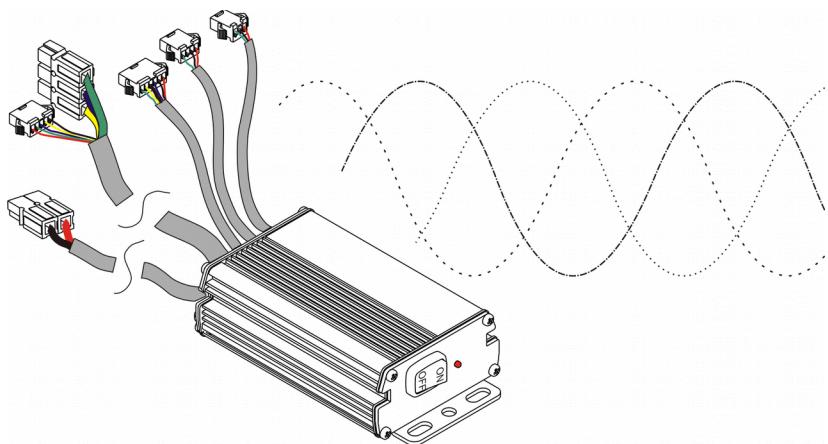




The SineWave Grinfineon Motor Controller

User Manual - Rev 2.2



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1 Introduction

The Grinfineon SineWave controller is based around the popular Xie Chang device with the XCKJ3232C control chip, but with custom firmware to allow both sensored and sensorless operation and proportional regenerative braking. The generous cable harness lengths and crimpable connector standards make it broadly useful in aftermarket and DIY ebike applications for just about any geared or direct-drive brushless motor in the 500-3000 watt power range.

1.1 Key Features

Here are some of the features that make this controller stand out which you won't usually find with most 3rd party ebike motor controllers

- Long phase leads (120cm)
- On/Off Switch
- Proportional Regenerative Braking
- Dual Mode, works With and Without Hall Sensors
- Silent Sine Wave Operation in Sensored Mode
- High Sensorless eRPM Compatible with Geared Motors
- Fwd/Rev Input
- LED Status Indicator
- Watertight Enclosure
- Direct Cycle Analyst Plug
- User Crimpable Connectors (JST-SM and Anderson Powerpoles)

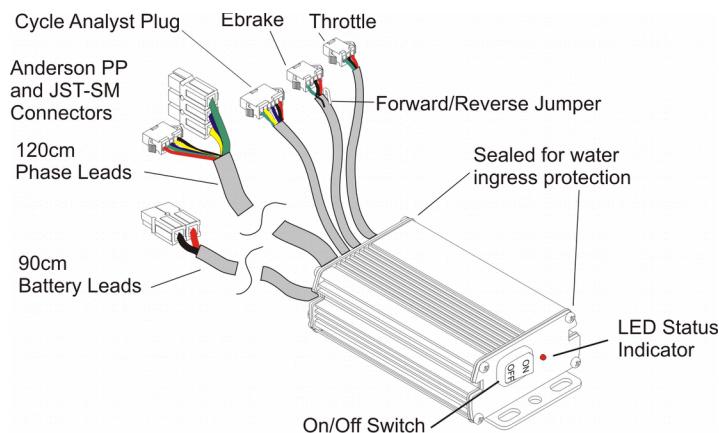


Figure 1: Key Controller Hardware Features

2 Installation and Hookup

The motor controller end plates have a flange with holes to facilitate securing to the vehicle. We recommend locating it in place where the ON/OFF switch is accessible and where it still has good exposure to air flow. Common bicycle locations include on the front of the rear rack support, between the seat tube and the rear wheel, or on the top tube with front motors.

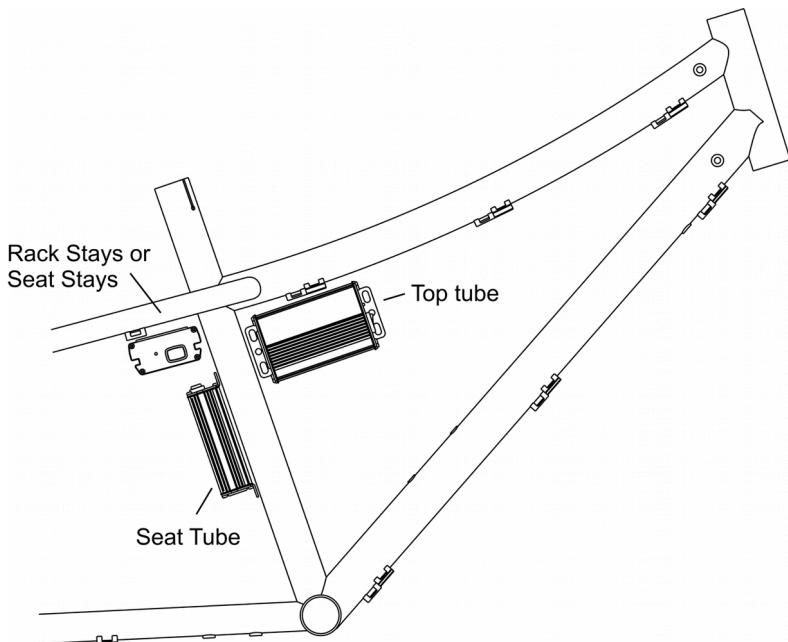


Figure 2: Common mounting locations and orientations

Although it is tempting, we do not recommend putting the controller inside a bag or enclosure box that blocks exposure to air flow, as it will be more susceptible to overheating. The silicone grommets on the controller end plates do an excellent job of keeping water out, so there is little concern about having the controller exposed to the elements, and the orientation of the installed controller does not matter.

2.1 Basic Hookup

The controller has 6 cables coming out of it: Battery, Motor Phase, Motor Hall, Throttle, Ebrake, and Cycle Analyst. At the bare minimum, the controller just needs a throttle, battery pack, and motor connection in order to work:

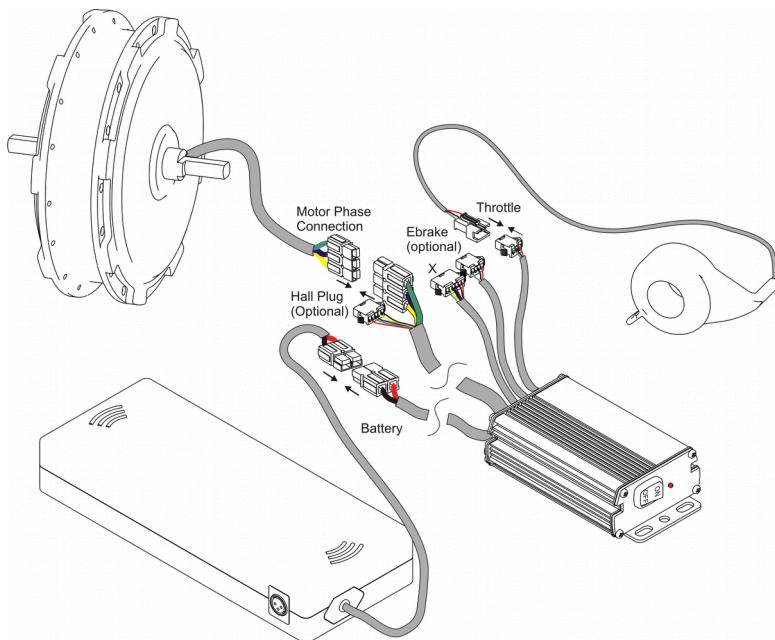


Figure 3: Basic hookup diagram (motor, throttle, and battery)

The throttle is a 3-pin JST-SM plug intended for Hall Effect throttle devices. It supplies 4.3V to power the throttle plug and expects a signal of 0.9V - 3.6V as the throttle is twisted. Throttle signal voltages higher than 4.0V are considered a fault condition, so if a potentiometer based throttle is used then appropriate resistors are needed to keep the voltage swing within range.

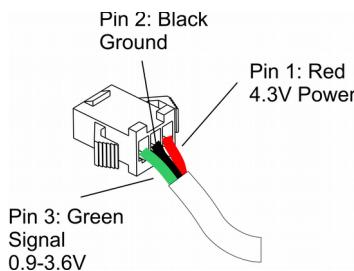


Figure 4: Controller Throttle Pinout

The brushless hub motor will have 3 phase wires that need to terminate with the 3 controller wires. Typically these are green, yellow, and blue, but many other possibilities exist. If you are running the motor sensorless, then it is only these 3 wires you need to connect and the color pairing does not really matter. If the motor spins backwards, then simply swap any pair of wires to reverse it.

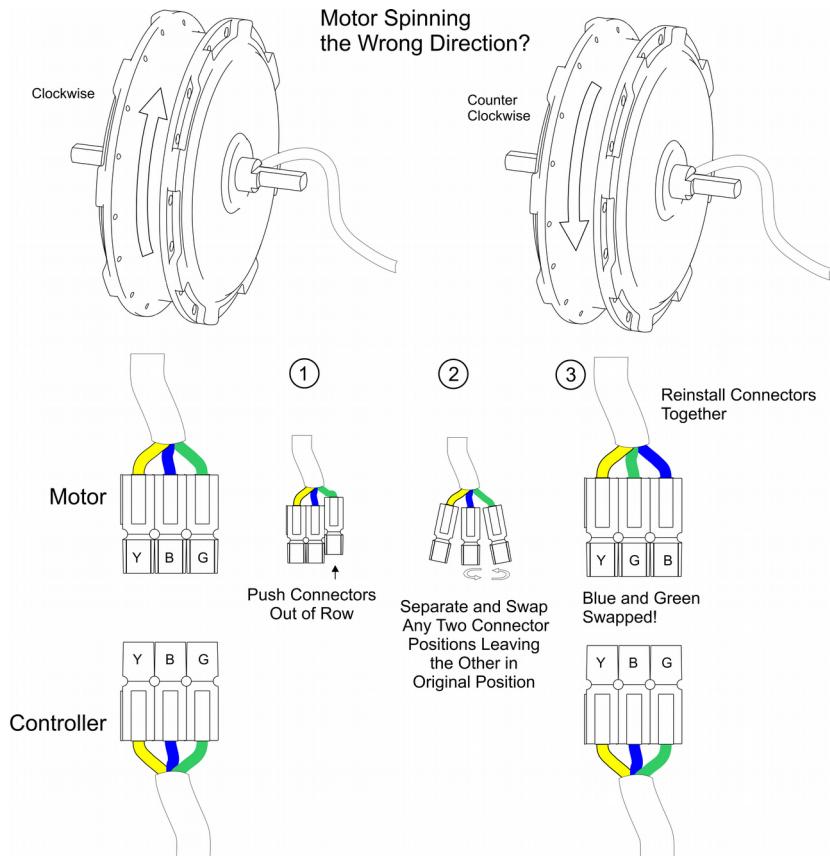


Figure 5: Example of Motor Direction Change by Swapping Phase Wires

If you want regenerative braking in a basic setup, then you can connect either an ebrake cutoff lever or other momentary push switch to the 4-pin ebrake plug.

2.2 Cycle Analyst Hookup

You can also add a V2 Cycle Analyst to this basic setup in order to have an informative display of all your vehicle and battery stats. The system still responds the same way to your throttle, but the V2 Cycle Analyst has the ability to over-ride and limit the throttle signal if you are exceeding the CA's programmed current limit, speed limit, or battery low voltage cutoff.

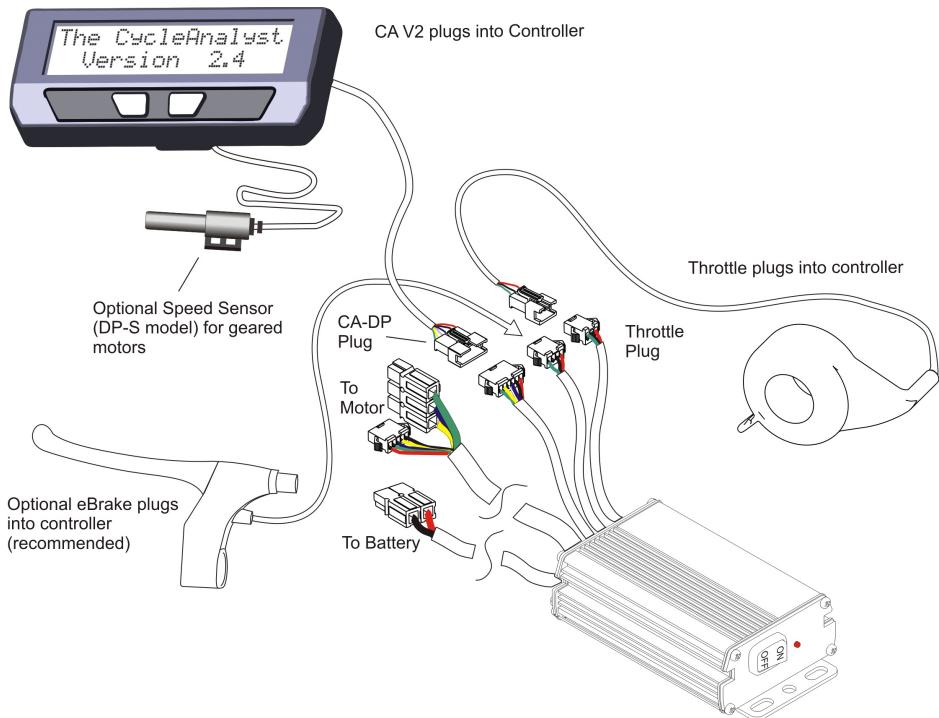


Figure 6: CA V2 Hookup. Throttle and eBrake Plug into Controller
(motor and battery not Shown)

Finally, if you are using a V3 Cycle Analyst, then your throttle and ebrake signals will connect to the Cycle Analyst rather than to your motor controller. Only the 6-pin CA-DP plug of the controller is used.

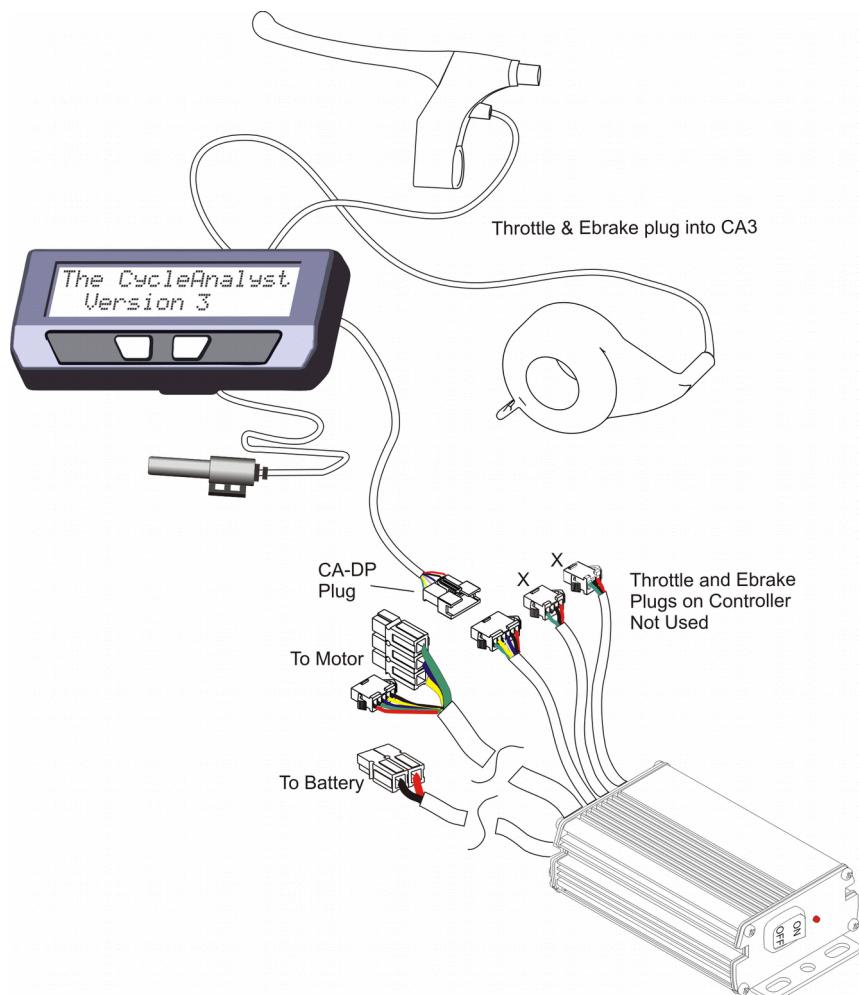


Figure 7: CA V3 Hookup. Throttle and eBrake Plug into CA (not controller)

The V3 Cycle Analyst is useful when much more advanced control features are desired, like PAS operation, motor over-temperature protection, torque sensing pedalec, mode presets etc.

2.3 Sensored vs. Sensorless

While the Grinfineon controller will work sensorless with the hall connector unplugged, there are several limitations to this mode.

- Starting from a standstill can be a little bit jerky while the controller attempts to self start the wheel.
- The controller will operate in a trapezoidal rather than the more silent sine wave mode, resulting in some audible buzz or hum from the motor.
- With high gear reduction geared hub motors, you may hit the sensorless eRPM limit of the controller (~28000 eRPM, see 4.1)
- When using a Cycle Analyst, you won't have the option of picking up the speed signal from the motor hall line and will require an external speedo sensor and spoke magnet (i.e. CA-DPS or CA3-DPS).

If the motor has hall sensor wires, then we recommend connecting them to the controller as well so that you can benefit from sensored sinusoidal operation. The hall sensor plug has 5 wires, red and black supply power to the hall sensors in the motor, and the yellow, green, and blue wires carry the resulting hall signals.

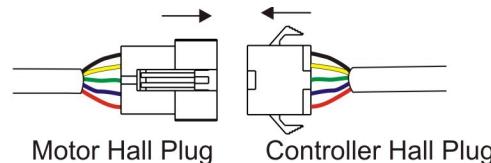


Figure 8: Hall Signal Plug

2.4 Hall / Phase Mapping Procedure

Previous generations of Grinfineon controller had the ability to automatically map the hall and phase wires so that the exact pinout details did not matter. This was very convenient but it is no longer possible with the addition of sinusoidal sensored mode. It is essential that the hall and phase pinout is correct.

The hall and phase pinout mapping on the SineWave Grinfineon controller is consistent with how both eZee and Crystalyte motors choose their colour coding, and they can be matched yellow to yellow, green to green, and blue to blue.

Other popular motor series use a different colour interpretation, and some trial and error is usually needed to determine the correct pinout.

Of the 36 possible ways to map the hall and phase wires, only 3 will spin the motor properly in the forwards direction. Another 3 combinations will spin the motor in reverse, and the remaining 30 combinations will either not turn the motor at all, or will turn it with great inefficiency.

We recommend using a systematic approach to determine the hall and phase mapping. First, plug together the hall wires in any pinout that you like. Then connect the 3 phase wires together and test the motor. If it spins smoothly with low current draw, then great. If not, then separate the Anderson phase plugs (they dovetail slide into each other) and keep cycling through the 6 possible alignments testing each one. An easy way to keep track of this is by first 'rotating' the phase connectors through the first 3 positions as shown below.

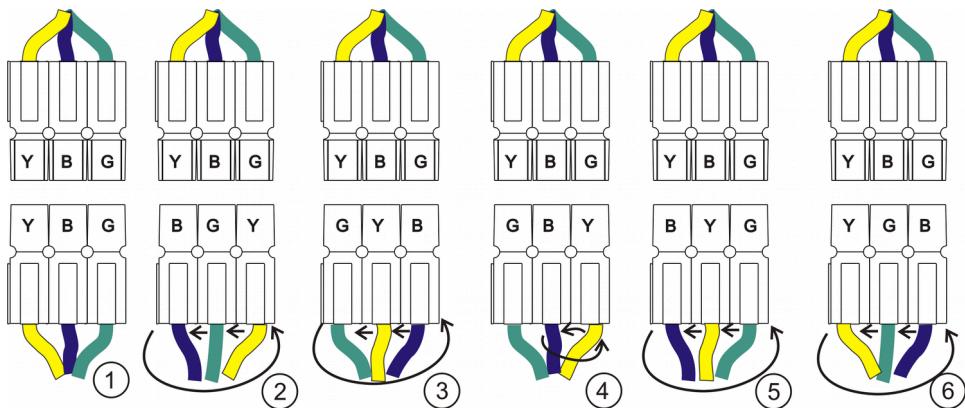


Figure 9: Systematic Approach to Phase Pinout Mapping

Then swap any pair of plugs (yellow and blue swapped in above example), and rotate through the 3 positions again. This will cover all 6 possible phase pinouts, and one of those 6 should allow the motor to run smoothly.

If that one position spins the motor backwards, then you can swap a pair of the hall sensor wires, repeat the test to find the correct phase pinout and it will spin the forwards direction.

Be aware that there are some incorrect hall/phase pinouts which will still spin the motor when you apply throttle, but the motor will turn with great inefficiency and draw higher than normal current, usually with a small 'kick' when the throttle is first applied. You do not want to run the motor under load in this condition.

When the motor is running in sensored mode, the LED will be on steady without blinking unless there is a fault error. In sensorless mode, the LED will flash at a slow ~1 Hz rate.

3 Core Features

3.1 Silent Sine Wave Mode

When the controller has hall sensors connected, the 3 phase output drive waveform is sinusoidal rather than trapezoidal. On most direct drive hub motors, this means a butter smooth feeling as you apply the throttle rather than the normal buzz or growl you may be used to. And even on geared motors the audibly sound from the hub is somewhat reduced.

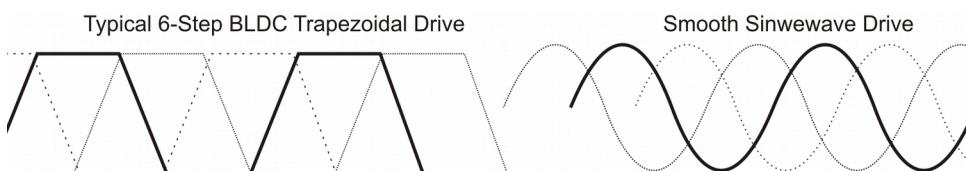


Figure 10: Illustration of Voltage Waveform of Trapezoidal vs Sine Wave Outputs

3.2 LED Indicator

The LED status indicator lets you know if the controller is powered up, what state it's in, and most importantly if there are any fault conditions that would cause things not to work. The following are normal operating modes:

LED Off	No power to controller (either battery is disconnected, or ON/OFF switch is OFF)
LED Slow Flash	Controller powered up, throttle is not pressed or it is running but in sensorless mode
LED Steady On	Controller is running the motor in sensored mode

The following state flash signals occur with quick blinks and then a pause. Note though that in sensorless mode, the error flash codes may not be visible due to the regular blinking that happens when running sensorless:

3 Blanks	Controller is in over voltage fault or has damaged MOSFETs
4 Blanks	Battery voltage below low voltage cutoff
5 Blink	Brake cutoff is engaged
6 Blanks	Throttle either too high or engaged when controller turned on

3.3 On/Off Switch

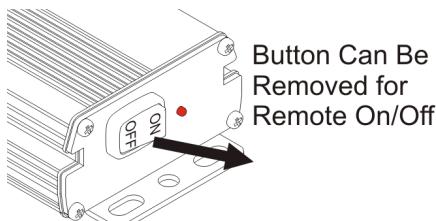


Figure 11: On Off Switch Details

If you want the switch to be accessible from the handlebars or mounted on a dashboard, then it is possible to remove it from the end plate and extend the wires up to your desired switch location and then seal the hole with a grommet. The wire gauge can be fairly thin, but if it is being used with a Cycle Analyst with light or other accessories powered from the DC jack, then we recommend using at least 20 AWG.

3.4 Regenerative Braking via Ebrake

The Grinfineon controllers have regenerative braking capabilities, allowing you to use the hub motor as a brake and return kinetic energy back into the battery pack. This can be achieved either with the ebrake lever for a constant 50% braking force, or with a 0.0 to 0.8V throttle signal for variable 0-100% braking.

In the first method, you connect an ebrake cutoff lever or other momentary switch between pins 2 and 4 of the 4-pin ebrake plug (Pin 1 = 4.3V power is useful for powering Hall Effect ebrake cutoffs). When the ebrake signal is pulled to ground, then the controller switches to a baseline level of regenerative braking, putting drag on the wheel and a small amount of current in the battery pack.

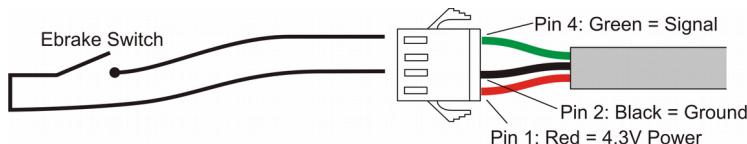


Figure 12: eBrake Connector. 5V+ for Hall Brakes

The intensity of this regenerative braking torque is fixed at about 50% of max regen, and is not affected by applying the throttle.

3.5 Proportional Regen via 0-0.8V Throttle Signal

The second method to engage regen is with a throttle signal that is less than 0.8 Volts. Normally a Hall Effect throttle will only swing from 0.9V to about 3.6V, leaving the range of 0.0-0.9V unused. In the Grinfineon controllers, this unused range is mapped to regenerative braking, with regen starting below 0.8V and then increasing to a maximum as the throttle signal goes down to 0.0V. This can be seen in the graph below showing the torque measured from a hub motor as the throttle signal is swept from 0.0V to 4.0V.

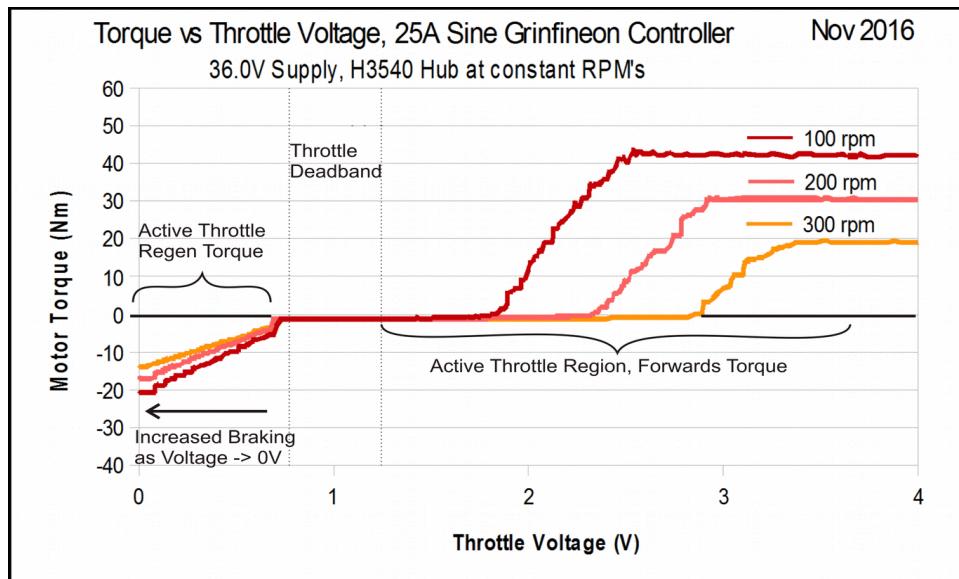


Figure 13: Regen intensity for throttle 0V-0.8V

The test was done with the motor spinning at 100, 200, and 300 rpm. You can see that at lower RPMs, the breaking intensity was higher for a given throttle voltage.

Even though the regenerative braking intensity is reduced at higher speeds, the actual regen current flowing into the battery pack increases at high speeds as there is more mechanical power being converted into electrical energy.

You can see this relationship clearly in Figure 14, which shows both the torque and the amperage flowing back into the battery at 4 different levels of throttle regen (0.0, 0.2, 0.4, and 0.6V) versus the motor RPM. It also shows how much regen current and braking force you can expect from the fixed ebrake input switch, which is shown by the dashed black lines.

Regen Torque and Current vs. RPM, at 4 Regen Voltage Levels (0.0V - 0.6V) Justin L-E, Nov 2016

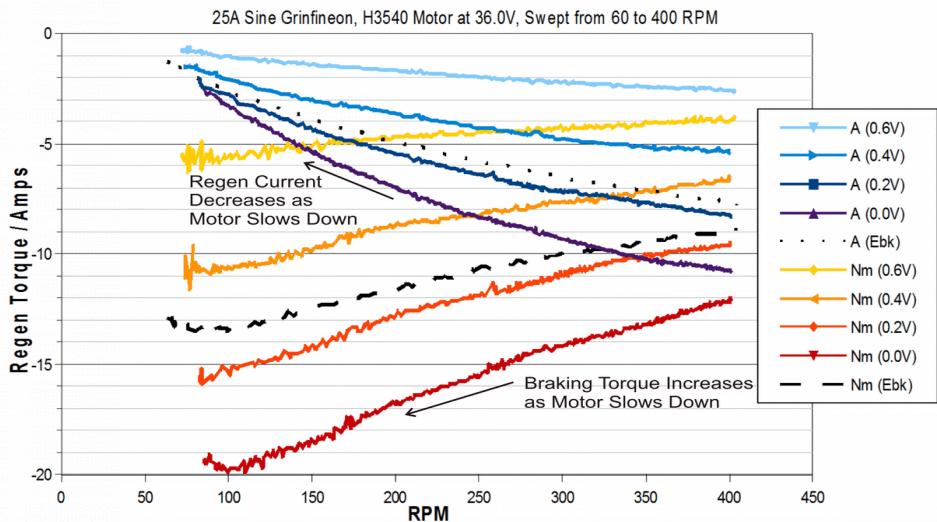


Figure 14: Regenerative Braking Torque and Current as a Function of Motor RPM at 4 different throttle regen voltages and also with ebrake lever pressed (Eb, dashed lines)

This throttle mapped regen is handy since it allows for variable braking without any additional wires to the controller, and in principle a small bidirectional throttle would allow you to both accelerate and slow down without the need for any kind of brake sensors. It is also how regenerative braking is activated with the V3 Cycle Analyst, which can send any voltage signal to the throttle line.

If you have a geared motor or mid-drive motor, then the regen won't have much effect. It will cause the motor to quickly stop spinning when you squeeze the brakes, but it won't be able to help slow the bike down due to the intrinsic freewheel of these systems. There is no need to disable controller regen in this situation, it is harmless.

3.6 Fwd / Rev

If you have an application where the motor direction needs to be reversed at times, as is handy with trike and quad applications, then there is an additional white forwards/reverse direction wire that is tucked under the ebrake heatshrink. If this wire is exposed and then connected via a switch to the adjacent black ground wire, it will enable you to change the motor direction on the fly without swapping the motor phase and hall leads.

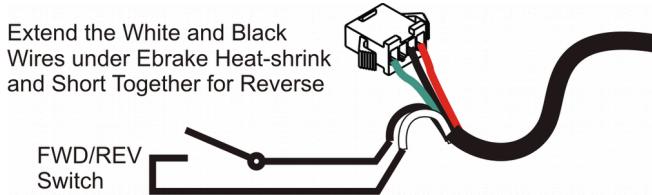


Figure 15: FWD/REV, Remove heatshrink tubing over ebrake connector to expose spare white and black signal wires, and extend those to your reverse switch.

3.7 Fault Tolerant Hall

Normally a sensored motor/controller setup is somewhat vulnerable to damage of the hall sensor itself, the hall wires, or the hall connector pins. If this happens, the motor will run very rough or not at all. On the Sinewave Grinfineon controllers, the control logic will still be able to operate in sensored sine wave mode even if one of the hall sensors is damaged as it can interpolate the missing signal. However, the initial starting can be a bit rough, and the ebrake input no longer does regenerative braking but just does a controller cutoff.

4 Limitations

Although we tried to make this controller fairly universal, there are also more than a few limitations that can affect its use in some applications.

4.1 eRPM Sensorless & Sensored

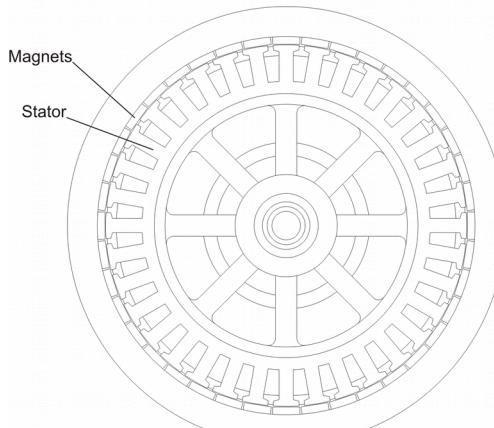
The maximum commutation frequency in sensorless mode is about 28000 eRPM. This is substantially higher than previous Grinfineon controllers (13000 eRPM) and will work with most geared hub motors just fine at typical ebike speeds, but may still be limiting in very fast setups.

The electrical RPM is easy to calculate by taking the mechanical RPM of the motor, multiplying it by the number of magnetic pole pairs in rotor, and then again by the gear ratio if it is a geared hub.

For instance, Figure 16 is a diagram of a direct drive motor with 40 magnets. That means there are 20 magnetic pole pairs. A 28000 eRPM would correspond to a 1400 maximum mechanical RPM at the wheel, which is much faster than you would have on a bicycle (200-400 rpm is more common); therefore this hub would have no problem running sensorless at bicycle speeds.

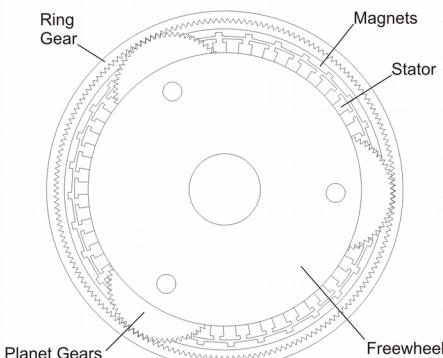
The geared motor in Figure 16 has 32 magnets and a 7:1 gear reduction. In this case, the maximum speed in sensorless mode would be $28000 \text{ eRPM} / 16 / 7 = 250 \text{ rpm}$. In a 26" wheel that would correspond to 31 kph. Below this speed the bike would run fine but any faster and the controller is liable to shut down in a fault mode.

Direct Drive Hub Motor



$$\begin{aligned}40 \text{ Magnets} &= 20 \text{ Pole Pairs} \\28000 \text{ eRPM} / 20 \text{ Pole Pairs} &= 1400 \text{ RPM max}\end{aligned}$$

Geared Hub Motor



$$\begin{aligned}32 \text{ Magnets} &= 16 \text{ Pole Pairs} \\7:1 \text{ Gear Ratio} \\28000 \text{ eRPM} / (16 \text{ Pole Pairs} \times 7:1 \text{ Gear Ratio}) &= 250 \text{ RPM max}\end{aligned}$$

Figure 16: Direct Drive and Geared Hub Motor eRPM examples

The maximum speed when running with hall sensors is much higher, but at values over 50,000 eRPM the commutation timing can be off and motor performance will suffer.

4.2 Power Oscillations at Full Throttle when Sensored

In sensored sine wave mode, the motor controller is always attempting to interpolate the exact motor position at any given moment in between hall sensor events.

With certain geared hub motor installations, the controller can be prone to having large power fluctuations at full throttle while this interpolation overshoots and undershoots. This can be triggered by sudden changes in motor RPM (such as hitting a pothole or popping a wheelie) and it may require releasing and reapplying the throttle to smooth out. If the motor setup is prone to this behavior, we recommend unplugging the halls and running the sensorless.



4.3 60 Degree Hall Timing

Most brushless motors use 120 degree hall timing, where at any given point there is always at least 1 hall signal that is high, and 1 hall signal that is low. But some motors use 60 degree hall spacing, where 000 and 111 are also valid hall patterns.

The Sine Wave Grinfineon controller will not work in sensored modes with brushless motors that have 60 degree hall timing. If your motor has 60 degree halls, then you will have to run it sensorless and leave the halls unplugged.

4.4 No Change to Internal Settings

For a number of reasons the controller's internal settings for low voltage cutoff, battery and phase current limits, max regen current etc. are fixed in the controller IC and can't be reprogrammed by the user. The fixed values are sensibly chosen to be around the maximum allowable range for flexibility while keeping the controller in a conservative operating area.

If you want to further limit these settings for custom low voltage rollbacks or current/power limits, then either a V2 or V3 Cycle Analyst will provide that functionality and a lot more just via modulation of the throttle signal.

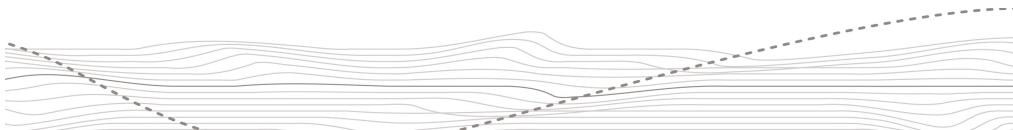
4.5 Max Regen Voltage

The maximum regen voltage is set to ~58V for the 25A and 35A controllers, allowing them to work with up to 14s (52V) lithium batteries, but without risk of high voltage spikes if the battery BMS circuit trips.

The 40A controllers have a maximum regen voltage of 88V, allowing them to work with 72V (20s) lithium and LiFePO4 batteries.

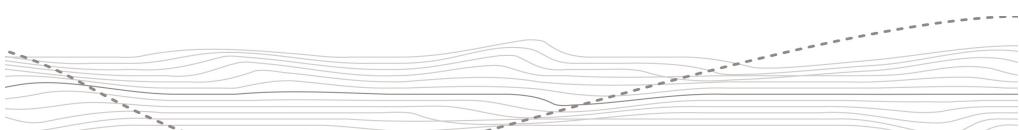
This upper voltage regen cutoff is critical to prevent damage to the controller if ever the battery is disconnected during regenerative braking, since the regen will stop abruptly before the voltage has a chance to spike. It is also higher than the full charge voltage on most battery packs you would use, and there can be a possibility of overcharging a battery if you start with a full charge at the top of a hill and your battery's BMS circuit does not have an overvoltage cutoff.

In that scenario it is prudent to have a Cycle Analyst or other volt meter to keep an eye on the battery voltage level. In practice you will almost always consume many more amp-hours than you put back in while braking and overcharging from regen is not much of a concern.



4.6 Won't Show CA Accessory Current Draw

The CA-DP plug on the motor controller is wired up so that it will show the current draw of the motor and controller, but not the current draw of any other devices (like front lights) that are plugged into the CA's power tap. If you want the Cycle Analyst to show auxiliary device current, then the controller can be opened up and the black wire from the CA-DP cable moved from the - side of the shunt (adjacent to the blue wire) to the + side of the shunt (adjacent to white wire).



5 Specifications

5.1 Electrical

	C4825-GR	C4835-GR	C7240-GR
Battery Current (+2% / -10%)	25 A	35 A	40 A
Phase Current Limit (+/- 10%)	75 A	90 A	120 A
Nominal Battery Voltage	36V-52V	36V-52V	36V-72V
MOSFETs	6x	12x	
	IRFB4110	AOT460	IRFB4110
Max Regen Voltage (+/- 2%)	58 V	58 V	88 V
Low Voltage Cutoff (+/- 2%)	27 V	27 V	31 V
Control Chip	XCKJ3232C		
eRPM Limit Sensorless	~28,000		

5.2 Mechanical

	C4825	C4835	C7240
Dimensions (mm)	110x71x34	154x87x46	
Weight (kg)	0.49	0.75	0.78
Chassis Material	Extruded Aluminum		
DC Battery Connector	Genuine Anderson Power Poles		
Motor Phase Connector	Genuine Anderson Power Poles		
Hall Sensor Connector	JST-SM Series		
Other Signal Connectors	JST-SM Series		
Waterproofing	Gasketed at end plates and wire exits, sealed switch		

5.3 Connector Pinout

	Throttle*: 1=4.3V 2=Gnd 3=Signal:1-3.6V
	Ebrake: 1=5V 2=Gnd 3=NC 4=Ebrake
	Hall Sensor**: 1=Gnd 2=Yellow 3=Green 4=Blue 5=5V
	Cycle Analyst***: 1=Vbatt 2=Gnd 3=-Shunt 4=+Shunt 5=Hall 6=Throt

* White wire in sheath is for FWD/REV - Jump to GND to enable

** Leave hall sensors unplugged for sensorless operation

*** **Caution with Old Small Screen Cycle Analysts** (will go full throttle unless additional diode wired inline with green throttle-override wire)