# DC Motor control Reversing



## *DC motors*

Electrical Motors are actuators that convert electrical energy into mechanical energy in the form of a continuous angular rotation that can be used to rotate pumps, fans, compressors, wheels, etc. There are basically two types of conventional electrical motor available: AC and DC Motors. AC Motors are generally used in high power single or multi-phase industrial applications where a constant rotational torque and speed is required to control large loads. In this article we will look only at simple DC Motors, which are used in many consumer and industrial applications.
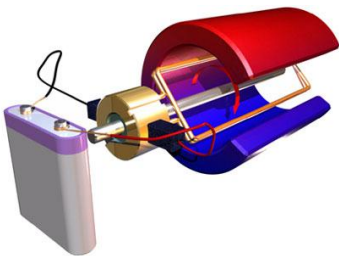


The **DC Motor** is the most commonly used actuator for producing continuous movement whose speed of rotation can easily be controlled, making them ideal for use in applications where speed control, servo type control, and/or positioning is required. A DC motor consists of two parts, a "Stator" which is the stationary part

and a "Rotor" which is the rotating part. Basically there are three types of DC Motor available:

- Brushed Motor
- Brushless Motor
- Stepper Motor

In this newsletter we will speak only about the control of **Brushed Motors**. This type of DC motor produces a magnetic field in a wound rotor (the part that rotates) by passing an electrical current through a commutator and carbon brush assembly, hence the term "Brushed". The stators (the stationary part) magnetic field is produced by using either a wound stator field winding or by permanent magnets. Generally, brushed DC motors are least costly, small, and easily controlled, without the complication of a dedicated electronic board for the control.

## *On-Off control*

A DC motor can be controlled in various ways, the simplest being the ON-OFF switch, which allows control of the motor only at the maximum speed of rotation in one direction (switch ON) or stop (switch OFF). This control can be implemented with a switch (an electromechanical switch, a MOSFET or a BJT transistor) and a free-wheel diode (necessary to avoid "Back EMF" damage to the rest of the circuit, as the DC motor is an inductive load).
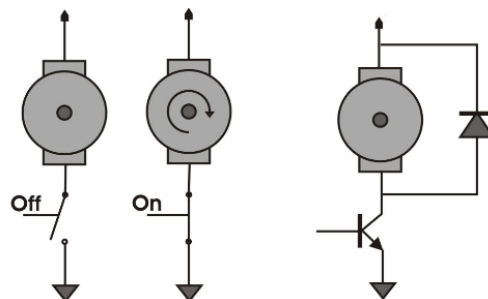
Concerning an SSR solution for this kind of control, the connection is exactly the same. In fact the DC SSR outputs are designed with FET's or BJT's allowing the connection of the DC SSR on either side of the load, as shown in the following pictures:
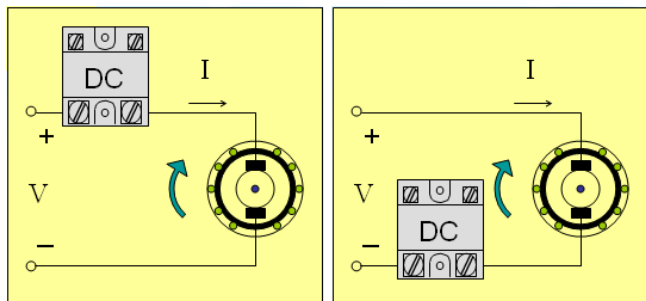


This type of control allows speed control of the motor using PWM techniques, but does not have the ability to run the motor in both directions.
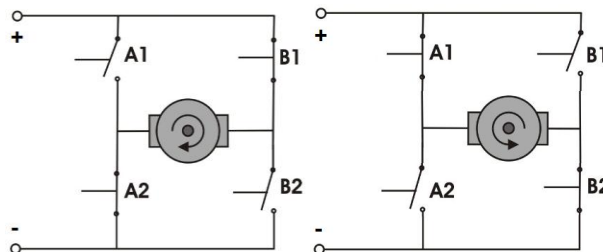
## *H-Bridge*

To run the motor in the opposite direction, it is necessary to reverse the polarity of the current flowing in the motor using a circuit called an H-bridge. It consists of four controlled switches connected as shown in the picture below:
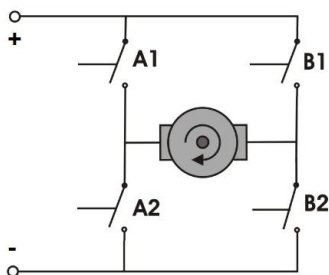


The key fact to note is that there are four switching elements within the bridge. These four elements are often called, high side left, high side right, low side right, and low side left (in clockwise order). Activating switches A2 and B1 provide current flow through the motor in one direction, while activating switches A1 and B2 provide current flow in the opposite direction.



The configuration with both A or B transistors turned on must be avoided. The short circuit current on one side of the bridge could create serious damage to the bridge itself or to the supply circuit.

The following truth table shows for each of the switch's states, what the bridge will do. There are 16 possible states:

| A1 | A2 | B1 | B2 | Quadrant description |
|----|----|----|----|----------------------|
| OFF | OFF | OFF | OFF | Motor off |
| OFF | OFF | OFF | ON | Motor off |
| OFF | OFF | ON | OFF | Motor off |
| OFF | OFF | ON | ON | Short circuit condition |
| OFF | ON | OFF | OFF | Motor off |
| OFF | ON | OFF | ON | Motor "brakes" and decelerates |
| OFF | ON | ON | OFF | Motor goes Counter-clockwise |
| OFF | ON | ON | ON | Short circuit condition |
| ON | OFF | OFF | OFF | Motor off |
| ON | OFF | OFF | ON | Motor goes Clockwise |
| ON | OFF | ON | OFF | Motor "brakes" and decelerates |
| ON | OFF | ON | ON | Short circuit condition |
| ON | ON | OFF | OFF | Short circuit condition |
| ON | ON | OFF | ON | Short circuit condition |
| ON | ON | ON | OFF | Short circuit condition |
| ON | ON | ON | ON | Short circuit condition |

Since any state that turns both switches on one side on is "bad" (red lines), there are in fact only four useful states (blue and green lines) where the transistors are turned on. Of course there is also the state where all the transistors are turned off or only one is on (black lines), where the

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motor coasts if it was spinning, and does nothing if it was at rest.

### *Dynamic brake function*

The two blue rows of the table describe a technique where the motor is deliberately "short circuited" after removing power by closing either the lower 2 or upper 2 switches as shown below, which uses the motor's generator effect to work against itself.
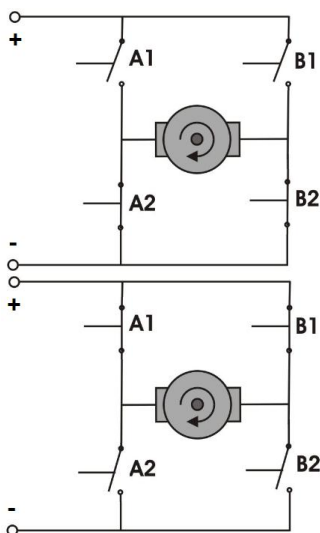


Generating into essentially a "short circuit" causes the motor to stop spinning rapidly and is called "**dynamic braking**".

### *PWM function*

If speed control of a DC motor if desired, in addition to on/off and reversing, the DC voltage source can be varied (which can be difficult and expensive), or it can be accomplished through the use of **Pulse width modulation** (PWM) if using solid state "switches" or SSR's.
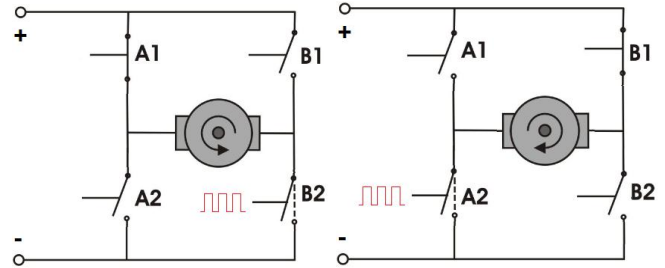


This means basically to send a square wave at a certain frequency to control the switch (as shown in the previous pictures, on A2 when B1 is closed, on B2 when A1 is closed). The controller is essentially opening and closing the switch at very high rates (from 200Hz up to 20kHz). Through inductance the motor is neither fully on or fully off, but somewhere in between at a slower speed. Note that motor torque, under PWM, remains the same whether fully on or only a percentage on. Varying voltage for speed control reduces torque, usually an undesired effect.
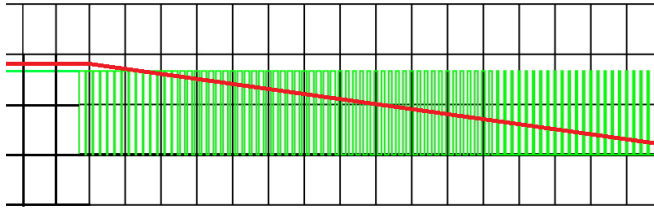
### *Soft start/stop function*

This is a modified start where the DC power supply is applied to the load using a PWM with a duty cycle going from 0% to 100%.
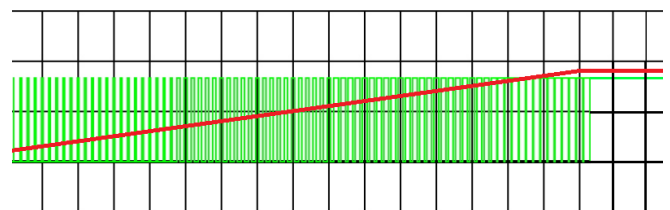


In the graph, the green line is the control voltage of the switch, the red line is the average voltage on the motor.
Soft Start/Ramp Up time is the duration of this PWM ramp, used to avoid initial inrush current and abrupt motor movement.
The same applies for the soft stop function. During the "ramp" time, the PWM goes from 100% to 0% producing a soft stop, without mechanical jolts.

## 4 SSRs H-Bridge solution

For an SSR solution of this kind of control, 4 DC SSR's can be connected in the same way as the switches previously depicted. (See picture below)
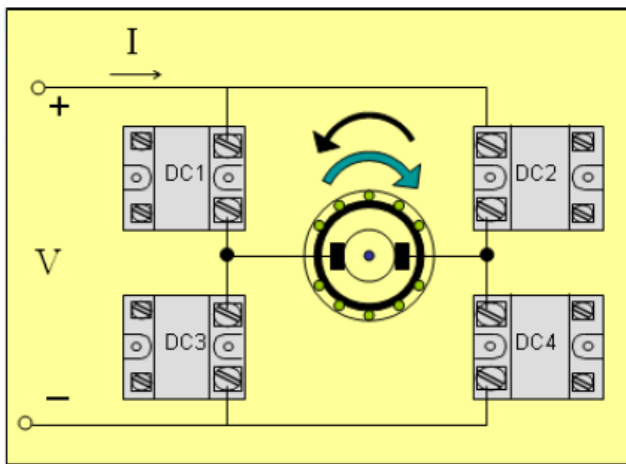


Concerning PWM control with SSR's (for speed control and soft start/stop function), there is a limit in the PWM frequency, due to the turn-on and turn-off time of the SSR used, along with other factors including the characteristics of the power MOSFET's within the SSR.

Crydom's "PowerPlus" series of DC SSR's specifically includes a PWM table within the datasheet to determine the allowable PWM frequency for each SSR type under various loads.

## All-in one package SSRs H-Bridge solutions

Beside offering single DC output SSR's that can be configured into an H-Bridge, Crydom now offers complete DC H-Bridge products in the DRA and DP Series described below. These provide easy to use, simple solutions. The integrated logic control along with interlocking provide added benefit by reducing overall system design effort.

### DRA Series



The **DRA Series** DC Motor Reversing Contactors use Crydom's advanced SSR DC switching technology to provide an integrated "H-Bridge" type DC switching contactor for DC motor reversing applications. Featuring FET outputs UL rated for ¼ horse power at 90 or 180 VDC and 6 A @ 180V and 12A @ 90V resistive ratings, all SSC 2500 Vac optical isolation, logic compatible DC input control with status indicator and interlock, the DRA Series provides a simple and easy to use control solution for DC motor reversing.
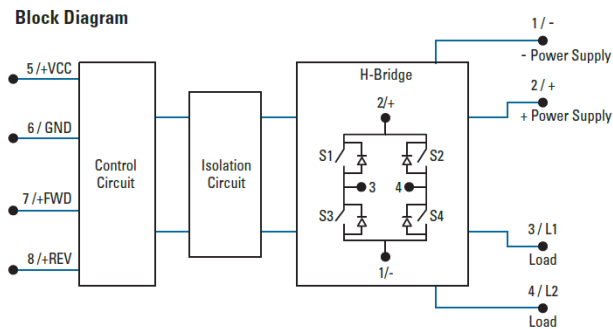
### DP Series



The **DP Series** of DC Load Reversing SSC, (Solid State Contactors), include four optically isolated DC low dissipation FET outputs rated up to 60A at 48Vdc, wired in an H-Bridge configuration with a common input control to provide a convenient

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method to both power on and off and reverse the polarity to a variety of DC loads including motors, brakes, clutches, electro magnets, solenoids, plating baths and electrolytic cells.

**Block Diagram**



The DP Series is housed in a compact encapsulated industry standard 75 x 105 mm panel mount package featuring screw termination for power and load connections and a 4 conductor connector for control connections.

In addition to the on/off and reversing functions, DP Series Contactors include an internal interlock circuit to prevent damage due to overlapping forward/reverse control commands .

The DP Series also offers options for a variety of combinations:

- PWM Soft Start/Ramp Up
- PWM Soft Stop/Ramp Down
- Dynamic Brake functions.

Available with a selection of set ramp times, the soft start and stop functions provide a convenient means to eliminate or reduce the mechanical shocks associated with starting and stopping DC electro-mechanical loads.
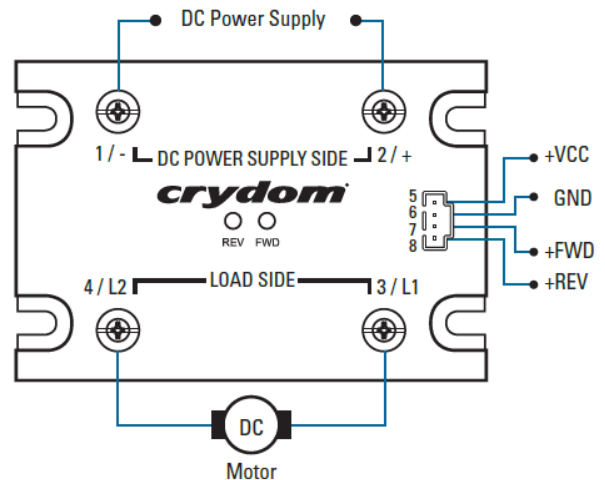


The operating modes of the DP family are:

**Start:** When either FWD or REV Control signal is applied, and after Control Signal Validation Delay, DC power supply on terminals 1/- and 2/+ is directly connected to Load at terminals 3/L1 and 4/L2 with a polarity according to the control signal.

**Stop:** Load is disconnected from DC power supply. All FET switches (S1, S2, S3 & S4) inside the DP Series SSC are turned off.

**Soft Start/Ramp Up:** It is a modified Start where the DC power supply is connected to the load using a 200 Hz pulse width modulation with a duty cycle going from 10% to 100%. After Soft Start/Ramp Up time is elapsed, the Load will remain continuously energized for as long as FWD or REV Control signal is applied.

**Soft Stop/Ramp Down:** It is a modified Stop where the DC power supply is disconnected from the Load using a 200 Hz pulse width modulation with a duty cycle going from 100% to 0%. After Soft Stop/Ramp Down time is elapsed, the Load will remain continuously de-energized waiting for a new FWD or REV Control signal.

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**Dynamic Brake:** It could be used as a modified Stop where the FET switches inside the DP Series SSC are arranged in such a way that they provide a path for the Load Current to keep flowing after the DC power supply has been disconnected. This mode allows for energy stored in some type of loads to be discharged. i.e. back EMF on DC motors.

**Interlock:** It will shut down all FET switches inside the DP Series SSC within 0.2 sec after both control signals FWD and REV are applied at the same time. An Interlock condition will trigger a modified Stop such as Soft Stop/Ramp Down or Dynamic Brake if an option has been included.

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