SOLCON USA

MOTOR CONTROL IS OUR NATURE

IEEE Houston Section

Medium Voltage Reduced Voltage Starters

Facilitated by **Christopher Sanderson**, *Gulf Coast Regional Sales Manager*
September 22, 2016

1

September 27, 2016

Importance of Properly Specifying Motors for the Application.

May 26, 2016
IEEE Houston Section Presentation
Facilitated by **Jonas.Pinon**@nov.com

NOV

SOLCON USA

MOTOR CONTROL IS OUR NATURE

Basic Starting Techniques & More

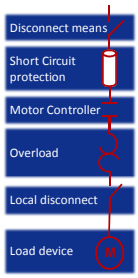
Facilitated by **George Tichi**, *VP Sales SOLCON USA*
July 5, 2016

3

September 27, 2016

Motor Control Outline

- **Introduction**
  - What is a Motor?
  - History of AC / DC
  - Starting Methods
    - ATL - Across The Line Starters
    - EM-RVS -Electro Mechanical Reduced Voltage Starters
      - Autotransformer
      - Wye-Delta Starting
    - RVS - Reduced Voltage Solid State Starters
- **Applications**
- **Knowledge Assessment & Resources**
- **SOLCON POWERED**
  - Who is SOLCON?
  - Application Solutions



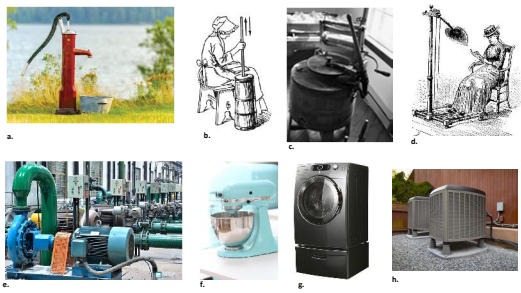
WATER | OIL & GAS | INDUSTRY | MINING | MARINE

What is a Motor?

What is a Motor?

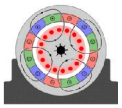
Motor Control Introduction

Why do we need Electric Motors



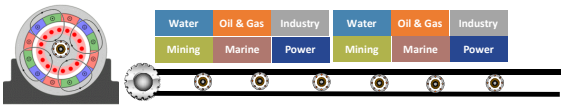
Motor Introduction

- An **electric motor** is an electrical machine that converts electrical energy into mechanical energy.
- The reverse of this would be the conversion of mechanical energy into electrical energy and is done by an electric generator.
- In normal motoring mode, most electric motors operate through the interaction between an electric motor's magnetic field and winding currents to generate force within the motor.



Motor Controller Introduction

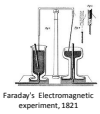
- A **motor controller** is a device or group of devices that serves to govern in some predetermined manner the performance of an electric motor.[1] A motor controller might include a manual or automatic means for starting and stopping the motor, selecting forward or reverse rotation, selecting and regulating the speed, regulating or limiting the torque, and protecting against overloads and faults.



DC Motor History

Year	Discoverer	Discovered
1740	Andrew Gordon	Electrostatic
1820	André-Marie Ampère	Ampère's force law
1821	Michael Faraday	Electromagnetic
1828	Ányos Jedlik	Electromagnetic Coils
1834	Moritz von Jacobi	1st DC Motor
1832	William Sturgeon	1st Commutator
1837	Thomas Davenport	1st Commercial Patented
1855	Ányos Jedlik	Electric Vehicle
1864	Antonio Pacinotti	Ring Armature
1871	Zénobe Gramme	Reinvented Pacinotti's design connected 2 DC motors
1886	Frank Julian Sprague	Non-Sparking Motor
1887	Frank Julian Sprague	1st Electric Trolley System

- The first electric motors were simple electrostatic devices created by the Scottish monk Andrew Gordon in the **1740s.**
- 1st Commercial Patented Motor in **1837** by Thomas Davenport


Faraday's Electromagnetic experiment, 1821


Andrew Gordon

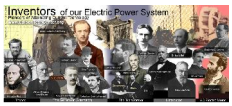

Thomas Davenport

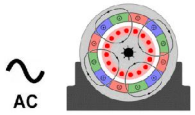

Jedlik's "Electromagnetic Self-Rotor"

AC Motor History

Year	Discoverer	Discovered
1824	François Arago	Rotating Magnetic Fields
1835	Hippolyte Pixii	1st Alternator
1855	Guillaume Duchenne	Uses AC in Electrotherapeutic Triggering of Muscle Contractions
1878	Ganz Company	Single Phase AC Motor
1879	Walter Baily	1st. Primitive Induction Motor
1884	Lucien Gaulard	Develops transformers and the power transmission system
1885	George Westinghouse	Buys the rights to Gaulard and Gibbs system
1887	C.S. Bradley	Builds 1st AC 3 phase generator.
1888	Galileo Ferraris Nikola Tesla	Paper: A New System for Alternating Current Motors and Transformers
1896	General Electric and Westinghouse	Signed a cross-licensing agreement for Squirrel-Cage Rotor

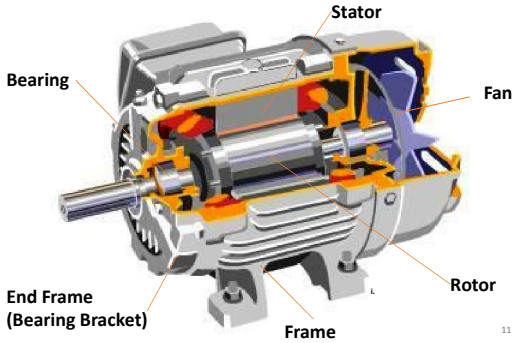
- The first primitive induction motor was discovered by manually turning switches on and off, by **Walter Baily in 1879**.





Induction Motor Basics

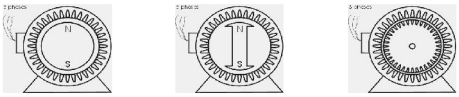
Main Components



AC Motor Basic Theory

As a current is "**induced**" into the stator windings, a magnetic field is created

The rotor rotates as the polarity of the changes.



Motors Facts Today…

- Today in North America, more than 1 billion motors are in service.
- Motors consume 25% of electricity in North America.
- Electricity consumption by motors in manufacturing sector is 70%.
- In oil, gas and mining industries around 90%.
- Three phase squirrel-cage induction motors account for over 90% of the installed motor capacity.

Motor Failure Rates and Costs

- Motor failure rate is conservatively estimated as 3-5% per year
  - In Mining, Pulp and Paper industry, motor failure rate can be as high as 12%.
- Motor failures divided in 3 groups:
  - Electrical (33%)
  - Mechanical (31%)
  - Environmental, Maintenance, & Other (36%)
- Motor failure cost contributors:
  - Repair or Replacement
  - Removal and Installation
  - Loss of Production

IEEE STUDY		EPRI STUDY		AVERAGE
FAILURE CONTRIBUTOR	%	FAILED COMPONENT	%	%
Persistent Overload	4.20%	Stator Ground Insulation	23.00	Electrical Related Failures
Normal Deterioration	26.40%	Turn Insulation	4.00	
		Bracing	3.00	
		Core	1.00	33%
		Cage	5.00	
Electrical Related Total	30.60%	Electrical Related Total	36.00%	
High Vibration	15.50%	Sleeve Bearings	16.00	Mechanical Related Failures
Poor Lubrication	15.20%	Antifriction Bearings	8.00	
		Trust Bearings	5.00	
		Rotor Shaft	2.00	
		Rotor Core	1.00	31%
Mechanical Related Total	30.70%	Mechanical Related Total	32.00%	
High Ambient Temp.	3	Bearing Seals	6.00	Environmental, Maintanence & Other Reasons Related Failures
Abnormal Moisture	5.8	Oil Leakege	3.00	
Abnormal Voltage	1.5	Frame	1.00	
Abnormal Frequency	0.6	Wedges	1.00	
Abrasive Chemicals	4.2			
Poor Ventilation Cooling	3.9			
Other Reasons	19.7	Other Components	21.00	36%
Environmental Related & Other Reasons: Total	38.70%	Maintanence Related & Other Parts: Total	32.00%	

Harsh Conformal Coating Can Reduce Environmental Failures

What is Motor Control?

What is Motor Control?

Motor Control Starting Techniques

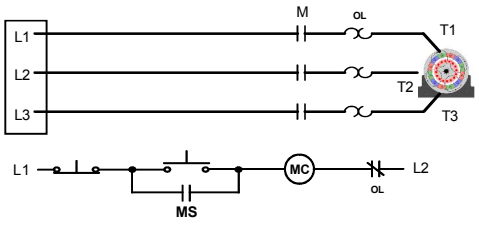
How many different Motor Control Starting techniques are their?

Motor Control Outline

- Introduction
  - What is a Motor?
  - History of AC / DC
  - Starting Methods
    - **ATL/DOL - Across The Line Starters/Direct Over the Line**
    - EM-RVS -Electro Mechanical Reduced Voltage Starters
      - Autotransformer
      - Wye-Delta Starting
    - RVS - Reduced Voltage Solid State Starters
- Applications
- Knowledge Assessment & Resources
- SOLCON POWERED
  - Who is SOLCON?
  - Application Solutions

AC Motor Full Voltage/Across the Line

Full Voltage/Across the Line Motor Starters



AC Motor Full Voltage ATL/DOL

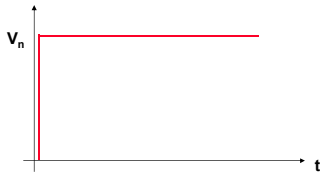
ATL/DOL - Across The Line/Direct Over the Line

- There are various methods that can be used to start an AC induction motor. The simplest method is by closing a contactor and allowing the motor to start at full voltage, or *Across The Line (ATL). This is the **oldest method** used to start a motor and, although compact and* inexpensive, it is far from the best. ATL starting is marked by **inrush currents of six to eight times** the motor's full load amp (**FLA**) value, on average. **Premium efficiency motors** can have inrush currents greater than **ten times full load amps**. These high inrush currents result in **electrical as well as mechanical problems** for the motor and the application.

AC Motor Full Voltage ATL/DOL

Full Voltage/Across the Line Motor Start

Voltage Applied on Start = 100% (Vn)



AC Motor Full Voltage ATL/DOL

- The diagram is a **current/speed curve** for a motor started at **full voltage**.

Note: The amount of current that is drawn by the motor to accelerate the connected load. *The motor produces maximum torque in less than three seconds.* **The majority of applications require less than half this amount of torque to accelerate the connected load.**

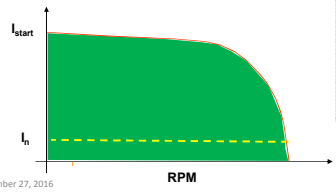
For many applications, this excess amount of torque will create premature mechanical and electrical failures in the drive train of the application. Starting a motor in this manner is very similar to "**dropping the clutch**" in your car or truck while revving the engine.

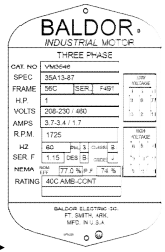
AC Motor Full Voltage ATL/DOL

SOLCON USA

Across the Line "ATL" Motor Inrush Current

Typically = 600-800%
Motor Nameplate Current

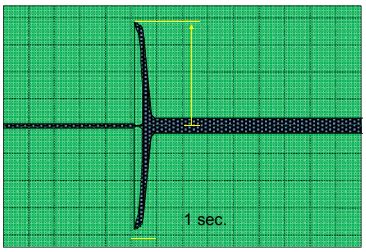




AC Motor Full Voltage ATL/DOL

SOLCON USA

ATL Start Current Surge
(Oscilloscope View)

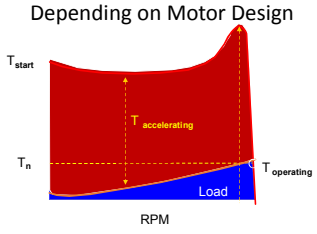


AC Motor Full Voltage ATL/DOL

SOLCON USA

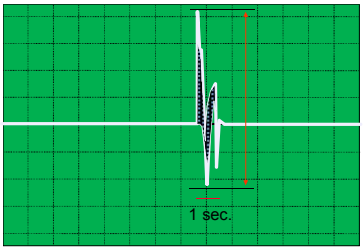
ATL Start Accelerating Torque

Typically = 150-250% Tn
Depending on Motor Design



AC Motor Full Voltage ATL/DOL

ATL Start Mechanical Shock
(Oscilloscope View)



AC Motor Full Voltage ATL/DOL

Disadvantages of Full Voltage ATL Starting

1. High inrush currents create stress on the motor's windings. This stress will cause the windings to move in the end turns of the stator. This will **cause the insulation to break down**. Eventually, **phase to phase shorts will occur and result in early motor failure**.

2. Full voltage starting will **cause damage to belts, sheaves, gearboxes, and other mechanical components throughout the application drive train,** thus causing downtime and replacement costs. For the most part**,** it is the **down time** that proves to be the most costly in any industry.

3. Full voltage starting can **create line drops/voltage dips which may result in penalties from the utility company.** The line drops that large motors can create may also cause problems with other applications throughout the plant.

4. Across The Line starting puts large amounts of **stress on the contactor contacts** which, in turn**,** require a relatively large amount of maintenance.

5. Poor motor protection with the use of overload with 20% accuracy.

6. No capability to **control the deceleration.**

Motor Control Outline

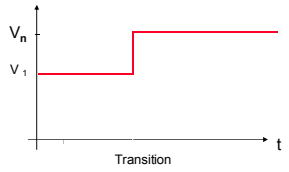
- Introduction
  - What is a Motor?
  - History of AC / DC
  - Starting Methods
    - ATL/DOL - Across The Line Starters/Direct Over the Line
    - **EM-RVS -Electro Mechanical Reduced Voltage Starters**
      - Autotransformer
      - Wye-Delta Starting
    - RVS - Reduced Voltage Solid State Starters
- Applications
- Knowledge Assessment & Resources
- SOLCON POWERED
  - Who is SOLCON?
  - Application Solutions

AC Motor Electro Mechanical RVS

SOLCON USA

Electro Mechanical Reduced Voltage Starter EM-RVS

Traditional EM-RVS starters apply an initial low voltage level and transition to full voltage during start phase. This results in a step function.

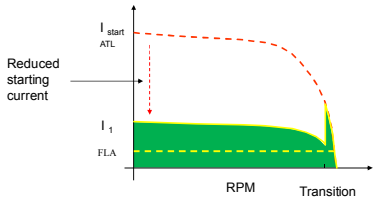


AC Motor Electro Mechanical RVS

SOLCON USA

EM-RVS Starter Motor Inrush Current

Starting current is reduced as the square of the applied voltage reduction. Current spikes occur at transition.

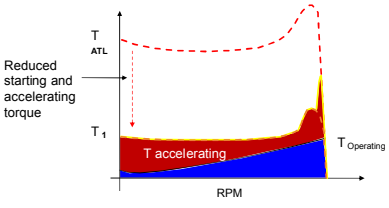


AC Motor Electro Mechanical RVS

SOLCON USA

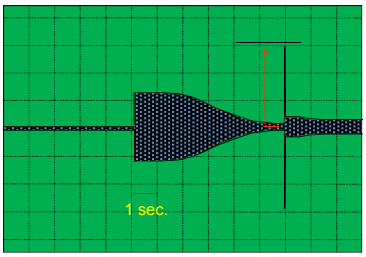
EM-RVS Start Accelerating Torque

Torque is reduced proportionately with the reduction in motor current. Torque surges occur at transition.



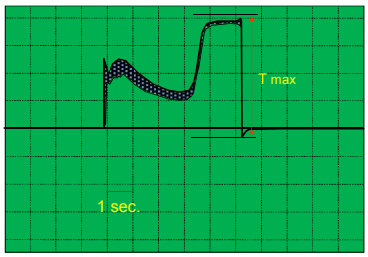
AC Motor Electro Mechanical RVS

EM-RVS Start Current Surge
(Oscilloscope View)



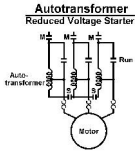
AC Motor Electro Mechanical RVS

EM-RVS Start Mechanical Shock
(Oscilloscope View)



Motor Control Outline

- Introduction
  - What is a Motor?
  - History of AC / DC
  - Starting Methods
    - ATL/DOL - Across The Line Starters/Direct Over the Line
    - EM-RVS -Electro Mechanical Reduced Voltage Starters
      - **Autotransformer**
      - Wye-Delta Starting
    - RVS - Reduced Voltage Solid State Starters
- Applications
- Knowledge Assessment & Resources
- SOLCON POWERED
  - Who is SOLCON?
  - Application Solutions

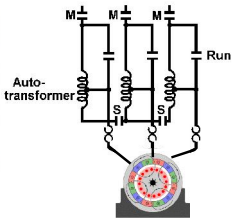


AC Motor Electro Mechanical RVS

SOLCON USA

Electro Mechanical Reduced Voltage Starter

Autotransformer
Reduced Voltage Starter



AC Motor AutoTransformer

SOLCON USA

Autotransformer Reduced Voltage Starting

- The Autotransformer starter is simply a **transformer configured with contactors to allow a stepped acceleration to full speed.** This is accomplished by "**tapping**" the transformer at **50, 65, or 80 percent of full voltage**. One of these taps is the first step of voltage applied to the motor and is subsequently followed by a second step to full voltage.
- The **first is an open transition type.** With this type, the motor is **disconnected from the voltage source** during the transition step to full voltage. Even though this is very quick, a large current spike and torque transient is created.
- The **second is for a closed transition starter**. This type of starter **does not disconnect the motor from the voltage source** during the transition step to full voltage. Although this is an improvement over the open transition, a significant current surge and torque transient is still experienced.

AC Motor Electro Mechanical RVS

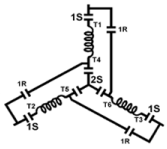
SOLCON USA

Disadvantages of Autotransformer Starting

1. Limited adjustability to load conditions.
2. Mechanical shock to system between steps.
3. Large size; takes up control room space.
4. High contactor maintenance.
5. High purchase cost.
6. Unable to compensate easily for input voltage variations.
7. Uncontrolled deceleration.
8. Poor motor protection with the use of bimetallic overload with 20% accuracy.

Motor Control Outline

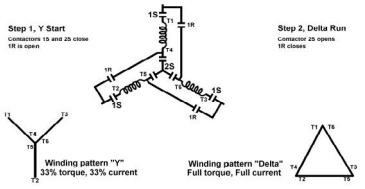
- Introduction
  - What is a Motor?
  - History of AC / DC
  - Starting Methods
    - ATL/DOL - Across The Line Starters/Direct Over the Line
    - EM-RVS -Electro Mechanical Reduced Voltage Starters
      - Autotransformer
      - **Wye-Delta Starting**
    - RVS - Reduced Voltage Solid State Starters
- Applications
- Knowledge Assessment & Resources
- SOLCON POWERED
  - Who is SOLCON?
  - Application Solutions



AC Motor Electro Mechanical RVS

Electro Mechanical Reduced Voltage Starter

Star Delta (Also Called Wye-Delta) Starting



AC Motor Electro Mechanical RVS

Wye-Delta (Also Called Star Delta) Starting

- **Wye-Delta** starter utilizes a special wound motor that **has the wires from each of the sets of windings brought out to the terminal leads.** These windings can be connected in a "**Delta**" pattern for full motor starting torque, or in a "**Y**" (Wye) **pattern for reduced starting torque.** In the Delta pattern, all of the windings are **connected phase-to-phase in series,** just as they would be in a standard motor.
- In the "**Y**" configuration, each set of **phase windings is brought together at a common point.** This increases the impedance of the motor itself, **reducing the current and torque to 33% of normal.** Three contactors and a timer are used to switch the six leads brought out of the motor into the Y-then-Delta configuration in a two-step starting process.

AC Motor Electro Mechanical RVS

To illustrate the **disadvantages** with the electromechanical type of starters, let's look at a speed torque curve for a typical variable torque load started at full voltage, at 85% voltage with an Autotransformer and Wye-Delta. The area between the typical load torque curve and the full voltage, Wye-Delta or Autotransformer torque curve is the **excess torque that is created during starting.** Electromechanical reduced voltage starters reduce the inrush current and applied torque when compared to starting with full voltage; unfortunately the motor still produces an **excess of torque compared to the torque actually required to start the connected load.**

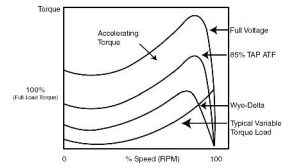


Figure 3-6: Typical Constant Torque Motor Speed Torque Curves for Electromechanical Starting

AC Motor Electro Mechanical RVS

For a better understanding of the effects associated with full voltage starting and the voltage steps associated with electromechanical reduced voltage starters like the Autotransformer and Wye-Delta, ***let's look at the relationship between applied motor voltage and motor output torque:***

Rule of thumb: Torque varies as (Amps)^2

Thus, if **only 50% of nominal voltage is applied**, the motor's starting torque is only 25%. The following examples apply for a 480V or 575V Induction motor and various applied voltages.

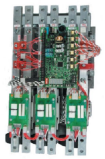
AC Motor Electro Mechanical RVS

Disadvantages of Wye-Delta Starting

1. Limited adjustability to load conditions.
2. Mechanical shock to system between steps.
3. High contactor maintenance.
4. Unable to compensate easily for input voltage variations.
5. Uncontrolled deceleration.
6. Poor motor protection with the use of bimetallic overloads with 20% accuracy.

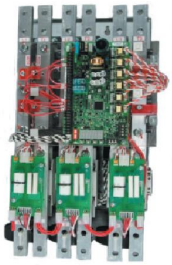
Motor Control Outline

- Introduction
  - What is a Motor?
  - History of AC / DC
  - Starting Methods
    - ATL/DOL - Across The Line Starters/Direct Over the Line
    - EM-RVS -Electro Mechanical Reduced Voltage Starters
      - Autotransformer
      - Wye-Delta Starting
    - **RVS - Reduced Voltage Solid State Starters**
- Applications
- Knowledge Assessment & Resources
- SOLCON POWERED
  - Who is SOLCON?
  - Application Solutions



AC Motor Solid State RVS

Solid State Reduced Voltage Starters

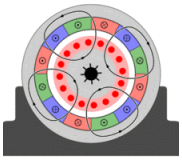


AC Motor Solid State RVS

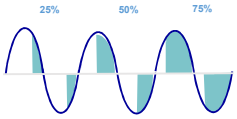
Solid State Reduced Voltage Starters (Soft Starters)

Available for:

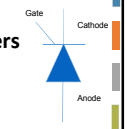
- *Standard Induction Motors*
- *Synchronous Motors*
- *Wound Rotor Motors*
- *Multi-Speed PAM Motors*



AC Motor Solid State RVS – SCR



- Reduced voltage starting with softstarters is accomplished by **Silicone Controlled Rectifiers** or SCRs technology.
- Chopping the sine wave on start and stop

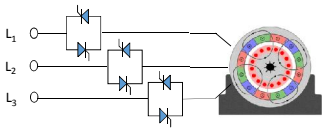


AC Motor Solid State RVS

Solid State "Soft Start" Control

Typical SSRVS Full Wave Bridge Power Stack

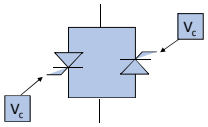
SCR=Silicon Controlled Rectifier

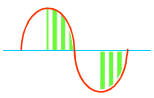


AC Motor Solid State RVS

Solid State "Soft Start" Control

When voltage is applied to the gates of the SCR's, they pass current to the motor.



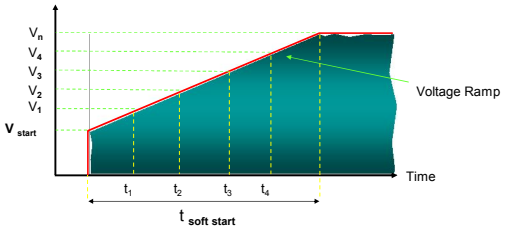


AC Motor Solid State RVS

SOLCON USA

Voltage Ramp

Gradual Voltage Increase

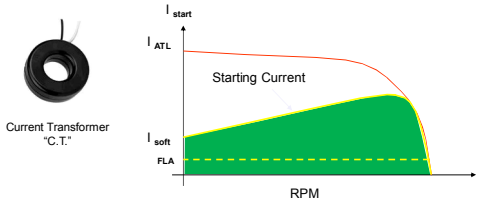


AC Motor Solid State RVS

SOLCON USA

Soft Start Motor Current Ramp

Typical Closed Loop Current Ramp Profile

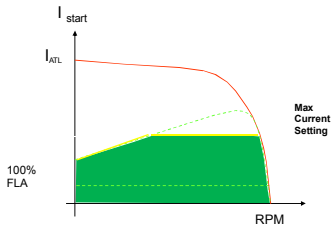


AC Motor Solid State RVS

SOLCON USA

Soft Start Motor Current Ramp

Current Ramp with Max Current Setting

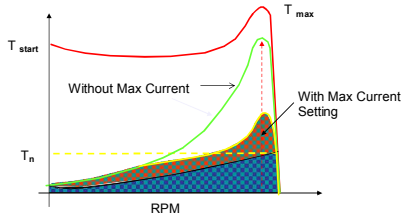


AC Motor Solid State RVS

SOLCON USA

Soft Start Accelerating Torque

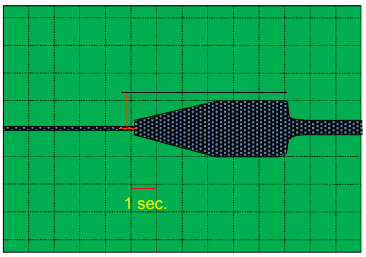
Accelerating Torque Curves with and without Max Current Setting.



AC Motor Solid State RVS

SOLCON USA

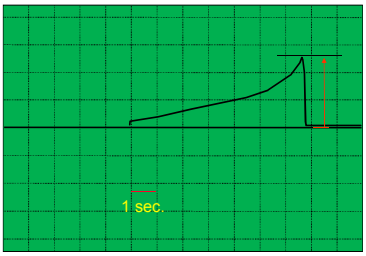
Soft Start Eliminates Current Surge (Oscilloscope View)



AC Motor Solid State RVS

SOLCON USA

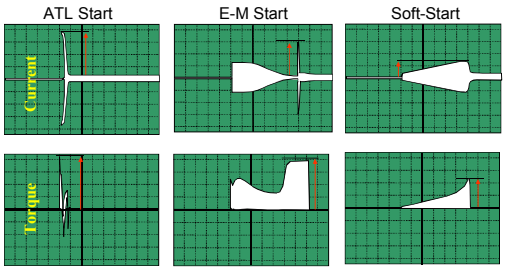
Soft Start Eliminates Mechanical Shock (Oscilloscope View)



AC Motor Solid State RVS

SOLCON USA

Motor Starting Comparison
(Oscilloscope View)



Motor Control Outline

SOLCON USA

- Introduction
  - What is a Motor?
  - History of AC / DC
  - Starting Methods
    - ATL/DOL - Across The Line Starters/Direct Over the Line
    - EM-RVS -Electro Mechanical Reduced Voltage Starters
      - Autotransformer
      - Wye-Delta Starting
    - RVS - Reduced Voltage Solid State Starters
- **Applications**
- Knowledge Assessment & Resources
- SOLCON POWERED
  - Who is SOLCON?
  - Application Solutions

Motor Control
Industrial Application

SOLCON USA

- Oil and Gas
- Plastic
- Glass
- Paint
- Paper
- Heat Treatment
- Metalurgy
- HVAC
- Heaters
- Electrolysis
- Multi-zone heating (heater/phase)
- Variety of resistive and inductive loads
- Semiconductor Equipment

Motor Control Outline

- Introduction
  - What is a Motor?
  - History of AC / DC
  - Starting Methods
    - ATL/DOL - Across The Line Starters/Direct Over the Line
    - EM-RVS -Electro Mechanical Reduced Voltage Starters
      - Autotransformer
      - Wye-Delta Starting
    - RVS - Reduced Voltage Solid State Starters
- Applications
- **Knowledge Assessment & Resources**
- SOLCON POWERED
  - Who is SOLCON?
  - Application Solutions

Motor Control Resources

https://en.wikipedia.org/wiki/Motor_controller

https://en.wikipedia.org/wiki/Electric_motor

http://www.edisontechcenter.org/AC-PowerHistory.html

http://www.solconusa.com/medium-voltage-soft-starter.html

http://www.solconusa.com/low-voltage-soft-starter.html

Motor Control Resources

Article: ***Across The Line (DOL) vs. Reduced Voltage Starters***

http://www.solconusa.com/News-Events/solconusa-christopher-sanderson-across-the-line-vs-reduced-voltage-starters.html

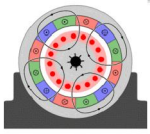
Presentation: ***Motor Protection Principles***

- By Craig.Wester@GE.com, GE Multilin

SOLCON™ USA

MOTOR CONTROL IS OUR NATURE

Motor Control



Christopher Sanderson

Gulf Coast Regional Sales Manager

WATER | OIL & GAS | INDUSTRY | MINING | MARINE