

Switched Reluctance Motor (SRM) Inverter Design With the DRV8343-Q1

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ABSTRACT

Switched Reluctance Motors (SRM) are seeing a resurgence as motor manufacturers improve their performance, reliability, efficiency, and cost as compared to other motors types. These motors, sometimes called variable-reluctance motors can be considered as a class of brushless stepper motors. SRMs always require electronic commutation which makes the design of the inverter a key factor in optimizing their use. This article discusses basic SRM operation, electronic commutation requirements, and how the DRV8343-Q1 gate driver unit can enable more efficient and robust SRM inverter designs.

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1 SRM Construction and Operation

The switched reluctance motor is a *double salient-pole* motor, which means that the magnetic field projects outwards from the stator and the rotor. The rotor in an SRM does not contain permanent magnets or windings while the stator is wound to produce the poles across the diameter of the motor. The rotor for an SRM, unlike a traditional permanent magnet motor is constructed from a stack of ferroelectric material like laminated iron sheets. This is also known as an armature. [Figure 1](#) shows the construction of an SRM along with the flux lines.

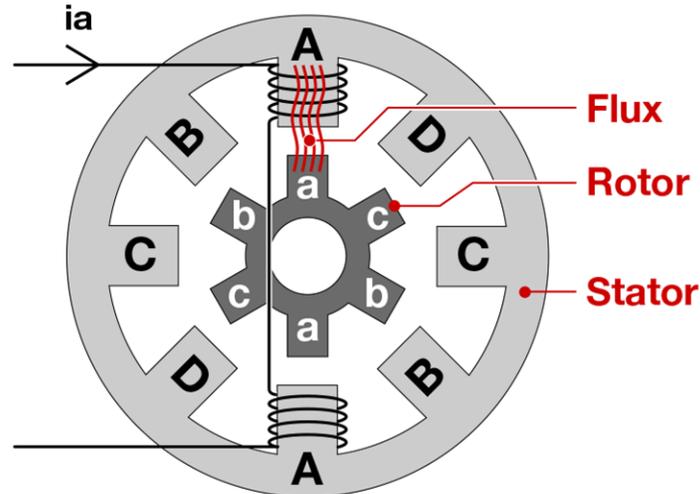


Figure 1. SRM Construction and Flux Lines

This unique yet simple construction and the lack of magnets give SRMs a significant cost benefit as compared to rare-earth based permanent magnet motors. Furthermore, the lack of magnets allows for a lighter and more robust rotor which makes them well suited for use in hostile corrosive environments or extreme temperatures. SRMs also have the benefit of being immune from single point failures in their winding allowing limp home or degraded operation in automotive applications. Advances in control methods have also enabled SRMs to operate across a wider range of speeds (0 rpm to > 10,000 rpm in some designs) with high starting and accelerating torque. These properties have started to make adoption of SRMs very attractive in automotive pumps, transmission actuators, and traction motors. SRM motors; however, are more sensitive to mechanical construction and small variations in the air gap between the stator and the rotor can result in poor vibration and acoustic performance.

The fundamental operating principle of an SRM is based on the higher magnetic permeability (or low reluctance) of ferroelectric materials and the resulting electromagnetism. When the stator is electrically excited, the magnetic flux generated is always maximized over the smallest reluctance path, which happens through the ferroelectric material in the rotor pole. This results in magnetization of the rotor pole which rotates to come in alignment with the excited stator phase. This causes a further reduction in the reluctance due to the reduction of the air gap and further maximization of the flux. This is the main motoring mode and it occurs at the positive slope of the stator coil inductance profile. The rotor poles and stator poles are exactly aligned at this point and the motor will stay in this aligned position if not sequentially excited. To continue motor operation, the current is switched from one stator phase to the next synchronously with the position of the rotor. The direction of rotation of the SRM is independent of the direction of the current flow in the coils or of the resulting subsequent magnetization pole. The direction is simply dependent on the sequence of stator excitation. Sequential clockwise rotation of the stator field will result in counterclockwise rotation of the rotor.

This operation is what clearly distinguishes an SRM from a stepper motor or a brushless DC motor. In an SRM, the field follows the rotor, while in a stepper motor or a brushless DC motor the rotor follows the field. SRMs can be built with multiple stator and rotor poles. SRM configurations commonly reference the ratio of the stator poles (y) to the number of rotor poles (x). Typically configurations are $x = y - 2$. A 6/8 SRM for example has 6 stator poles and eight rotor poles (4 pairs). The 6 stator poles make it a three-phase motor.

2 SRM Control Techniques

Sequential excitation of the stator of an SRM requires knowledge of the rotor position and hence a position sensor like a Hall sensor or an encoder is required. Before discussing the control strategy, the required motor operation parameters and commutation sequences must be analyzed.

To understand the interaction between the rotor and the stator, a parameter “L” is introduced, which is the flux linkage. Flux linkage is the flux through a certain surface, whereas flux describes the total amount of field lines. [Figure 2](#) shows the sequence of “L”, voltage (V), current (I) and torque (T) through the commutation of the SRM.

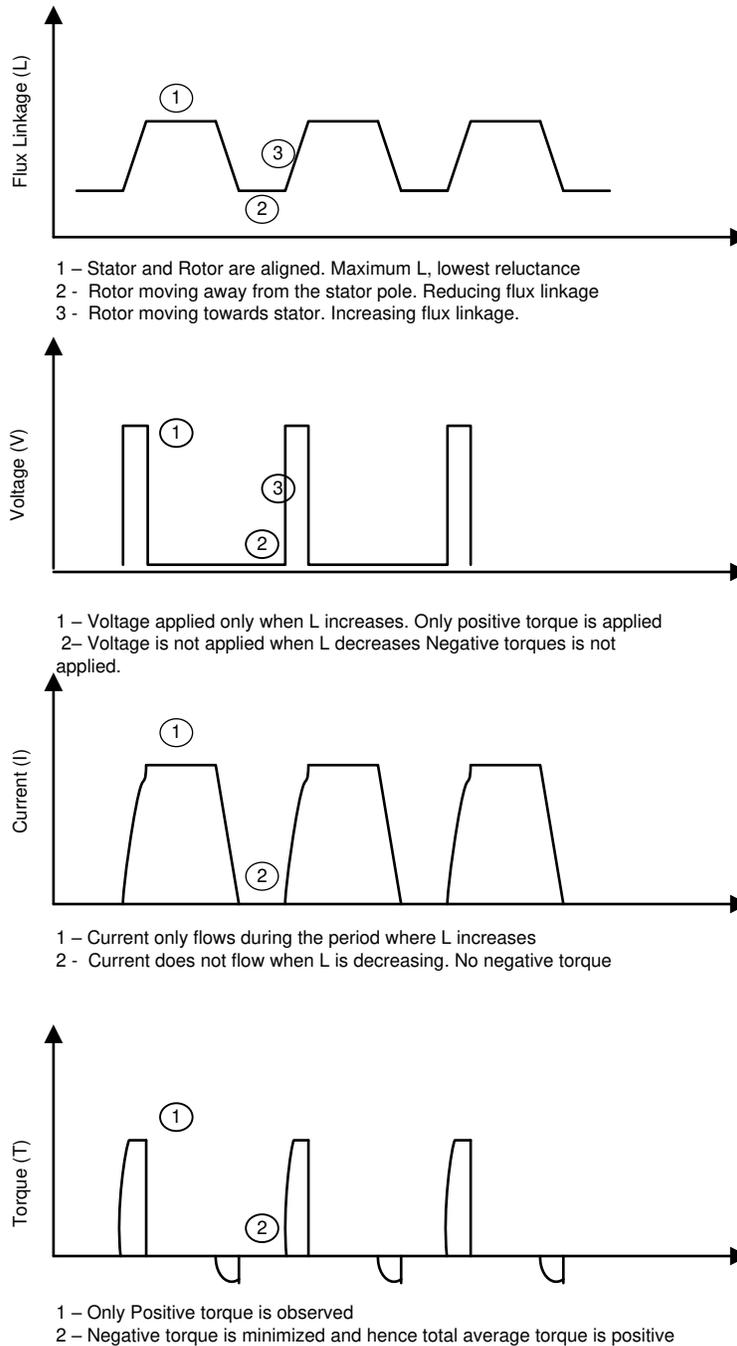


Figure 2. Sequence of “L”, Voltage (V), Current (I) and Torque (T) Through the Commutation of the SRM

Observe that the flux in the SRM is not constant and in order to establish it, each of the motor phases must be energized and de-energized independently at appropriate mechanical angles. The difference between these angles is known as the dwell angle. Hence, the average torque of the motor can be controlled by controlling the magnitude of the stator winding current or by adjusting the dwell angle. Control of the winding energy can be achieved by using drivers like the DRV8343-Q1 device in conjunction with a microcontroller as Figure 3 shows.

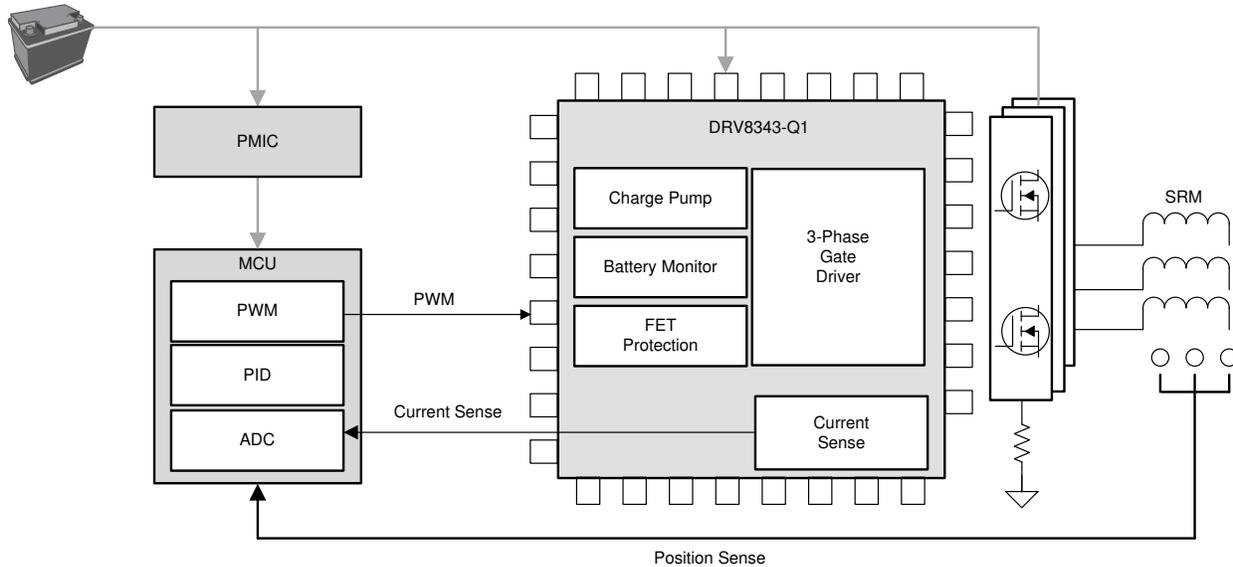


Figure 3. System for SRM Operation

3 SRM Inverter Configurations

The two most common inverter configurations for SRMs are the Asymmetric-bridge and the Miller inverter configuration which are shown and compared in Figure 4 and Figure 5 using the DRV8343-Q1 driver and MOSFETs. Note that the loads are connected between high side (HS) and low side (LS) FETs of the same phase, unlike DC and BLDC motors where the load is connected across the HS and LS FETs of two different phases. These configurations use MOSFETs for energizing current and fast diodes for de-energizing currents.

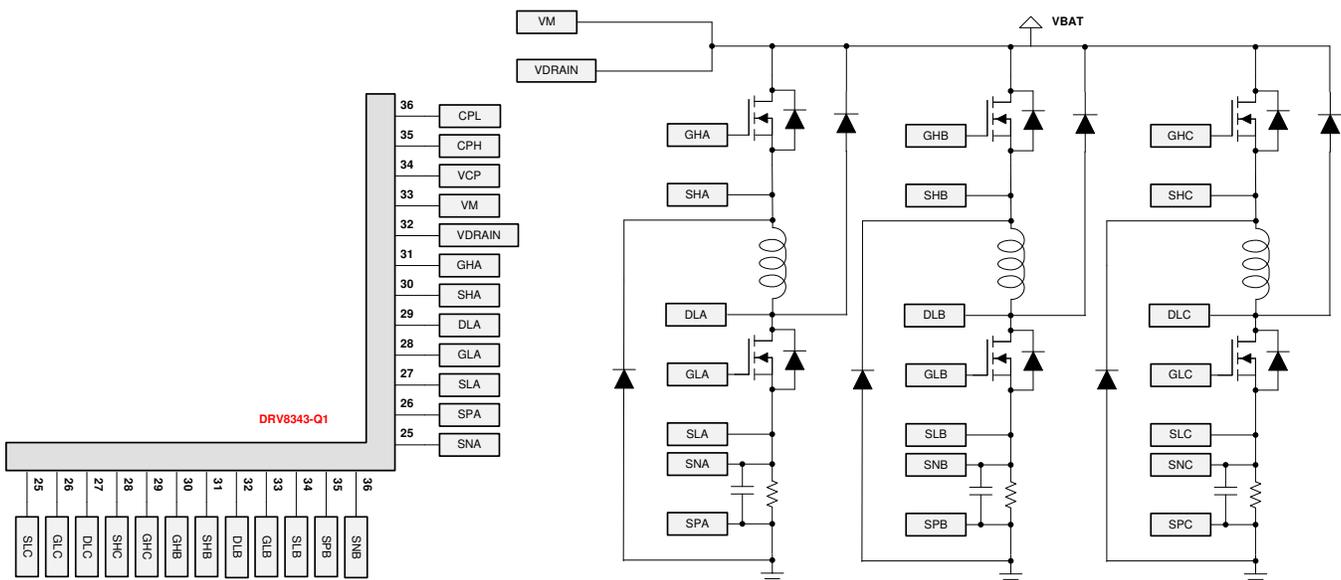


Figure 4. DRV8343-Q1 Inverter in Asymmetric Bridge Configuration

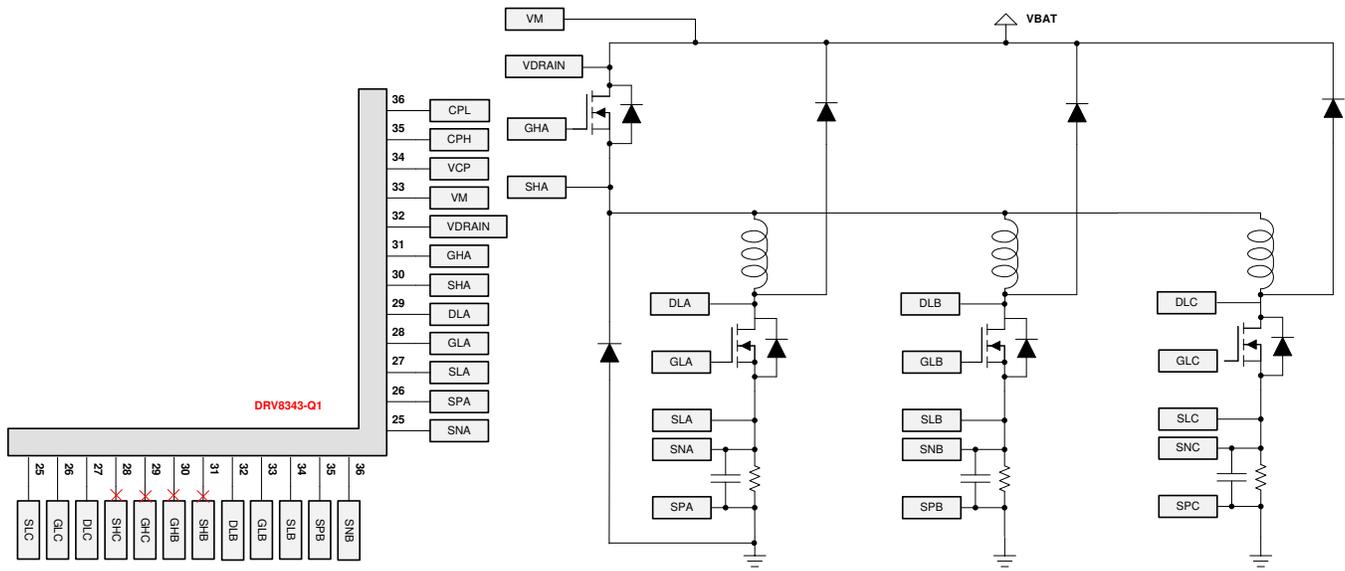


Figure 5. DRV8343-Q1 Inverter in Miller Configuration

Table 1 shows a comparison of the two topologies.

Table 1. Comparison of SRM Inverter Topologies

Asymmetric Bridge	Miller Inverter
Most common implementation	-
Synchronous and asynchronous half bridge operation is possible	-
Requires 6 switches and 6 diodes for a three-phase SRM	Requires only 4 switches and four diodes for a three-phase SRM
Phases can be energized independently allowing phase overlap and redundancy	Phases cannot be energized independently
Robust against shorts on a single phase since each phase is in series with two leg FETs	Less robust since the main driver FET can be a common failure point for all phases
Control somewhat limited through the entire range of operation	Control possible through the entire range of operation

4 SRM Modulation Techniques

SRMs can be controlled through PWM techniques using either a voltage chopping or current chopping scheme. This allows easier implementation of control schemes using microcontrollers with integrated feedback loops and PWM generators paired with MOSFETs and MOSFET gate drivers.

4.1 Voltage Chopping

In the voltage chopping technique, the supply voltage for the phase being energized is controlled by monitoring the current through the phase and then controlling the voltage of the phase by adjusting the PWM duty cycle. This technique allows control of the current as well as the rate of change of the current. A fixed frequency PWM is applied to both the HS and the LS FETs at the same time (asynchronous) or independently to the HS and the LS (synchronous). Asynchronous operation may result in a higher current ripple from the hard switching cycles. In synchronous operation, this effect is reduced since the LS FET is left on through the dwell angle and only the HS FET is switched.

The tradeoff between the two techniques is that synchronous operation requires independent control of each FET.

4.2 Control Chopping

In the current chopping technique, the supply voltage for the phase being energized is kept constant. The current through the phase is monitored and then controlled by varying the frequency of the PWM applied to the HS and LS FETs. Similar to the voltage chopping technique, this method can be implemented synchronously or asynchronously.

Table 2 summarizes the two control techniques.

Table 2. Comparison of SRM Control Techniques

Voltage Chopping	Current Chopping
Current controlled indirectly through voltage	Precise current control
Suitable for varying load applications	Suitable for constant load applications
Constant frequency allows adjustments for immunity against EMI and noise	Potential EMI or noise issues if the frequency variation is too high

5 Designing SRM Inverters With DRV8343-Q1

Some of the key requirements for the drivers used in SRM inverters include:

- Provide sufficient current or gate drive bias across the operating range
- Shift the level of the PWM input signals to the appropriate MOSFET driving voltages
- Independently drive multiple phases of the SRM
- Independent drive half bridges for asynchronous switching
- Independently control each FET of the half bridge for synchronous switching
- Switch at variable frequencies (current chopping technique)
- Energize more than one phase at the same time (increase torque)
- Operate only 2-phases in case of failure of the third phase
- Drive various FET sizes in Miller converters where the main power MOSFET is sized larger to control the total winding current

In addition to the driver, the control of SRMs also requires independent current sensing for each phase of the SRM.

Three-phase drivers with independent FET control and integrated current sensing like the DRV8343-Q1 device provide a compact, integrated and protected solution for SRM motors. Both voltage and current chopping PWM techniques can be implemented with this driver in either asymmetric or Miller configurations. The three integrated current sense amplifiers can be used for current control and feedback.

Some of the salient features of a DRV8343-Q1 based implementation include:

Independent control of each FET:

In the independent MOSFET drive mode (PWM_MODE = 111b or MODE Pin = 0.47 k Ω to DVDD) the INHx and INLx pins control the outputs, GHx and GLx, respectively. This control mode allows the DRV8343-Q1 device to drive the HS and LS FET for a phase independently. In this mode, turning on both the high-side and low-side MOSFETs at the same time in a given phase is possible. The dead time or cross-conduction protection, usually enforced in most half bridge or three-phase drivers is bypassed.

Independent FET monitoring:

SRM motor windings are connected in between the HS and LS FETs of each phase. The unique architecture of the DRV8343-Q1 device provides dedicated drain and source pins for each of the FETs being driven which allows accurate short-circuit monitoring of each FET through VDS monitors. The VDS faults are reported independently for each FET in the SPI registers: VDS_x. The DRV8343-Q1 also has the ability to continue operation in spite of a damaged phase which is one of the key benefits of SRMs, hence the DRV8343-Q1 can be configured to only disable the damaged MOSFET. This allows the system to stop operation of the affected MOSFET and operate the motor with the remaining MOSFETs.

The VDS trip levels can also be set independently for each FET using the registers VDS_LVL_xx. This feature is particularly useful in the Miller configuration, so that the VDS fault level of the main power MOSFET can be set independently from the phase FETs.

Independent slew-rate capability:

The DRV8343-Q1 device allows the user to set the slew rate of each of the FETs independently and dynamically. This again is useful for Miller inverter configuration, where the main power FET is usually chosen to have a much larger switching current than the phase FETs.

Charge pump topology:

The charge pump topology of the DRV8343-Q1 eliminates several of the challenges associated with bootstrap topologies, especially when current chopping techniques are employed.

In synchronous operation, the LS FET for a phase is left on through the dwell angle and only the HS FET is switched. Bootstrap topologies require that the LS FET be switched on every cycle to refresh the bootstrap capacitor which makes synchronous operation impossible. Since the charge pump topology does not require the LS FET to be switched on every cycle, it can be operated at 100% duty cycle with no restrictions. Additionally bootstrap topologies require a finite time to refresh the bootstrap capacitor during every cycle, this places several restrictions on the choice of switching frequencies since the bootstrap capacitor is usually sized to support a single frequency and refresh time.

Current sense:

The DRV8343-Q1 device integrates three current-sense amplifiers which can be used to measure the current in each of the SRM phases. The sense amplifiers are bidirectional and can be used to monitor both the energizing and the de-energizing currents.

6 Summary

The flexibility of the DRV8343-Q1 drive, sense, and protection architecture makes it an ideal choice for SRM inverters in both 12- and 24-V automotive applications. Product details including the [DRV834x PSPICE model](#) that can be used for development can be found in the [DRV8343-Q1 product folder](#).

7 References

- Texas Instruments, [DRV8343-Q1 12-V / 24-V Automotive Gate Driver Unit \(GDU\) with Independent Half Bridge Control and Three Integrated Current Sense Amplifiers Data Sheet](#)
- Texas Instruments, [DRV834x PSPICE Model](#)
- Texas Instruments, [DRV8343-Q1 Product Folder](#)

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