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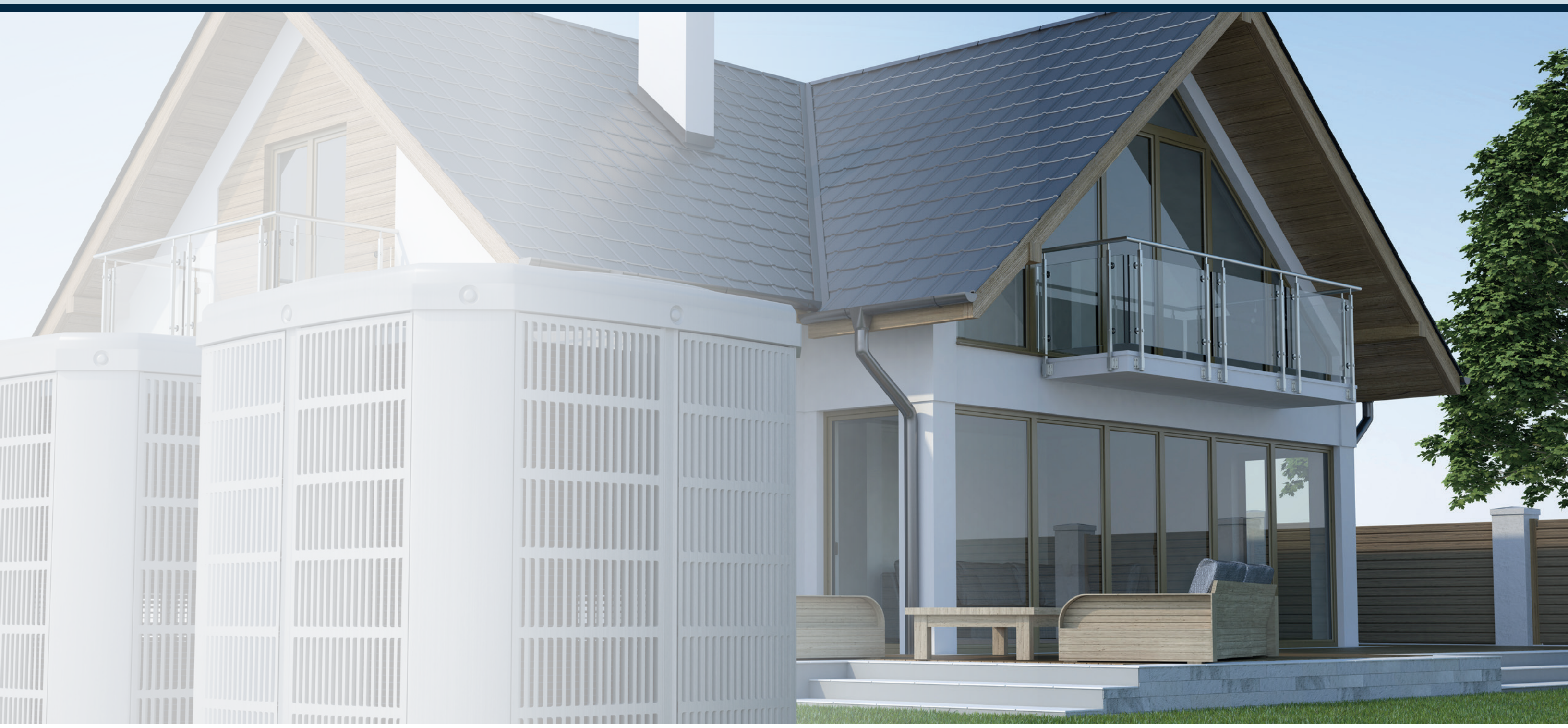

# HDMS High dynamic motor starter

## New soft starter technology eliminates start capacitors in single phase motor applications

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## INTRODUCTION

Capacitor failures are the achilles heel of traditional starters for single-phase compressors and pump applications. Both the start and run capacitor are susceptible to failure from various factors that include: voltage transients, mechanical vibration, thermal stress and motor aging. The resultant capacitor failure results in a service call, or worse, the starter has to be replaced, that can result in prolonged downtime.

Single phase motors are widely used in residential applications within heat pumps, air-conditioners, wastewater and deep-well pumps. In both HVAC and wastewater applications, electrical panels are frequently located outdoors and hence subject to harsh environmental conditions.

It is a known fact that single phase networks are very susceptible to voltage sags and voltage interruptions. Voltage interruptions can be as short as 10 msec and may cause a sudden re-start of the motor resulting in high voltage transients on the capacitors.

Another challenge when starting motors is that of high starting current. Single phase motors require about 6 times the rated current during start. The high starting current can cause:

- Voltage disturbances that may affect sensitive information technology (IT) equipment
- Voltage sags resulting in dimming of lights
- Over-sizing of back-up generators and DC-AC inverters within off-grid installations

Conventional starting devices for single phase motors do not address the main problem faced by machine builders and maintenance personnel. Hard start kits as much as existing soft starters still need one or more start capacitors to generate the required torque to start high torque single phase loads.

This document discusses the value of a new generation of soft starters that:

- Eliminates the need of start capacitors in capacitor-start (PSC and CSCR) motor applications
- Increases long term reliability of the equipment
- Rreduces starting current up to 70%

We have named them High Dynamic Motor Starters (HDMS), see below how their design is making a difference in these common applications.

## AN OVERVIEW OF SINGLE-PHASE MOTORS INTRODUCTION

The most commonly used single phase motors on the market are split-phase (SP), capacitor-start (CSIR), capacitor-start capacitor-run (CSCR) and permanent split-capacitor (PSC) type. The name of the motor is derived from the method used to make the motor self-starting.

Single phase motors are made up of two separate windings. The first winding is known as the main winding (also referred to as run winding) and it carries the largest part of the operational current of the motor at full load. The second winding is the auxiliary winding (also referred to as start winding).

In the case of SP, CSIR and CSCR motors, the auxiliary winding carries a higher portion of the total current during the motor start-up phase to generate sufficient starting torque. In the split-phase (SP), capacitor start (CSIR) motors, the auxiliary winding is removed from the circuit via a centrifugal switch or a potential relay when the motor reaches approximately 75% of its synchronous speed to avoid excessive power loss in the auxiliary winding at full load.

## PROPERTIES OF PSC AND CSCR MOTORS

Two commonly used motors in single phase applications are the PSC and CSCR type. The main difference between the two motor types is shown in Figure 1 and Figure 2.

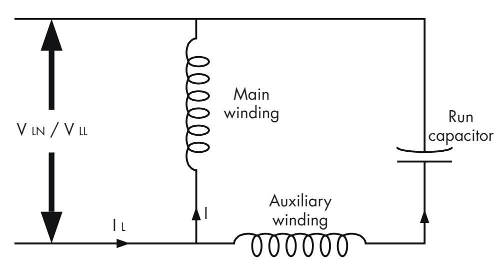



Figure 1: Schematic representation of a PSC motor

In a PSC motor, the run capacitor is used both during starting and running of the motor as shown in Figure 1. PSC motors are widely used in centrifugal pumps, fans as well as in modern heating and air-conditioning compressors.

Compared to CSCR motors, PSC motors obtain a lower starting torque making them unsuitable for high starting torque applications.

In CSCR motors, there are two additional components – the start capacitor and the potential relay - to overcome the limitations of PSC motors during the start-up phase – see Figure 2.
The start capacitor provides additional starting torque to the motor during the start-up phase. Due to its construction, the start capacitor must be removed from the circuit within 1 second to prevent any damage. This function is performed by the potential relay that senses the motor rotation through the pick-up of voltage in the auxiliary winding and opens its contacts to disconnect the start capacitor. After the start-up phase, the CSCR motor operates just like a PSC motor.

CSCR motors are commonly used in scroll compressors, deep-well and submersible pumps where a high starting torque and larger motors are used.

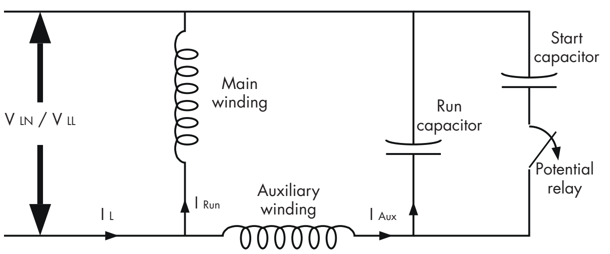



Figure 2: Schematic representation of a CSCR motor

# MOTOR STARTING METHODS

## DIRECT ON LINE STARTER

Direct on line starting is the most common method for starting both 1-phase and 3-phase motors especially in the lower power ranges (up to 5.5 kW/5 HP). With Direct on Line (DOL) starters, , the full voltage is applied across the motor windings, therefore, providing a high accelerating torque and fast acceleration times.

Figure 3: DOL starter

Figure 4: Hard start kit

## HARD-START KITS

A hard start kit generally consists of a start capacitor and a potential relay. By means of the additional torque provided by the start capacitor, the hard start kit accelerates the motor faster. Once the motor is up to speed and builds up enough voltage, the potential relay disengages the start capacitor from the circuit. Hard start kits do not reduce motor starting current but rather start the motor in a shorter time compared to DOL starters. This is accomplished through the additional accelerating torque (and higher current) provided by the start capacitor in the auxiliary winding.

Hard start kits are generally useful in installations with:

- Long wiring (therefore subject to voltage drops)
- Compressors starting with unbalanced pressures
- 208 V single phase applications

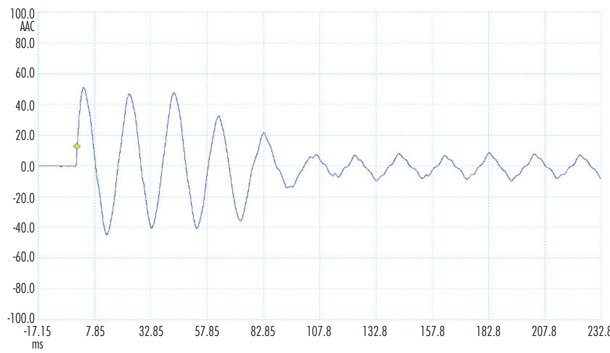



Figure 5: Starting current waveform for a 1.5HP rotary (CSCR) compressor

Starting the compressor via a DOL starter or hard start kit results in a starting current of 4 to 6 times the nominal compressor current.

Figure 5 shows the starting profile for a 1.5 HP, 9AAC @ 230 VAC single phase rotary compressor with a hard start kit provided by the compressor manufacturer. The peak starting current measured was 52Apk.

The compressor starts in about 5 mains cycles (~100 msec) after which the current drops indicating that the compressor reahed its nominal speed of operation.

## ISSUES WITH HIGH STARTING CURRENT FROM DOL AND HARD START KITS

Single phase networks are more sensitive to high current transients such as those associated with starting of inductive loads such as motors. Moreover, in certain countries there are restrictions from the utility regarding the maximum level of starting current allowed on single phase networks.

Another common phenomenon associated with high starting currents on single phase networks is that of light flickering. Light flickering is the result of severe voltage sags that can be generated due to the high

starting current generated when starting motors.
High starting currents can also cause nuisance fuse trips and/or require over-sized fuses and thicker cables

High starting currents reduce lifetime of motors due to the additional heat generated in the windings and higher mechanical stresses.

## SOFT STARTERS

Soft starters are electronic devices that use power semiconductors, typically Silicon-Controlled Rectifiers (SCRs) to reduce the voltage applied to the motor windings during start. The reduced voltage allows the motor to start with a lower current and a longer starting time as shown in figure 7.

The reduced voltage also results in a lower starting torque and therefore, for CSCR and CSIR motors, soft starters still require a start capacitor to generate enough starting torque. Just like in a hard start kit, the start capacitor (typically between 100 μF and 240 μF) creates a lower impedance path in the auxiliary winding thereby allowing more current to flow through the winding during the motor start-up phase. An internal electromechanical relay will then automatically disengage the start capacitor. Once the compressor is up to speed, the internal bypass relay is engaged to reduce heat dissipation within the electrical panel.

The range of Carlo Gavazzi soft starters, such as RSBS compressor soft starter also come with built-in diagnostic functions to protect the compressor in case of abnormal conditions such as under-voltage, short cycling and locked rotor conditions.

Figure 6: RSBS soft starter

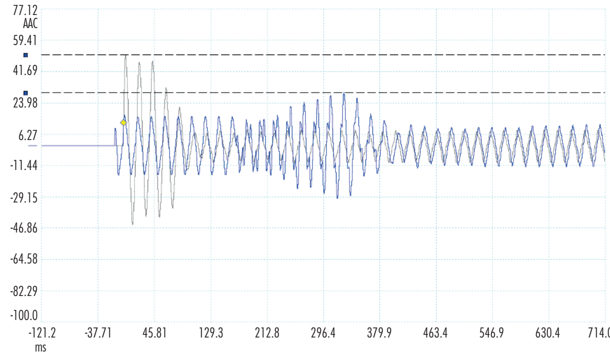



Figure 7: Starting current waveform for soft starter and hard start kit

Figure 7 shows the starting profiles for the 1.5 HP rotary compressor when started via an RSBS soft starter (blue curve) with respect to the start with the hard start kit (grey curve). The maximum starting current with the soft starter was 30 Apk. With the hard start kit, the starting current was 52 Apk under the same operating conditions. As expected, the soft starter is able to reduce the peak starting current by 43 % with respect to the hard start kit.
Due to the lower torque during the start-up phase, the motor takes a longer time (400 msec) to reach full speed

## BENEFITS OF RSBS SOFT STARTERS

- Reduce motor starting current
- Less disturbance to sensitive equipment
- Conforms to utility requirements (< 45 AAC starting current)

- Lower starting current eliminates light flickering
- Up to 50 % current reduction vs DOL and hard-start kits

- No need to over-size fuses and cables
- Reduce nuisance trips of protection devices

- Lower starting current reduces heat build-up in motor windings resulting in longer compressor lifetime
- Reduce mechanical vibrations during start
- Built-in protection functions safeguard the compressor under abnormal operating conditions

## SOLVING START CAPACITOR FAILURES WITH THE HIGH DYNAMIC MOTOR STARTER (HDMS)

As previously stated, the inherent weakness within single-phase motor starters remains the longevity of start capacitors. Outdoor installations such as heat pumps, air-conditioning units as well as waste-water control panels are subject to severe environmental temperature fluctuations.

Long transmission lines coupled with the inherent voltage sags associated with single phase networks create voltage instabilities. These are all associated with shortening the lifetime of start capacitors due to delayed disengagement of the capacitor from the circuit. Unlike run capacitors that are designed for continuous duty, start capacitors do not have the ability to dissipate as much heat and need to be taken out of the circuit in < 1 second to avoid capacitor failure. When a start capacitor fails (typically open), the motor does not get sufficient current flowing in the auxiliary winding and will not start.

To overcome this well-known weakness is not that trivial since applications such as single-phase scroll compressors and submersible pumps require significant starting torque. The conventional approach to providing the needed torque is by incorporating one or more start capacitors which are wired in series with the auxiliary winding

The HDMS, designed by Carlo Gavazzi R&D engineers, is an innovative single-phase motor starter designed with cutting-edge technology with the power section controlled by Insulated-Gate Bipolar Transistors (IGBTs). IGBTs are typically used in Variable Frequency Drives (VFDs) because of their high switching frequency and current handling properties.

Through a novel control methodology (patented), the HDMS generates sufficient torque to start single phase CSCR compressors and pumps without requiring a start capacitor.

The current on the mains supply is significantly lower than what is normally observed with soft starters. In fact, HDMS reduces the compressor starting current by up to 70% when compared to a DOL starter or hard-start kit making it an ideal solution in applications that are installed off-grid or supplied via back-up generators or DC/AC inverters.

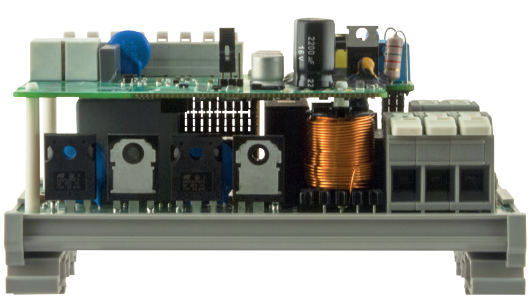


Figure 8: HDMS dynamic motor starter

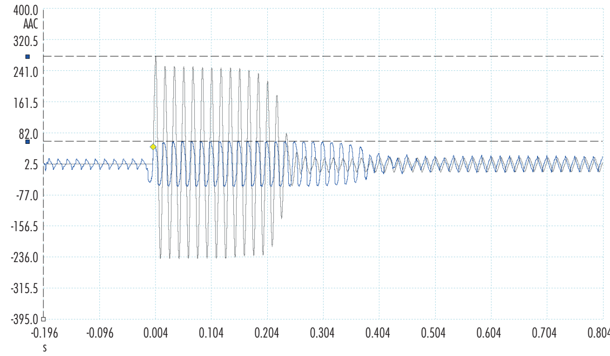



Figure 9: Starting current waveform for HDMS and DOL starter on a 5-ton scroll compressor

Figure 9 shows the results obtained on a scroll compressor with an LRA of 152 AAC. The DOL start peaked at 278.2 Apk (grey curve) whereas with HDMS the maximum current was 60.3 Apk (blue curve). The current reduction in this case was almost 80%.

## BENEFITS OF RSBS SOFT STARTERS

A further challenge when starting motor loads is that of varying torque during start. Compressors as well as pumps starting conditions are constantly changing. In the case of compressors, the pressure fluctuations are due to the shorter starting cycles, lower leakage through expansion valves as well as compressor ageing. As a consequence, motor starters need to adjust their start parameters to optimize motor starts accordingly.

Hard start kits as much as existing single-phase soft starters available on the market do not have such capabilities. On the other hand, the HDMS algorithm is based on a self-learning approach. At every motor start, the HDMS adjusts its starting parameters based on a control feedback that measures the motor starting time as well as the level of starting current. This data is then used to determine the parameters to adopt for the subsequent start.

This results in optimal motor starts even in low voltage conditions and ageing compressors.

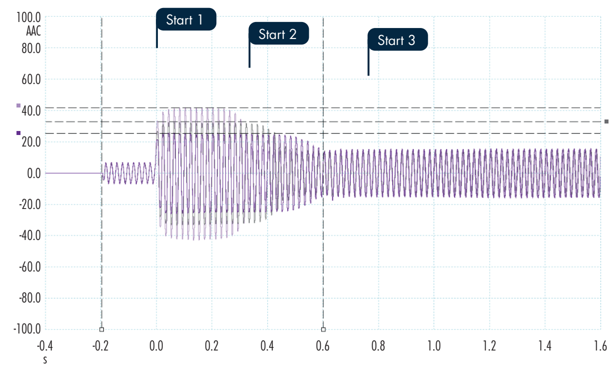



Figure 10: Self-learning algorithm performance on 3 different compressor starts

| Start number | Max. start current (Apk) | Starting time (msec) |
|---|---|---|
| 1 | 41.7 | 363 |
| 2 | 32.7 | 477 |
| 3 | 25.2 | 618 |

The waveforms in Figure 10 show the starting current and starting time for a scroll compressor controlled by HDMS.

The successive starts resulted in a continuous start current reduction whereby the maximum current measured during start 1 was reduced by a further 40% automatically by the HDMS – as shown in the above table.

## HDMS ADDITIONAL FEATURES

| Feature | Description | Benefit |
|---|---|---|
| Temperature ratings | • Current ratings for HDMS are specified at 65°C (149°F) | • No over-rating is required even in harsh installation conditions |
| Serial communication | • Modbus RTU port for real-time data communication with PLC<br>• Data includes main energy variables, starts performed, HDMS status | • Real-time diagnostics can be used to check proper motor operation<br>• Energy variables can be used to calculate compressor efficiency in real time |
| NFC antenna | • Internal memory of HDMS can be downloaded to a smartphone when device is not powered up<br>• Data format in .csv | • Quicker troubleshooting<br>• No need to remove any wiring |
| Push-in terminals | • The terminals on the HDMS do not require any tools | • Labour-time savings |
| Internal datalog | • Storage of the first 8 starts and the last 24 starts performed<br>• Last 149 alarm events are stored in memory<br>• Counters for running hours, kWh, starts performed by the HDMS | • Information within the datalog file included as a further check to verify correct installation<br>• Alarm events and starts log can help in faster diagnosis of problems and/or abnormal behaviour |
| Internal diagnostics | • Motor overload protection (Class 10)<br>• Under- and over-voltage detection<br>• Locked rotor detection<br>• Over-temperature protection<br>• Programmable anti-short cycling delays<br>• Automatic recovery from alarm condition | • Complete protection for the motor<br>• Extended motor lifetime<br>• Less service calls |

## HDMS BENEFITS

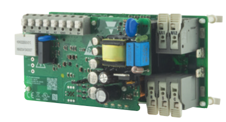
- Lower peak demand with best-in class current reduction
- Immune to unstable voltage conditions since start capacitor is not required

- Suitable for power-limited applications such as back-up generators and DC/AC inverter driven loads

- Up to 70% current reduction vs DOL
- Superior current reduction vs traditional soft starters
- No light flicker

- Extends motor lifetime
- Protects motor during abnormal conditions

## COMPARING THE DIFFERENT STARTING METHODS

| Starting methods for single phase motors | DOL starters | Hard-start kits | Soft starters (RSBS) | High Dynamic Motor Starter (HDMS) |
|---|---|---|---|---|
| |  |  |  |  |
| Starting current vs motor rated current (Ir) | Up to 6 * Ir | Up to 6 * Ir | Up to 3 * Ir | Up to 2 * Ir |
| Typical current reduction vs DOL | - | 0 % | Up to 50% | Up to 70% |
| Start capacitor required | Yes (when used with CSIR, CSCR motors) | Yes | Yes | No |
| Disturbance to voltage network | High | Moderately high | Low | No |
| Operation at high temperature | Yes | Not recommended due to start capacitor | Limited by the temperature of the start capacitor. Anti-short cycling function protects start capacitor against high number of starts | Yes |
| Operation on unstable supply network | Yes | Can result in higher failure rate due to late disengagement of start capacitor | Can result in compressor stoppages due to insufficient starting torque | Yes |

# CONCLUSION

Starting single phase motors presents various challenges partly because they are not self-starting but also due to the inherent weakness of the single-phase voltage network. Moreover, the high starting current during motor start may also cause disturbances on the voltage network and higher energy bills.
Capacitors used with single phase motors are the major causes of failure within HVAC and wastewater applications.
The novel control methodology available on the HDMS dynamic motor starter eliminates the start capacitor on PSC and CSCR motor. This solution helps machine builders, installers as much as homeowners to:

- **REDUCE MAINTENANCE COSTS**: By eliminating the start capacitor, the HDMS eliminates the weakest component from the circuit. Additionally, the lower current in the auxiliary winding reduces heat dissipation in the windings thereby extending motor lifetime.

- **AVOID PROBLEMS ON WEAK VOLTAGE NETWORKS**: HDMS can reduce starting current of PSC and CSCR motors by 70%. This lower starting current helps you avoid flickering of lights, tripping of fuses and, since no start capacitor is required, the HDMS can also be used in installations with limited power availability and/or installations with unstable voltage.

- **EXTEND MOTOR LIFETIME**: The self-learning algorithm on the HDMS continuously adjusts the start parameters to optimize motor starts even when the motor ages and load conditions change. The diagnostic functions built-in HDMS provide additional protection for your motors in case of abnormal operating conditions.

- **SAVE ON ELECTRICITY BILLS:** Using HDMS on applications powered by back-up generators or DC/AC inverters eliminates the need for over-sizing. Reducing the size of a back-up generator reduces both initial and running costs resulting in significant energy savings.

- **DIAGNOSE FAULTS FASTER**: Real-time data and internal datalogging can be used to identify potential issues within the application quickly. The HDMS can also interface directly to the machine PLC through the serial port. The data available through the HDMS can be used to identify faults but also to verify the correct running conditions of the motor.

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