (RTD's, CT's, SC's, Vibration Probes, Leak Detectors, Differential Press. Switch, Space Heaters, Diode Fault Detector, …)
- Main Conduit box and auxiliary boxes

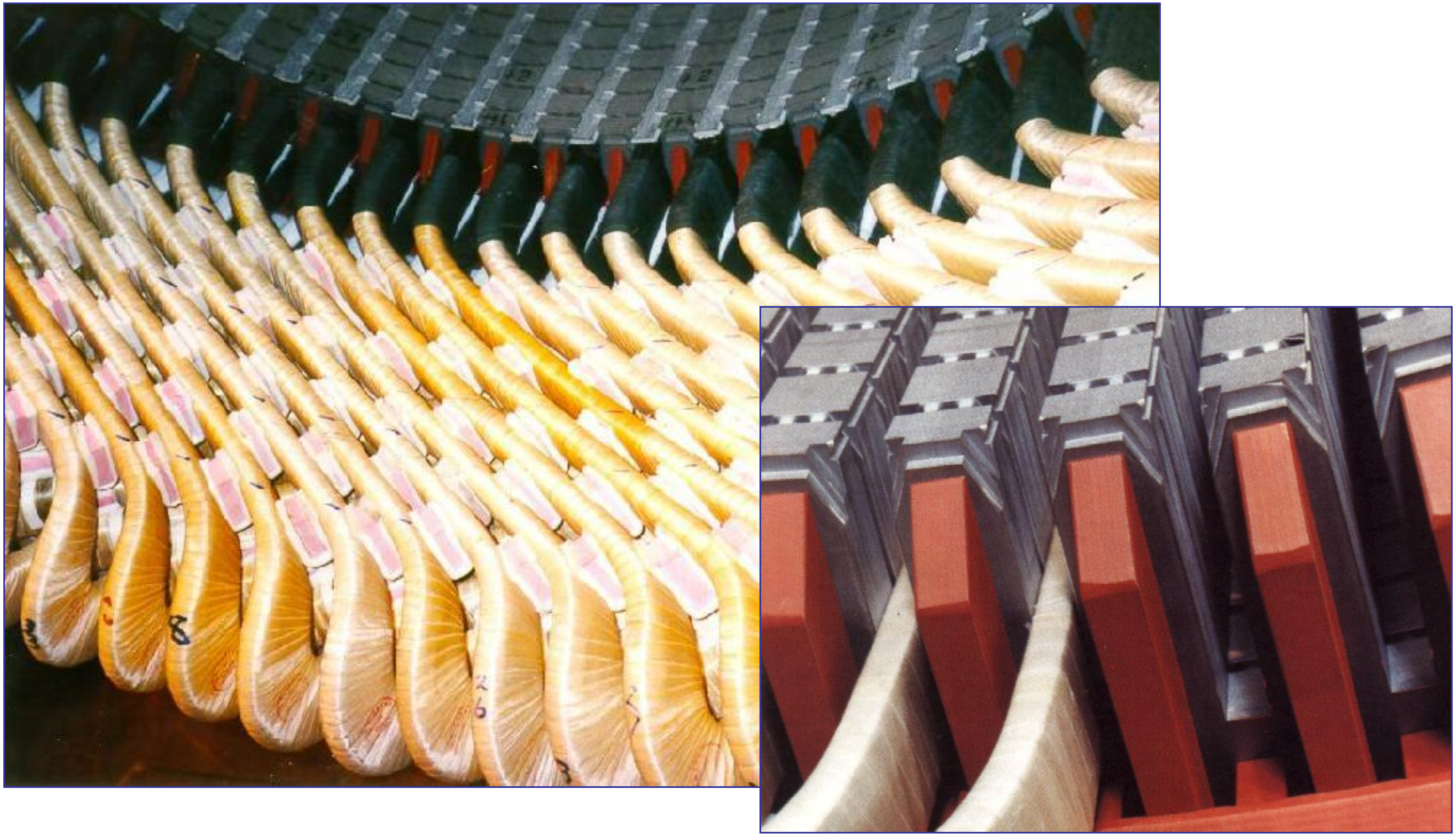
Motor design - Three Basic Components

1. **Stator Insulation system**
   – Medium and high voltage
   – Vacuum Pressure Impregnation [VPI insulation system]

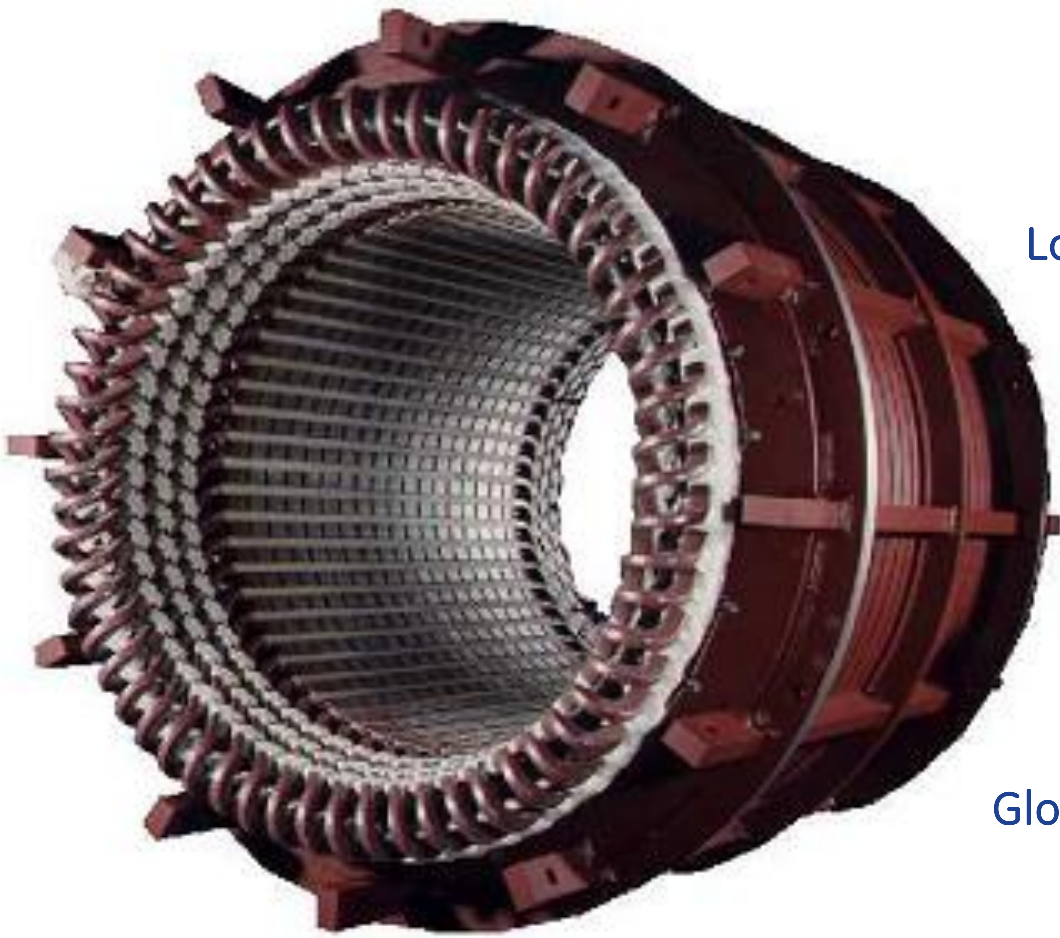
Stator Coil – Cutaway View



Wound Stators



Wound Stator



Low loss lamination grade

No core-pack welding

Individual Slot Wedging

Global VPI with Rotate Cure

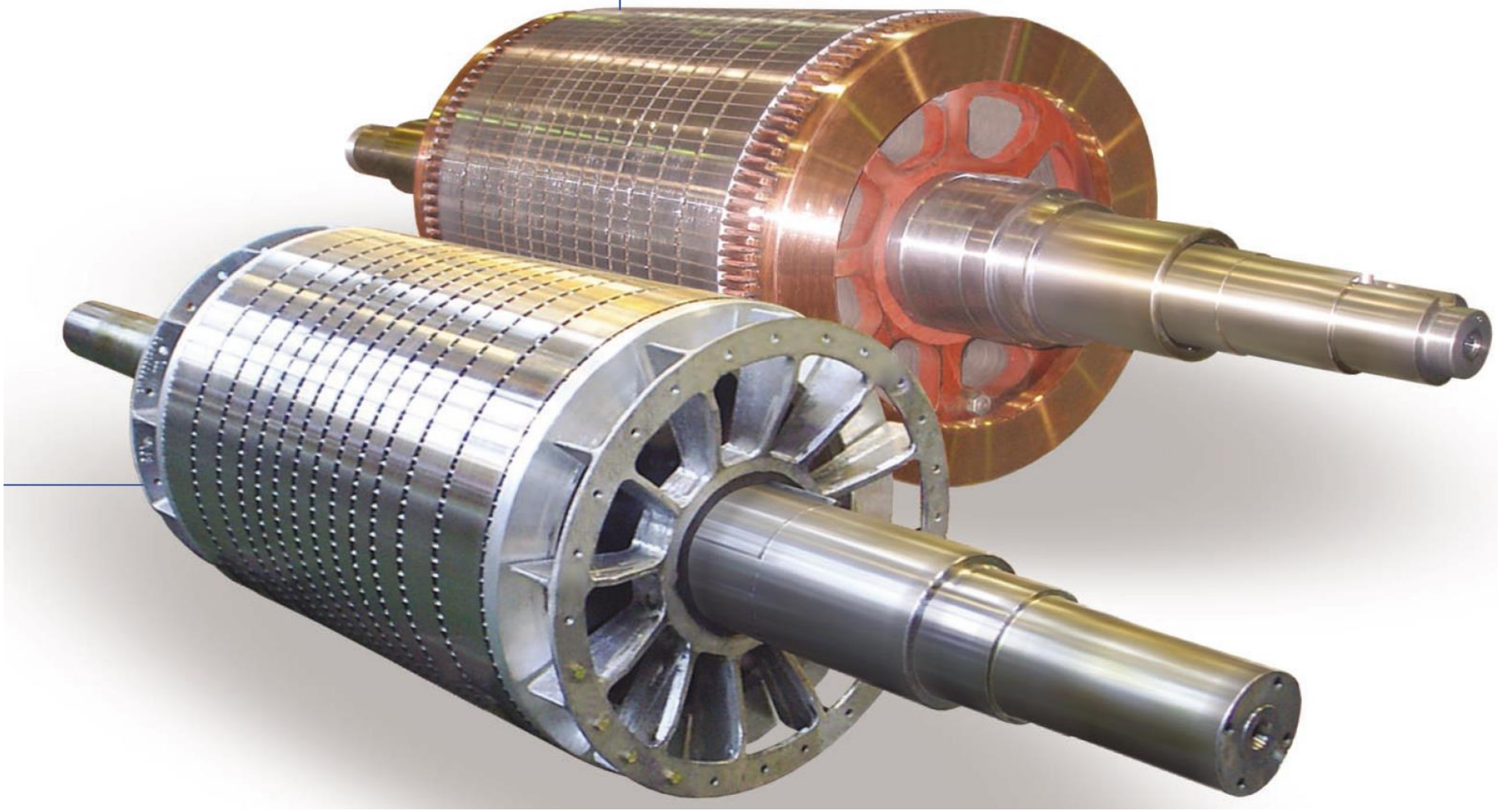
Motor design - Three Basic Components

2. Rotor design

- **Induction Squirrel Cage**
  - Aluminum bar
  - Copper Alloy bar
  - Special material bar

- **Synchronous**
  - Salient $\geq$ 4 poles
  - Cylindrical 2 & 4 poles

Aluminum & Copper Rotors



Example of Synchronous Rotors

SPP 1 - 4 Pole Laminated Rotor

SPP 2 - 4 Pole Solid Pole Rotor

SPP 3 - Multi-pole Laminated Rotor

SPP 4 - Separate Pole Connections

imagination at work

Motor design - Three Basic Components

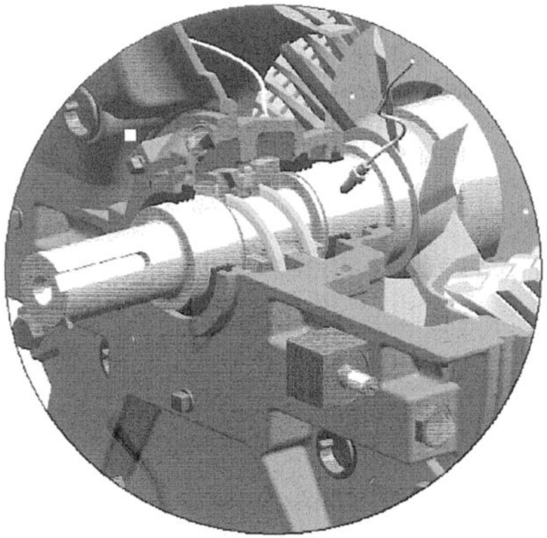
3. Bearing system design

- Rolling element
- Hydrodynamic (Sleeve) element
- Non-insulated & Insulated bearings
- Lubrication
  - Grease
  - Oil bath self–lubricated &/or forced fed lubrication

Bearing Types

Hydrodynamic (Sleeve) - Infinite Life $$$

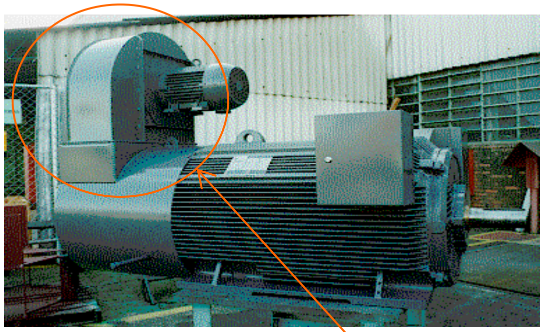
- Pedestal
- End bracket



Roller (anti-friction) – Low Power/Low Centrifugal Forces [Finite Life] $

Enclosure Types

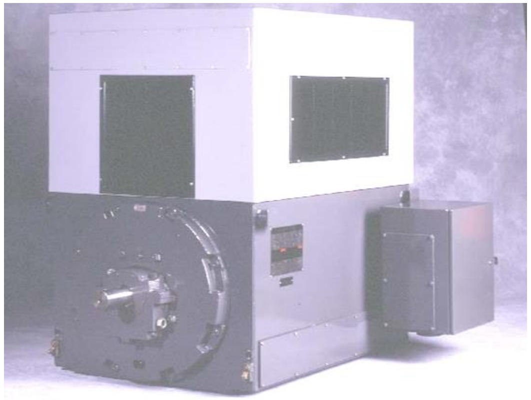
TEWAC



TEFC 4 AFD

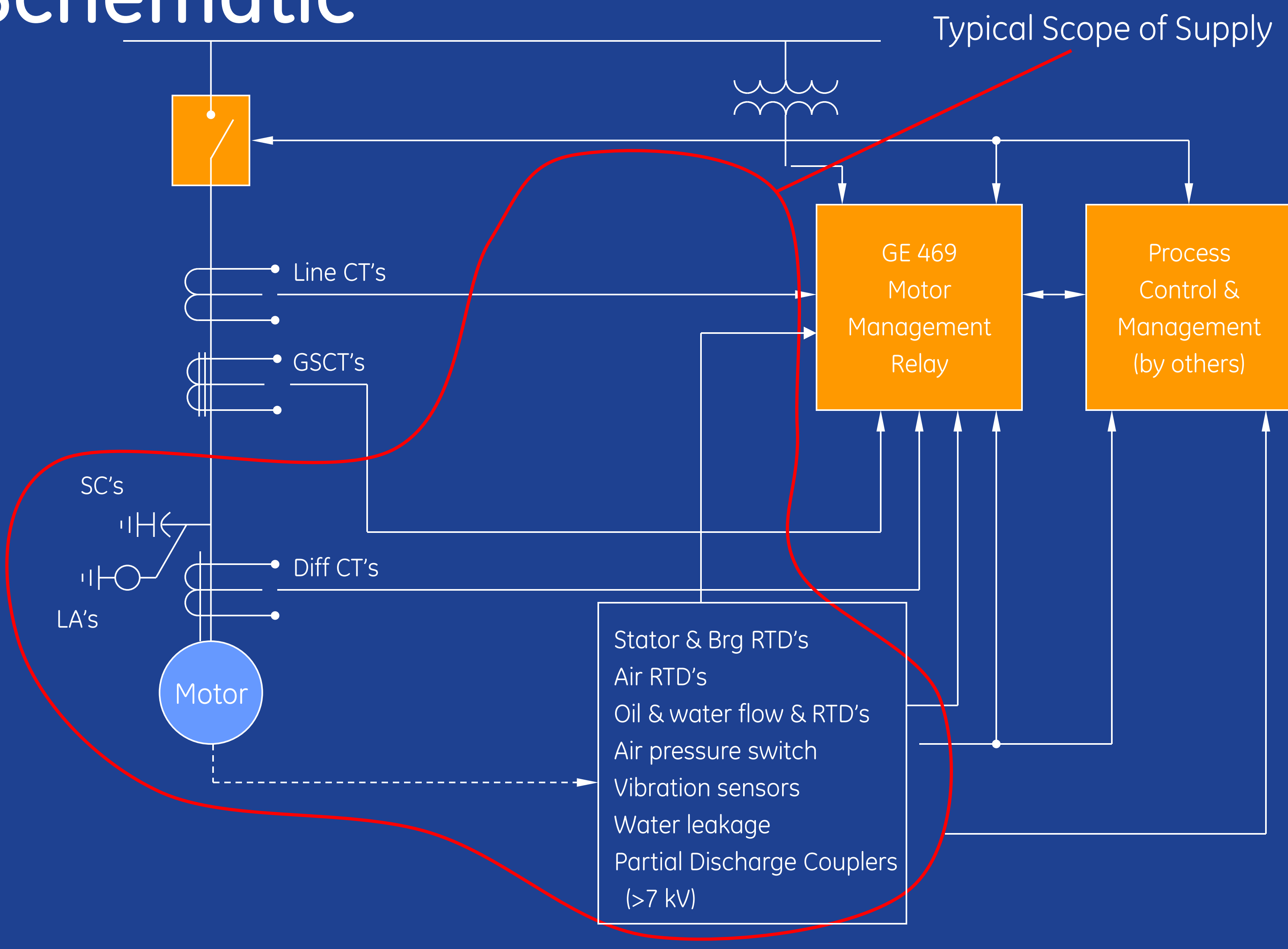
TEAAC

WP2



ODP-G

Induction Motor Protection Schematic



Specifications

Specifications Referred to with Motors and Generators

Reference Codes:

- ANSI
- API 541 5th Ed. & 547 (Induction) & 546 3rd Ed. (Synchronous)
- CSA
- IEC
- IEEE 112 (Induction) & 115 (Synchronous)
- NEMA MG1

Example (Typical) Specification

Motor Data #1	Application: Pulp Refiner
Rated Power	HP or kW
Rated Power Factor	Lagging for Induction (Leading to Unity – Sync Motor)
Phases	3
Frequency	50, 60 Hz, or Adj. Freq.
Poles	4
Speed	1800
Voltage	11 kv* (50 hz) or 13.8 kV *(60 hz)
Overspeed	120% of running speed
Insulation Class	F
Winding Temperature (rated power)	Class B
Number of main terminals	3
Sound pressure level @ 1m	85 dB(A) average

* There exceptions that require consulting with manufacturer

Example (Typical) Specification

Site Data	
Environment	Desert/ Marine/Salty/Arctic - FPSO
Site Area Classification	Hazardous or Non - Hazardous
Altitude	< 3300 ft. (1000 m)
Wind Speed	Plus 93 mph (150 km/h)
Design Temperature (Tropical)	15 (ISO) or 40°C ambient; 30°C fixed water temp
Design Temperature (Arctic)	-20°C ambient; 10°C variable water temp
Temperature Range min max (tropical)	5/40°C
Temperature Range min max (arctic)	-20/20°C
Relative Humidity	60 to 100%
Pitch and Roll (Water Vessel)	Pitch Max ± 10° Roll Max ± 15°

imagination at work

Example (Typical) Specification

Generator Data #2	
Type of Construction	IM1005
Cooling Type	TEWAC or CACW (IC8A1W7)
Neutral	Grounded
Rotation facing from Non Drive End looking towards driven equipment	CW
Phase sequence	3 Phase
Bearing Type	Sleeve
Bearing Housing Type	Bracket or Pedestal
Vibration limits at site	NEMA, API 541/ 46 or ISO10816
Lubrication	Self Lube or Forced Fed from separate lube system
Paint Spec	Mfr. Std.
Color	Manufactured Standard

Further Specification Items

- Vibration limits in factory
- Factory tests
- Terminal Boxes
- Cooling System
- Lube Oil System
- Auxiliary Equipment
- VT's and CT's
- Accessories including Stator & Bearing RTD's
- Vibration Probes
- Motor Protection (Surge Cap, L. A., Partial Discharge Couplers, Leak Detectors,..

Page 1 (Partial)

American Petroleum Institute	INDUCTION MACHINE API 541 5th Edition -- DATA SHEETS U.S. CUSTOMARY UNITS **PURCHASER'S SELECTIONS** ***Bold Italics* = *Indicate Default Selection***	JOB NO. ___ ITEM / TAG NO. ___ PURCHASE ORDER NO. ___ REQ. / SPEC. NO. ___ REVISION NO. ___ DATE ___ BY ___ REV. DATE ___ PAGE 1 OF 12

1	USER	APPLICATION
2	LOCATION	SUPPLIER / MOTOR MFGR. /
3	PROJECT NAME	SUPPLIER / MFGR. REF. NO. /
4	SITE / PLANT	MOTOR TAG NO(s)
5	Applicable To: △ Proposal ▽ Purchase ▷ As Designed □ As Built	TOTAL QTY. REQUIRED

***Bold Italics* = Indicate the Standard's Default Selection**

GENERAL

6	Applicable Standards (1.3.2; 1.6): ***North American (i.e., ANSI, NEMA)*** Use SI (metric) data sheets for International Standards (IEC, etc.)
7	**BASIC DESIGN (SECTION 2):** Power / RPM Ratings are Specified by: ❍ User/Project ❍ OEM ❍ Other ___
8	Nameplate Power Rating (2.2.1.1): ___ ❍ HP ❍ kW Motor Speed: ___ RPM (Synchronous)
9	Nameplate Voltage/Ph/Hz Rating (2.2.1.2): ___ Volts (2.2.1.2) ___ Phase ___ Hertz
10	Nameplate Ambient Temp. Rating (2.3.1.1,b): ***40°C*** ❍ Other: ___ °C ❍ Minimum Rated Operating Ambient Temp. ___ °C
11	Insulation Class (2.3.1.1,a): ***Class F*** ❍ Other Class: ___ ❍ Minimum Rated Storage Ambient Temp. ___ °C
12	Stator Temperature Rise (2.3.1.1,b)* ***Class B*** ❍ Other: ___ *(See Data Sheet Guide)
13	Duty (2.1.2): ***Continuous*** ❍ Other: ___
14	Voltage and Frequency Variations (2.2.1.3): ***Per NEMA*** ❍ Other: ___
15	Motor Power Source: ***Sine Wave Power*** ❍ ASD Power (complete below section) ❍ Solid State Soft Starter - Complete related data on Page 6
16	Adjustable Speed Drive Conditions, if applicable (2.1.4; 2.1.5; 2.3.1.2;):
17	❍ If available, describe ASD type / topology: ___
18	❍ ASD only operation ❍ ASD with DOL Start capability ❍ ASD with Bypass to Utility Frequency
19	❍ Variable Torque Speed Range: Min Speed ___ RPM ___ ft-lb Max. Speed ___ RPM ___ ft-lb
20	❍ Constant Torque Speed Range: Min Speed ___ RPM ft-lb Max. Speed ___ RPM ___ ft-lb

American Petroleum Institute	INDUCTION MACHINE API 541 5th Edition -- DATA SHEETS U.S. CUSTOMARY UNITS **PURCHASER'S SELECTIONS** ***Bold Italics = Indicate Default Selection***	JOB NO.		ITEM / TAG NO.	
		PURCHASE ORDER NO.			
		REQ. / SPEC. NO.			
		REVISION NO.	DATE		BY
		REV. DATE	PAGE 7		OF 12

ANALYSIS, SHOP INSPECTION, AND TESTS

		Required		Witnessed		Observed	
1	❍ (m) Indicates item is not required ◁ (v) Indicates item applies to only one machine in a multiple machine application/ order						
2	● (l) Indicates Purchaser required item ◀ (t) Indicates item applies to all machines in a multiple machine application/ order						
3	Make selections in only one column for each item	**Required**		**Witnessed**		**Observed**	
4		**(4.1.1; 4.1.3.3; 4.3.1)**		**(4.1.3; 4.1.3.1; 4.3.1.1)**		**(4.1.3; 4.1.3.2; 4.3.1.1)**	
5	Coordination Meeting (6.2)	❍					
6	Design Review (6.4)	❍					
7	Lateral Critical Speed Analysis (2.4.6.2.1; 6.6.2, b)	❍					
8	Torsional Analysis Data (2.4.6.2.2) Analysis By:	❍					
9	Submit Test Procedures and Acceptance Critreia 6 Weeks Before Tests (4.3.1.4)	❍					
10	Demonstrate Accuracy of Test Equipment (4.3.1.15)	❍	◁	❍	◁	❍	◁
11	Stator Core Test (4.3.4.1)	❍	◁	❍	◁	❍	◁
12	***Surge Comparison Test*** - required for all machines (4.3.4.2)	●	◀	❍		❍	
13	Special Surge Test of Coils (4.3.4.2.1)	❍	◁	❍	◁	❍	◁
14	Pow er Factor Tip-Up Test (4.3.4.3)	❍	◁	❍	◁	❍	◁
15	Stator Inspection Prior to VPI (4.3.4.5)	❍	◁	❍	◁	❍	◁
16	Sealed Winding Conformance Test (4.3.4.4)	❍	◁	❍	◁	❍	◁
17	Partial Discharge Test (4.3.4.6)	❍	◁	❍	◁	❍	◁
18	Rotor Residual Unbalance Verification Test (2.4.6.3.4)	❍	◁	❍	◁	❍	◁
19	Unbalance Response Test (4.3.5.3) (Purchaser must select one of below options)	❍	◁	❍	◁	❍	◁
20	❍ Purchaser to supply Half-Coupling or Mass Moment Simulator required for test	❍ Purchaser to supply data for Machine Vendor supplied Simulator					
21	Vibration Test w ith Half -Coupling (4.3.1.5) (req'd if vendor to mount cplg. 2.4.9.4)	❍	◁	❍	◁	❍	◁
22	Inspection of Equipment and Piping for Cleanliness before Final Assembly (4.2.3.3)	❍	◁	❍	◁	❍	◁
23	***Routine Test*** - Alw ays required for all machines (4.3.2)	●	◀	❍		❍	
24	Bearing Dimensional & Alignment Checks Before Tests (4.3.2.1, k)	❍	◁	❍	◁	❍	◁
25	Bearing Dimensional & Alignment Checks After Tests (4.3.2.1, l)	❍	◁	❍	◁	❍	◁
26	Purchaser Supplied Vibration Monitoring / Recording (4.3.3.7)	❍	◁	❍	◁	❍	◁
27	Complete Test (4.3.5.1.1) Includes all the follow ing:	❍	◁	❍	◁	❍	◁

Partial Page

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GE Energy
Power Conversion

We're at work making change happen

electrifying change

IEEE/IAS Atlanta Seminar on MV Motor Designs & Specifications