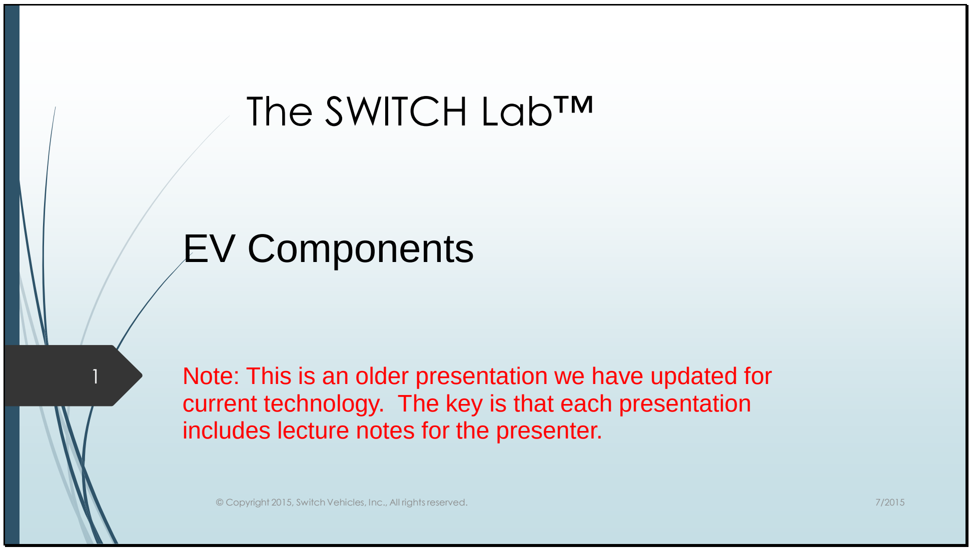
Slide 1



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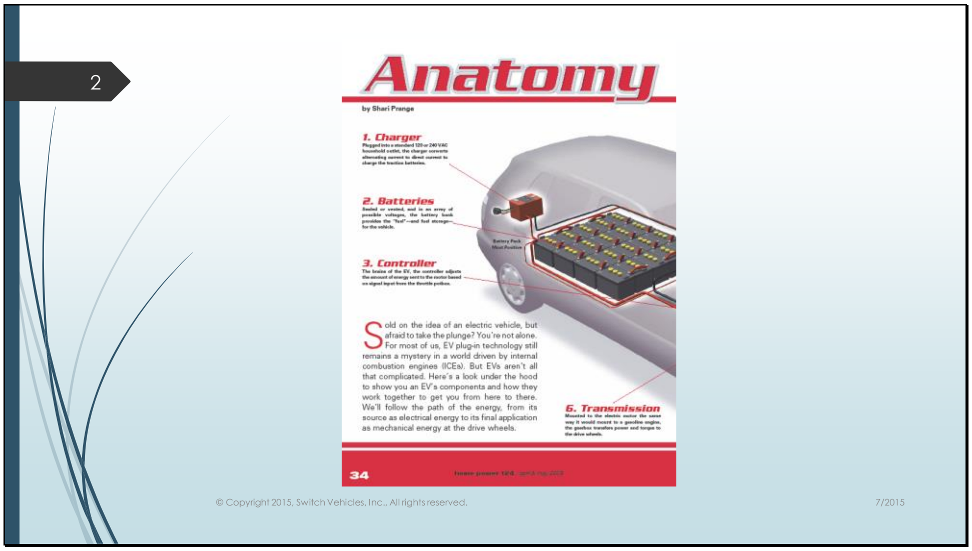
Slide 2


2
Anatomy
by Shari Prange
1. Charger
2. Batteries
3. Controller
Sold on the idea of an electric vehicle, but afraid to take the plunge? You're not alone. For most of us, EV plug-in technology still remains a mystery in a world driven by internal combustion engines (ICEs). But EVs aren't all that complicated. Here's a look under the hood to show you an EV's components and how they work together to get you from here to there. We'll follow the path of the energy, from its source as electrical energy to its final application as mechanical energy at the drive wheels.
6. Transmission
34
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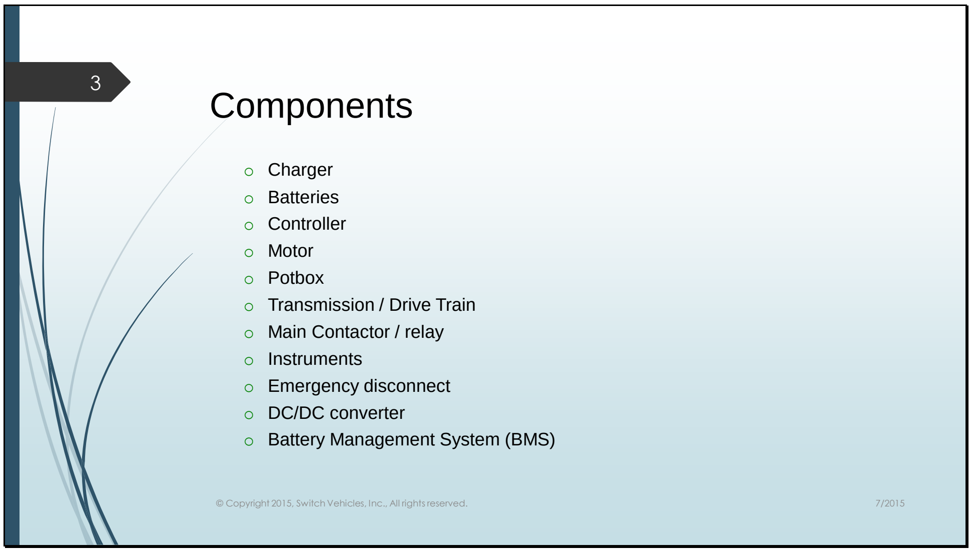
7/2015

Slide 3



These are the 10 primary components installed in an electric vehicle.

We will now explore these 10 items in some detail and also look at an introduction to the battery management systems available to preserve your battery pack and safely control the charging and discharging cycles.

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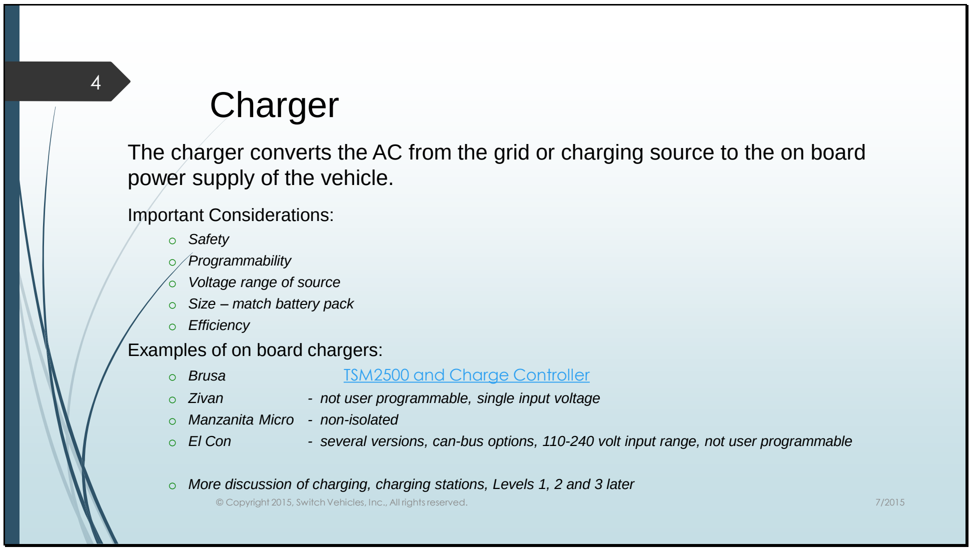

In the selection of components safety is always the primary concern.

Safety – look for UL or CE (European approval) approval. Some chargers do not isolate the plug from the high voltage battery pack. This creates a hazard when charging the vehicle, without isolating the traction battery pack from the plug you can be shocked or electrocuted while either plugging in the vehicle or unplugging the vehicle.

If your charger has the UL or CE seal of approval it is most likely an isolated charger, but you can always ask the supplier. You can also install circuitry to isolate the charger as a separate sub-system. We will not address how to accomplish this step in this course.

Programmability – There are several reasons to purchase a programmable charger.

All battery chemistries have different charging profiles

Lead acid batteries are charged to a specific voltage then charged at a much lower current until the cut off voltage is reached

Lithium Iron Phosphate cells are charged to a specific voltage then charging should stop

It is critical to learn the charging profile for your battery pack directly from the manufacturer or supplier. Then program your charger to match the requirements.

Also playing an important role in the charging cycle is the battery management system, a programmable charger is more likely to be able to receive instructions from the battery management system and correctly charge your battery pack.

Voltage range of source – another important charger characteristic is flexibility in the output voltage. It is not uncommon to add or remove cells to increase the range or power of a vehicle. If you add cells, increasing the traction battery voltage you will have to reprogram the charger to charge to a higher voltage. Regardless you must initially match the output of the charger to the requirements of the battery. Not all Evs have the same pack voltage. Remember our motors. The DC motors were set for 72 volts while the AC motor was set for between 144 and 450 volts.

Size – match battery pack – you have to be able to charge the pack in a specified time period. So the output, volts times amps times time must be less then the amount of time allowed for charging.

For instance, in one of my Speedster conversions the traction battery pack was so large, 30KWh, that when the car was driven 120 miles and the battery was basically empty or fully discharged, it would take about 16 hours to recharge to capacity when plugged into a standard 110 volt outlet. The options were to add another charger and charge in parallel or install a charger that would plug into a higher capacity outlet such as a 220 volt outlet. When plugged into a 220 outlet the maximum charging time was reduced to 6 hours which was acceptable for this particular vehicle.

Efficiency – chargers are rated for efficiency. Remember that you buy the electricity as it leaves the outlet. So a charger that is 75% efficient "wastes" 25% of the energy it consumes. Compare that to a charger that is 95% efficient (about as good as they get) and you can see that over a measurable period of time you will consume or purchase significantly less energy with the more efficient charger.

Brusa chargers are expensive but they are completely user programmable and can plug into outlets ranging from 110 volts to 440 volts. Completely isolated and able to receive instructions from a BMS unit using the Can BUS technology.

Zivan chargers are isolated and programmable but they must be returned to the supplier to be reprogrammed.

Manzanita Micro are not isolated but can be programmed and output the most power. Great for racing or specific controlled environments.

To compute charging time multiply volts times amps (both from the wall) to compute watts in then divide watts in into kilo-watts used to arrive at the approximate charging time. Charger efficiency is a major factor in charging time and expense.

Slide 5

Batteries

5

Batteries are the fuel source for the vehicle.

Important considerations:

- *Safety*
- *Number of Cycles*
- *Deep Cycle*
- *C factor for charging and discharging*
- *Power to Weight ratio*
- *Match to motor requirements*
- *Predictability*
- *Availability*
- *Cost*
  - *Potential Explosive Situations*
- YouTube http://www.youtube.com/watch?v=Ah2GrwGnlRw

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Safety – we will look at some exciting battery videos shortly. Batteries can explode because of many events, punctures, over charging, over discharging are all common problems for certain battery chemistries.

We will study battery safety in depth later in the course.

Number of Cycles – Cost is a major issue with the selection of your battery. In order to determine the actual cost you need to know the projected life cycle of any product, especially batteries.

We just discussed that lead acid batteries last long when not discharged more then 50%, lithium 80%. Each chemistry has its own rules for how deep discharging effects the life of the battery.

Typical lead acid deep cycle batteries will last around 450 cycles (a charge and discharge cycle) perhaps 250 cycles if discharged to 80% depth of discharge (DOD).

Lithium iron phosphate (LiFeP04) cells are predicted to last 3,000 – 4,000 cycles at 50% DOD or 2,000 – 3,000 at 80% DOD.

These numbers a key to determining the cost of the battery pack measured over time.

Deep Cycle - EV batteries differ from "normal" lead acid batteries used to start your ICE because they are designed to provide power over a longer period of time and be more deeply discharged. Using a series of starter batteries to power an EV would result in a dead battery pack very quickly. Starter batteries are NOT designed to provide the amount of energy over time required by an electric vehicle.

C factor for charging and discharging – another important consideration when evaluating battery cost is the amount of current a battery can deliver. This is generally referred to as the "C" factor. Similar to cold cranking amps used to define a starting battery the C factor is the rating for amps delivered in relationship to the amp hour rating of the battery.

C factors are generally related to time as well. For instance a battery will have tow or three or more C ratings for BOTH charging and discharging.

For example a lithium cell may have a C rating of 20 for 10 seconds, 10 for 30 seconds and a 3 for nominal.
So a 100 amp hour cell could produce 2,000 amps for 10 seconds, 1,000 amps for 30 seconds and continuously provide 300 amps.

A 50 amp hour cell with the same C rating would be able to provide 1,000, 500 and 150 amps respectively.

C rates are applicable for charging as well but are rarely tested in real life as chargers rarely exceed 100 amps and even regenerative braking rarely produces significant amperage.

Power to Weight ratio – when evaluating batteries ask how much power does it store and produce and how much does it weigh? Some cells store and deliver significantly MORE energy then others and can also weigh significantly less. More energy in less weight is general more expensive, and worth it.

Match to motor requirements – We discussed the AC motors and the DC motors and the fact that Watts = Power and watts = volts time amps. The DC motors used up to 450 amps the AC motor topped out at 200 amps. These three motors are just examples, some DC motors can draw 2,000 amps some AC motors nearly that much. If you are building a vehicle that requires 2,000 amps you must design a battery pack that can deliver 2,000 amps for the period of time required.

For instance if you are building a dragster and need 2,000 amps for 10 seconds the 100 amp hour cell discussed would work, but the 50 amp hour cell would not…..unless you put them in parallel. More later.

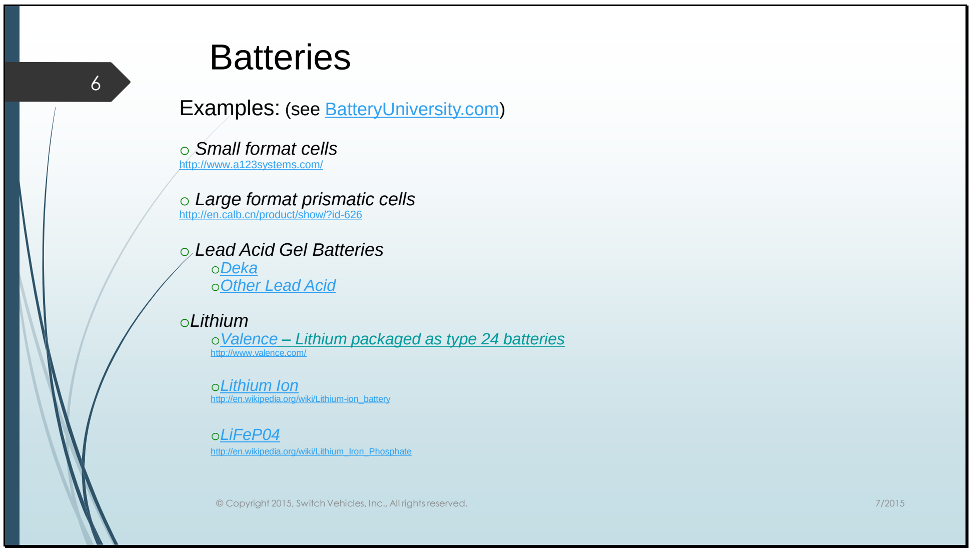
BUT if you are creating a formula one style car that requires 2,000 amps for 20-30 seconds you would need to design a different battery solution

Predictability – as an EV builder I want consistency, I need the products I build to perform as designed consistently and predictably. Predictability is an important factor in battery technology.

Availability – are the cells available and will they be available in the future? Where are they? I buy cells from China and Arizona and need multiple suppliers but mostly we need cells that are available not available soon.

Cost – is measured by the initial investment and over time. Rate cost by the number of cycles to calculate the actual cost. It is OK to build your EV now with lead acid and understand in 1-2 or maybe three years depending on care and maintenance of the battery pack you will need to replace the pack. At that time you can replace it with another lead acid pack or upgrade to a lighter longer lasting pack. If you plan to do this make a good decision in the purchase of your charger.

Slide 6

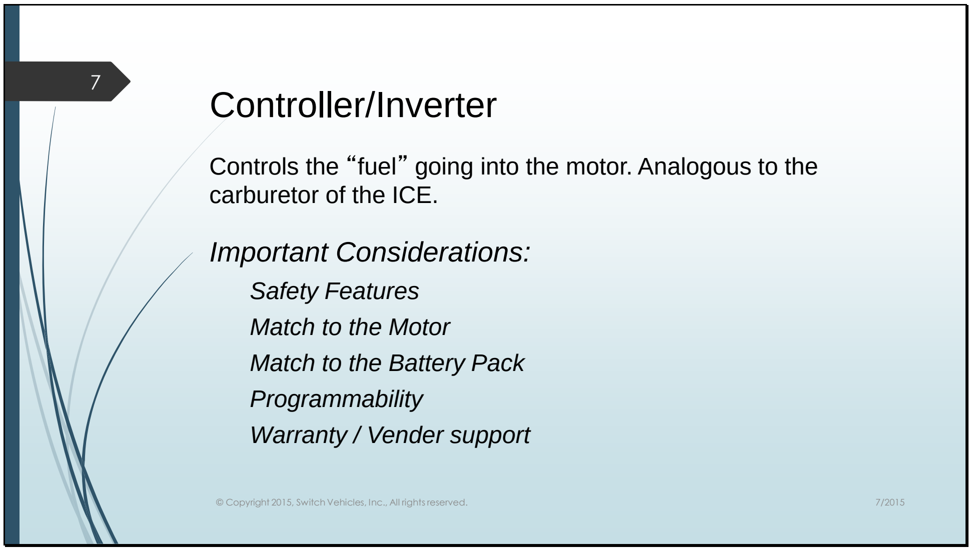


Have a look at the variety of cells available today

See BatteryUniversity.com for lessons about batteries.

View as many as you like time permitting – the batteries we are using in the DC Switch project are linked under LEAD

Slide 7



Safety Features – Since we are primarily concerned AC motors our primary concern is with the high voltage connections to the controller and from the controller to the motor. Are the connections sealed? Is the housing sealed, cooled?

Match to the Motor – The integration between the motor and controller is critical. Each AC motor has a sensor on the rotor to provide data back to the controller. This information includes rpm, location of the rotor in relationship to the stator and other information such as motor temperature. You will almost always buy the motor and controller as a package from a supplier as this is a more critical relationship then that of the DC motor to the controller.

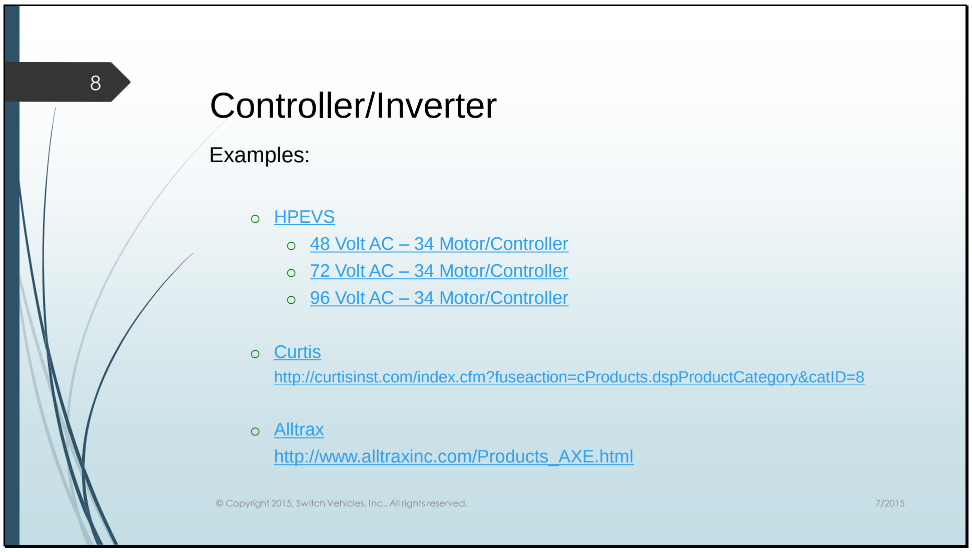
Match to the Battery Pack - The two critical elements to match are the battery pack voltage and the power availability. Remember the C rating? Will the traction pack battery provide enough amperage to fully power the motor? There are three voltages to concern yourself with regarding the traction pack. Whenever a pack is charged it reaches maximum voltage, then it discharges quickly to nominal voltage and finally discharges to minimum voltage.

An example AC Controller would be the Curtis controller we will install in our vehicle. The absolute maximum voltage is 130 volts. You would want to be sure that the controller would function with the traction battery fully charged.

Programmability – The ability to "tune" your EV is limited by the programmability of the controller. Features such as regenerative braking, input for a temperature gauge or tachometer or accessing performance characteristics are enhanced or limited according to the programmable feature set of the controller.

Warranty / Vender support – Critical to your decision is the support of the local supplier.

Slide 8



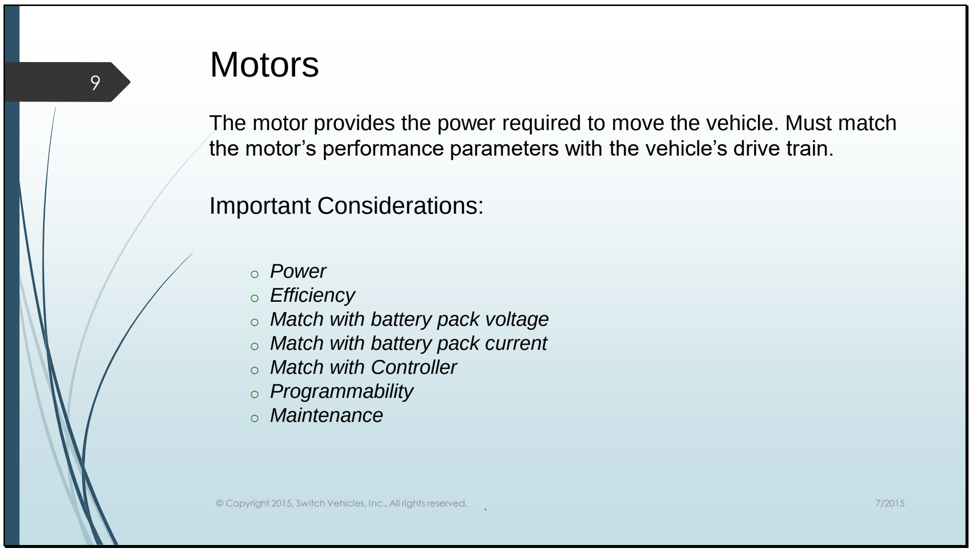
Some typical AC controllers.

EV controllers are the brains and provide the muscle to the motors. Essentially the controller receives input from the driver either through the potbox (soon to be discussed) or some other means to indicate how much power is required. The controller then provides the energy to the motor.

Many of us are familiar with the slot cars and the controllers we use to control the speed. Slot car controllers actually increase the voltage to increase the speed of the car on the track. EV controllers use pulse width modulation (PWM) to control motor. It was discovered that adding full power to the motor was more efficient so the EV controller acts like a switch turning on and off very quickly, the more power requested by the driver the longer the switch is on, the wider the pulse of energy, the more energy the motor receives.

PMW does generate heat and many controllers require cooling to stay within acceptable operating temperatures.

Slide 9



Power – you will want to match the power output to the use of the vehicle. Factors to consider are the weight of the vehicle, acceleration, top speed and cruising speed. Motors are generally rated for top power and nominal power. Top power is generally rated over time so you may have a 30KW motor (Approximately 40 horsepower remember?) but you will want to determine if the rating is peak or nominal, if its peak how long will it sustain that output? 10 seconds, 30 seconds or minutes? You will then want to be sure the battery pack can output the power required for the same duration.

Efficiency – there are several factors to consider regarding efficiency; overall efficiency with the motor controller, peak efficiency under full power, and the efficiency at the cruising speed. For instance if you are driving at 60MPH on the freeway what RPM will the motor spin? (See acceleration spread sheet to calculate) find a motor with a high efficiency rating at the most common RPM.

Match with battery pack voltage – all motors have specific voltage ranges be sure to select a motor matched to the voltage you expect to run

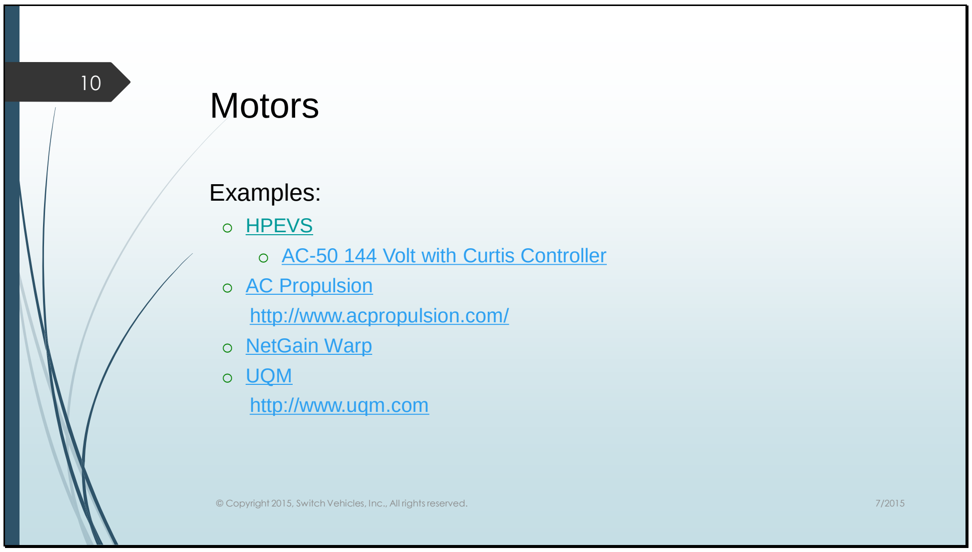
Match with battery pack current – The battery pack will have its own particular performance parameters. You will want to carefully match the requirements of the motor with the output performance of the battery for peak and nominal situations.

Match with Controller – the motor controller and motor should both be evaluated with the same factors together and in relationship to the battery. Voltage, peak and nominal current and efficiency. With an AC motor I would only purchase the motor and controller from a vender as a package guaranteed to work together. There is a sophisticated level of communication required between the motor and controller.

Programmability – can you change the functionality of the motor via wiring or instructions? This would allow more flexibility for future changes

Maintenance – less is better. AC motors require little or no maintenance, DC motors require brush changes and commutator clean up

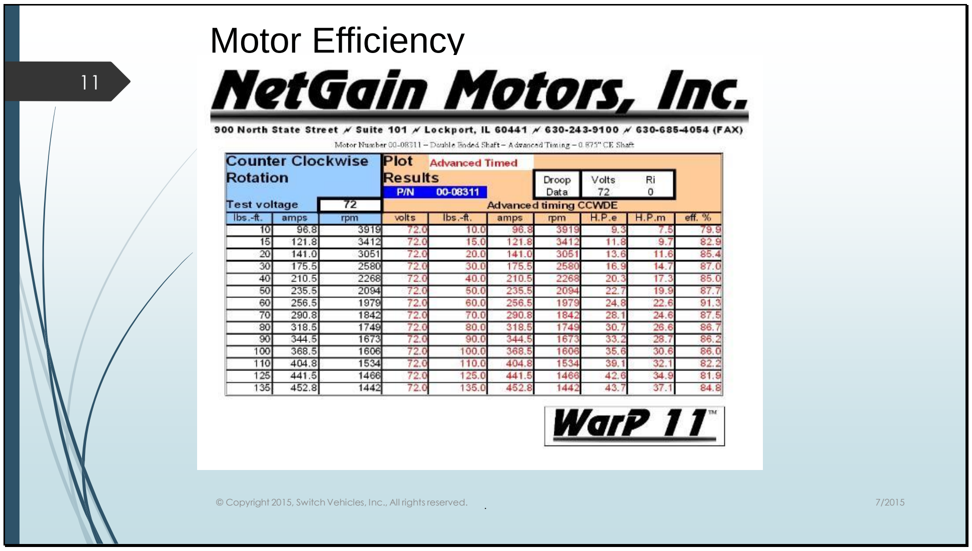
Slide 10



Here are four different motors to look at. The top two are AC motor and controller packages

The Netgain Warp is a DC motor and the UQM motor is a brushless DC motor which is very similar in function to the AC motor with regenerative braking but with torque curves more closely associated with the DC motors.

Slide 11



lbs.-ft.	amps	rpm	volts	lbs.-ft.	amps	rpm	H.P.e	H.P.m	eff. %
10	96.8	3919	72.0	10.0	96.8	3919	9.3	7.5	79.9
15	121.8	3412	72.0	15.0	121.8	3412	11.8	9.7	82.9
20	141.0	3051	72.0	20.0	141.0	3051	13.6	11.6	85.4
30	175.5	2580	72.0	30.0	175.5	2580	16.9	14.7	87.0
40	210.5	2268	72.0	40.0	210.5	2268	20.3	17.3	85.0
50	235.5	2094	72.0	50.0	235.5	2094	22.7	19.9	87.7
60	256.5	1979	72.0	60.0	256.5	1979	24.8	22.6	91.3
70	290.8	1842	72.0	70.0	290.8	1842	28.1	24.6	87.5
80	318.5	1749	72.0	80.0	318.5	1749	30.7	26.6	86.7
90	344.5	1673	72.0	90.0	344.5	1673	33.2	28.7	86.2
100	368.5	1606	72.0	100.0	368.5	1606	35.6	30.6	86.0
110	404.8	1534	72.0	110.0	404.8	1534	39.1	32.1	82.2
125	441.5	1466	72.0	125.0	441.5	1466	42.6	34.9	81.9
135	452.8	1442	72.0	135.0	452.8	1442	43.7	37.1	84.8

This is a typical DC motor performance presentation.

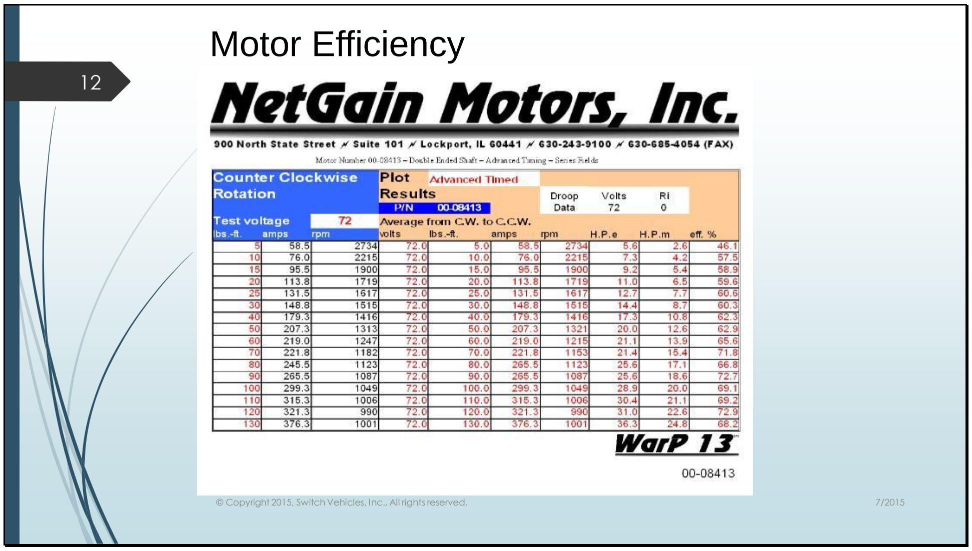
Note the first significant piece on information presented in the upper left corner is the rotation of the motor. This motor was designed to spin counter clockwise. You need to know which direction you need your motor to spin when installing a DC motor, they are designed to spin either clockwise or counter clockwise. Although some DC motors spin either direction based on how they are wired.

Next on the far right hand column the efficiency is available for various power outputs.
On the first line the horsepower created electrically is 9.3 but factoring in the efficiency of 79.9% the horsepower created at the motor is on 7.5 or 9.3 time 79.9 percent.

The motor is MOST efficient 91.3% at 1979 RPM and produces 24.8 HP electrically and 22.6 HP at the motor after allowing for efficiency.

If we were to use this motor to power our vehicle we would want to calculate a gear ratio that keeps the motor near or at the most efficient RPM or near 1979 RPM. This is good as most internal combustion engines run at about that speed when cursing along at 55-60 MPH.

Slide 12



Motor Efficiency

12

NetGain Motors, Inc.

900 North State Street ⁄ Suite 101 ⁄ Lockport, IL 60441 ⁄ 630-243-9100 ⁄ 630-685-4054 (FAX)

Motor Number 00-08413 – Double Ended Shaft – Advanced Timing – Series Fields

Counter Clockwise Rotation

Plot Results: Advanced Timed

P/N 00-08413

Droop	Volts	Ri
Data	72	0

Test voltage: 72

Average from C.W. to C.C.W.

lbs.-ft.	amps	rpm	volts	lbs.-ft.	amps	rpm	H.P.e	H.P.m	eff. %
5	58.5	2734	72.0	5.0	58.5	2734	5.6	2.6	46.1
10	76.0	2215	72.0	10.0	76.0	2215	7.3	4.2	57.5
15	95.5	1900	72.0	15.0	95.5	1900	9.2	5.4	58.9
20	113.8	1719	72.0	20.0	113.8	1719	11.0	6.5	59.6
25	131.5	1617	72.0	25.0	131.5	1617	12.7	7.7	60.6
30	148.8	1515	72.0	30.0	148.8	1515	14.4	8.7	60.3
40	179.3	1416	72.0	40.0	179.3	1416	17.3	10.8	62.3
50	207.3	1313	72.0	50.0	207.3	1321	20.0	12.6	62.9
60	219.0	1247	72.0	60.0	219.0	1215	21.1	13.9	65.6
70	221.8	1182	72.0	70.0	221.8	1153	21.4	15.4	71.8
80	245.5	1123	72.0	80.0	265.5	1123	25.6	17.1	66.8
90	265.5	1087	72.0	90.0	265.5	1087	25.6	18.6	72.7
100	299.3	1049	72.0	100.0	299.3	1049	28.9	20.0	69.1
110	315.3	1006	72.0	110.0	315.3	1006	30.4	21.1	69.2
120	321.3	990	72.0	120.0	321.3	990	31.0	22.6	72.9
130	376.3	1001	72.0	130.0	376.3	1001	36.3	24.8	68.2

WarP 13

00-08413

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Slightly different motor, same spin direction but most efficient at a much lower RPM of 1087 and only about 72% efficient. This would be for a different type of vehicle and the motor should cost much less.

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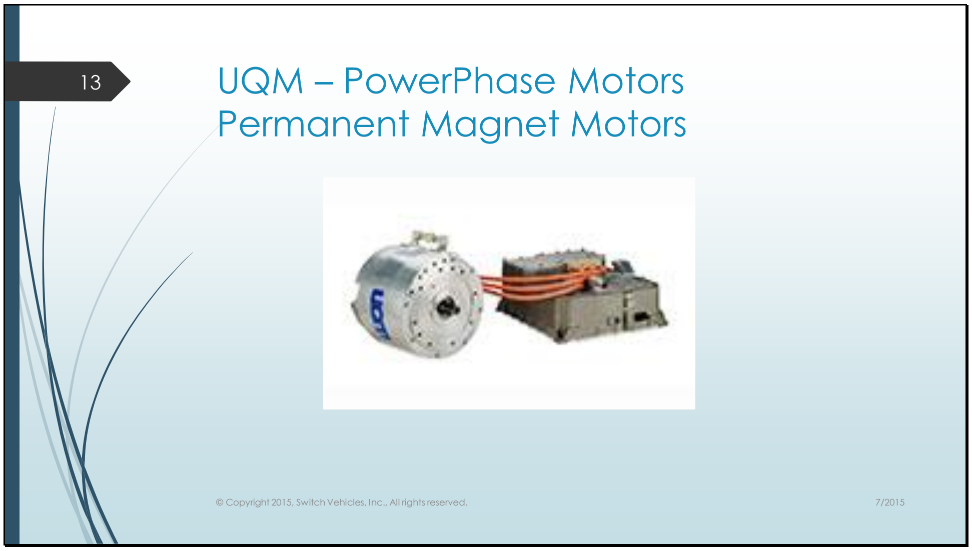
VEHICLES INC

Slide 13



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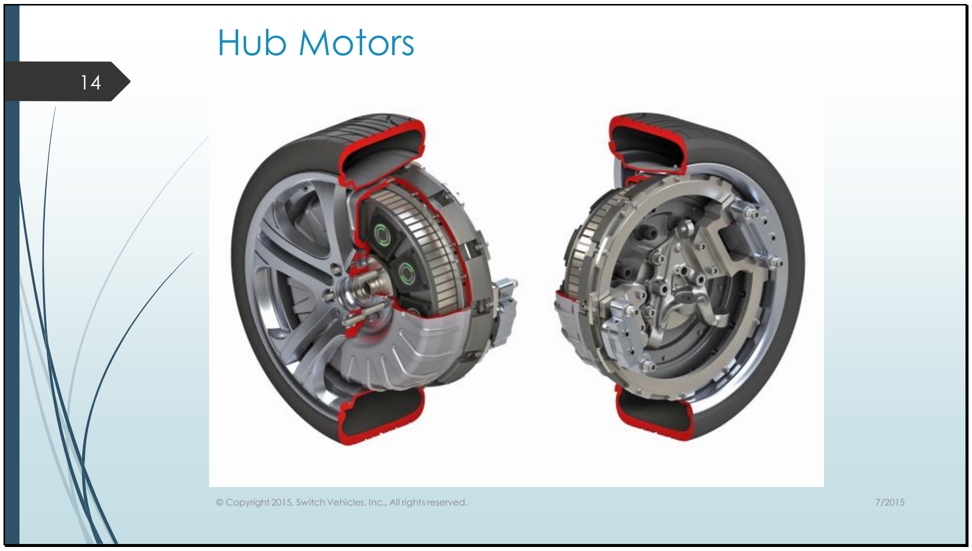
14
Hub Motors
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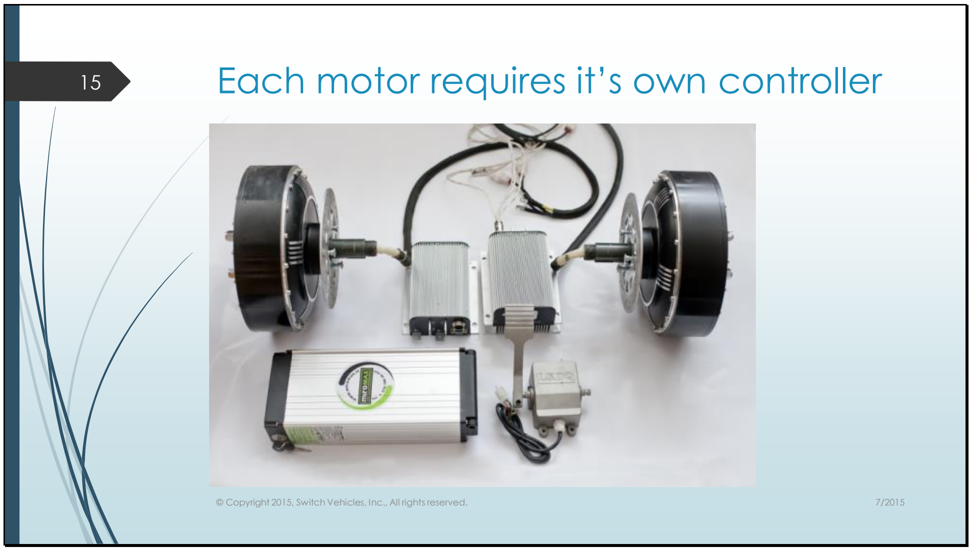
Slide 15


15
Each motor requires it's own controller
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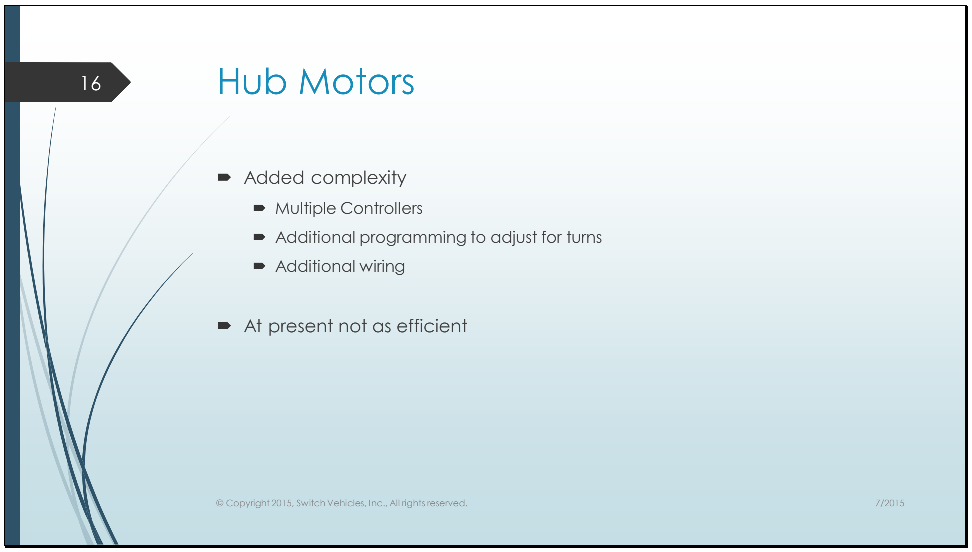
Slide 16


16
Hub Motors
Added complexity
Multiple Controllers
Additional programming to adjust for turns
Additional wiring
At present not as efficient
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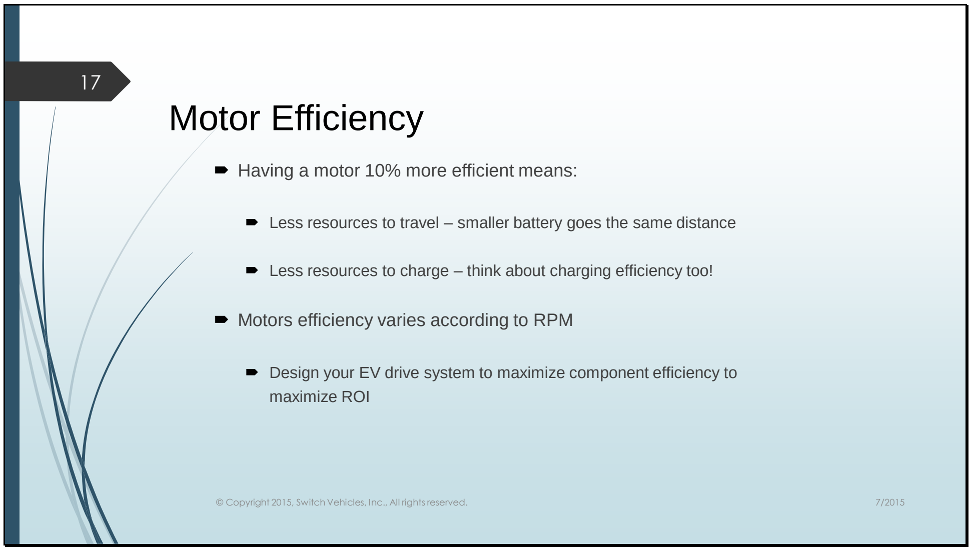
Slide 17

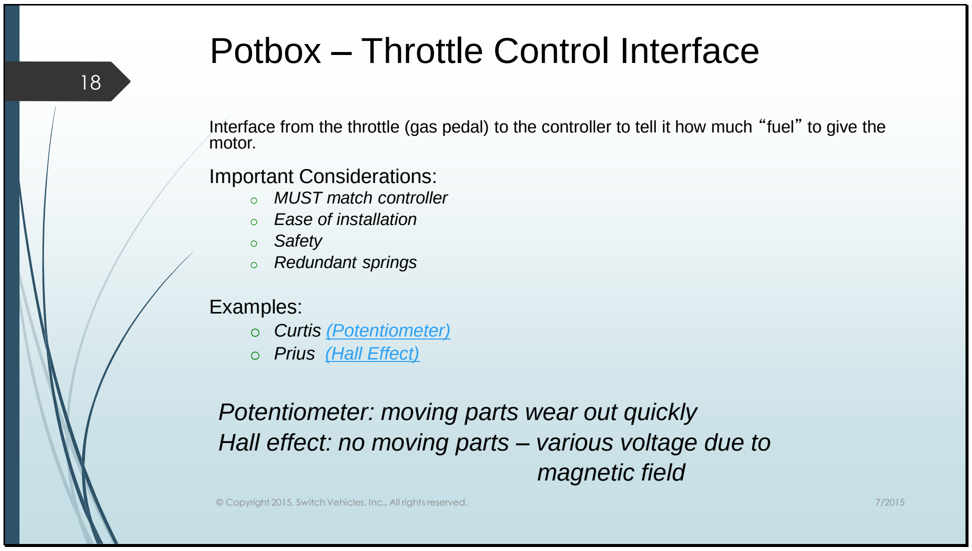


This is an AC motor and we are looking at more complete information is some respects as the efficiency rating includes the motor AND controller, whereas in the previous two slides we only looked at the efficiency of the motor.

This particular motor has two wiring options one for low voltage and one for high voltage you can see that the WYE (pronounced we) is more powerful and more efficient. We will examine this motor more in later discussions as well as looking at graphs to see where it is most efficient but in general AC motors spin at higher RPM levels and have more delivered efficiency then their DC counterparts.

We get a clue about the most efficient RPM levels are when you see that peak torque is between 4,000 and 4,700 RPM.

Slide 18



The potbox, ”pot” is short for potentiometer, receives input from the driver, usually through the old gas pedal now called the accelerator pedal since we have no gas.

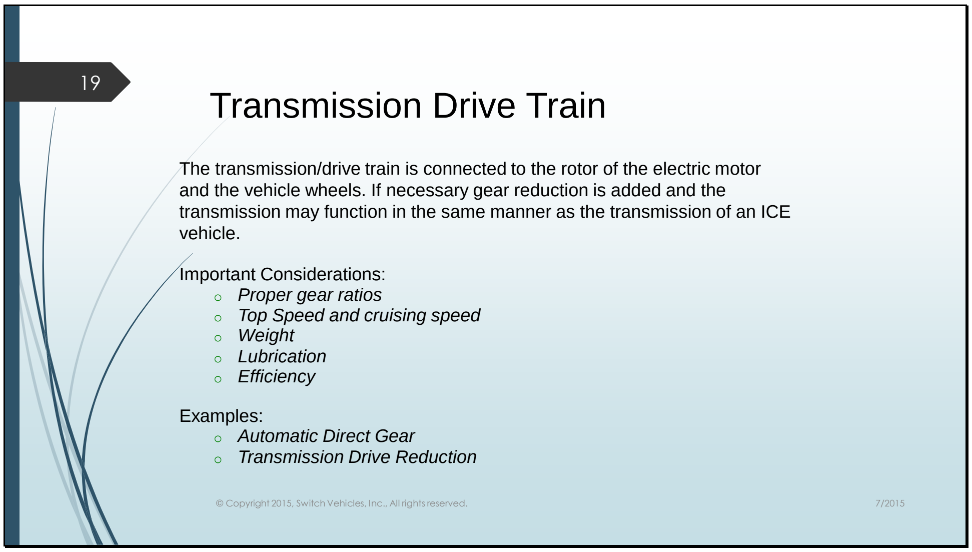
The potbox operates in a specific voltage range, usually 0 to 5 volts or 5 to 0 volts. It is important to match the potbox to the controller as some controllers provide no power at 0 volts and full power at 5 volts while other provide no power at 5 volts and full power at 0 volts. It would be unfortunate to install the wrong potbox.

There are other functions of the potbox, most have a micro switch which is activated by the lever, open when the lever is at rest or in the no power setting. Some controllers check the micro switch at power up to verify that the accelerator is NOT depressed before performing the startup sequence. This safety feature prevents accidental acceleration when the key switch is activated.

There are a variety of potbox configuration ranging from simple boxes with a lever to pedal units with the potentiometer installed. There are also hall effect styles that work with specific controllers. It is critical that you use a potbox that is specific to your controller.

Most potboxs include a return spring, an additional return spring must be added for safety.

Slide 19



There are several options for connecting the electric motor to the wheels of the vehicle:
Direct to the rear differential for rear wheel drive vehicles
Direct to the wheels in the case of hub motors
Via a gear reduction box for either front or rear wheel drive vehicles

To determine the best method you need to make some design decisions as well as assess your capabilities.

You will need to decide how fast you want to drive, how fast you want to accelerate and what range you need. The Trifecta of EV questions. Once you make those three decisions you will need to match the performance parameters of your proposed motor.

Key issues are low end torque as opposed to recommended peak RPM and nominal RPM. A vehicle with a one-to-one ratio between the motor and wheel revolutions per minute will be able to travel at very high speed but acceleration will be very slow unless the motor is very powerful.

Proper gear ratios - Ideally we will match the gear ratios to the most efficient operating range of the motor and controller. Since EV's have low end torque at very low RPM we can use a limited transmission for most installations. Most EV's that are converted from vehicles use the existing transmission, start in second or third gear and may shift in to third or fourth as speed increases.

When we look at the acceleration spreadsheet you can experiment with different gear ratios to select the perfect motor for your vehicle.

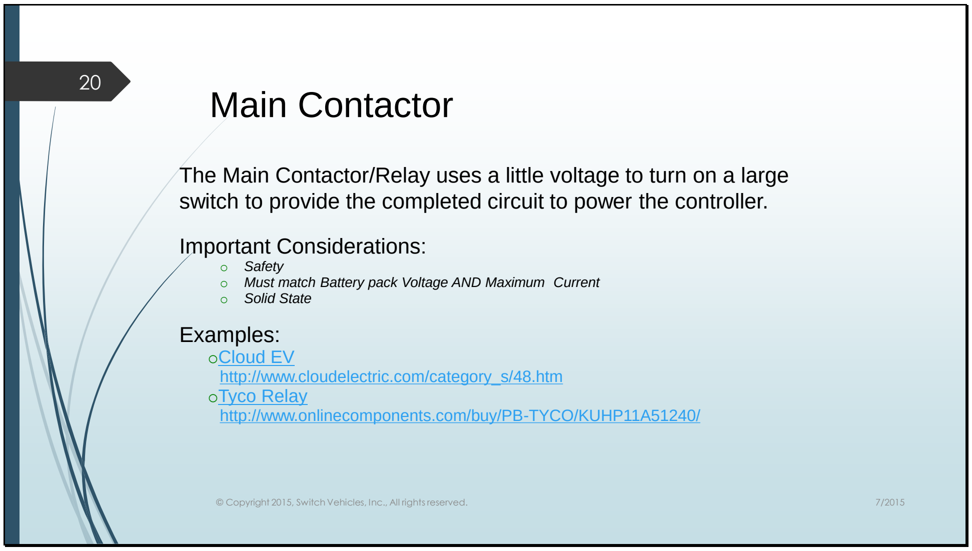
Top Speed and cruising speed – try to select and motor transmission combination that produces the most efficient operation at the desired cruising speed

Weight – You still want to be able to accelerate at a decent rate so the gears need to be low enough for comfortable acceleration

Lubrication – we can use a lighter weight lubricant as there will be a lot less shifting

Efficiency – racing transmissions are not as efficient as the gears are cut square for quicker shifting but actually create more friction, study your gear rations and make you selections

Slide 20



The purpose of the main contactor is to cut the power and de-initialize the vehicles energy supply. Normally I recommend opening the main contactor when the vehicle is powered off and closing the main contactor when charging or driving. This is a safety consideration so the pack voltage is minimized when the vehicle is not in use.

Additionally the main contactor should be opened in the case of an accident or EV event. With a DC vehicle there should be a switch near the driver to open the contactor in the case of a power surge. DC controllers can actually weld them selves into a full power situation and the only way to stop the motor in that event is to cut power externally by opening the main contactor or another fused device.

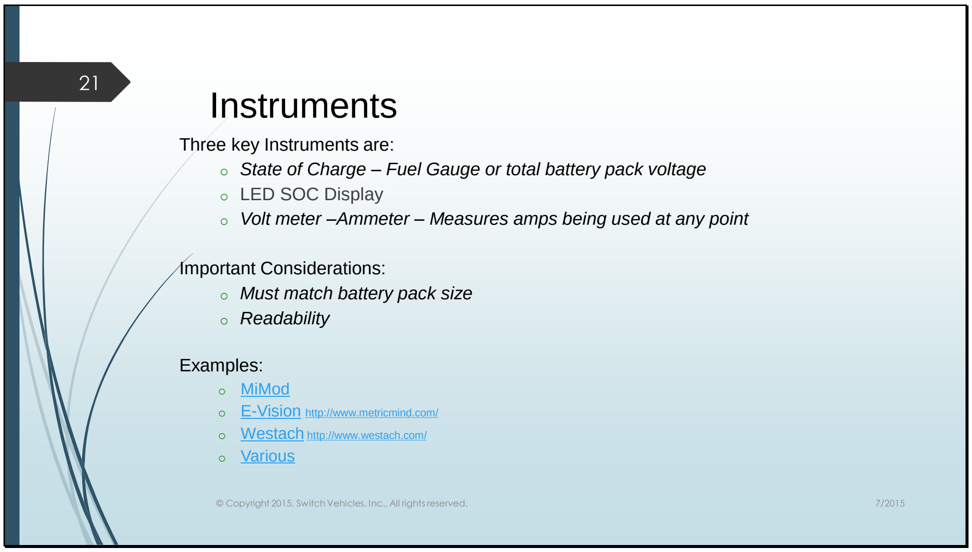
In an AC vehicle we use an inertia switch to cut the 12 volt power to the main contactor in the event of an accident. We will discuss this in detail when we wire the main wiring box.

Contactors are rated for voltage and current. The specifications for the contactors indicate the maximum amount of current the contactor can interrupt or break. You must select a contactor capable of breaking more then the maximum current supplied by your battery pack. There is also a maximum number of times the contactor is "allowed" to break specific current draws.

Most builders recommend that if the contactor is opened while the motor is in a high current draw situation, under a heavy load, the contactor should be replaced. This is because the actual surface area becomes pitted and will then more susceptible to failure because it can weld it self closed under load.

The Kilovac Contactor shown here also includes an “Economizer” upgrade that lowers the power consumption and therefore increase efficiency. Check your installation guidelines as sometimes the economizer function is not allowed, as you wil see in our installation.

Slide 21



The need for a driver to know what is going on with the vehicle is similar to the needs of and ICE driver.

How much fuel is left, or how far can I go before refueling?

How efficiently am I driving. Even most new gas powered vehicles provide an "Instant" fuel consumption reading.
The instruments of the EV must provide the same input. To do that we use three displays. Personally I prefer analog style displays, those with arrows, as opposed to digital read outs. Detroit tried digital read instrumentation some years back but drivers like to be able to glance at a needle and see relatively and quickly where things stand. Digital instruments require a driver to read the number and sort of figure out what it means. Plus is sunlight digital can be hard to read.

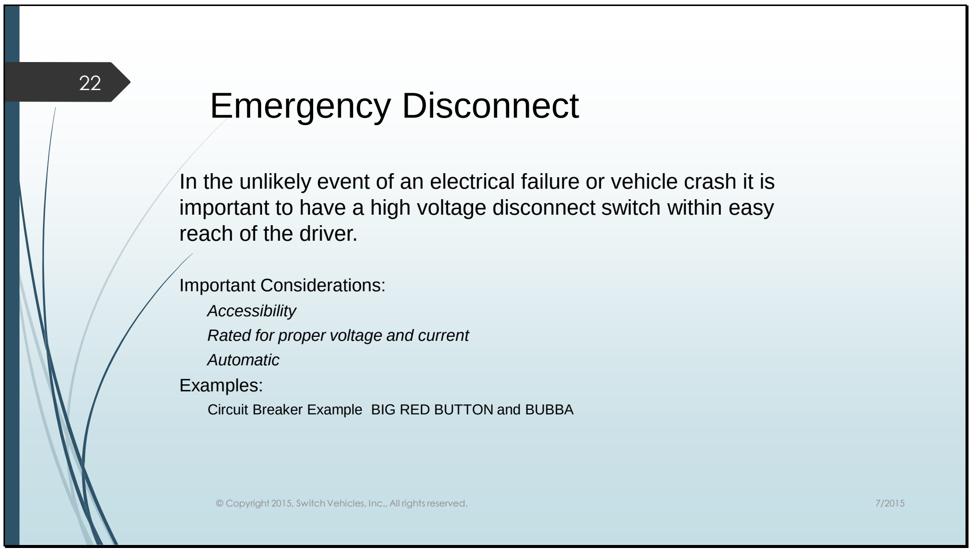
State of Charge – Fuel Gauge one end of the scale is the lowest voltage or "Empty" side, the other is maximum voltage or "Full". This style gauge works well with lead acid batteries as the discharge curve is flat and consistent.

LED SOC - With a Lithium pack the voltage stays pretty high until the cell losses it's charge then drops very quickly. So for a Lithium pack we usually use a coulomb counter with a series of LED's to indicate state of charge. More when we get to BMS.

Ammeter – Measures amps being used at any point. This instrument displays actual current being used and acts like an "Instant" gas gauge. Tells the drive how many amps are being consumed at that moment.

Check the links for some examples.

Slide 22

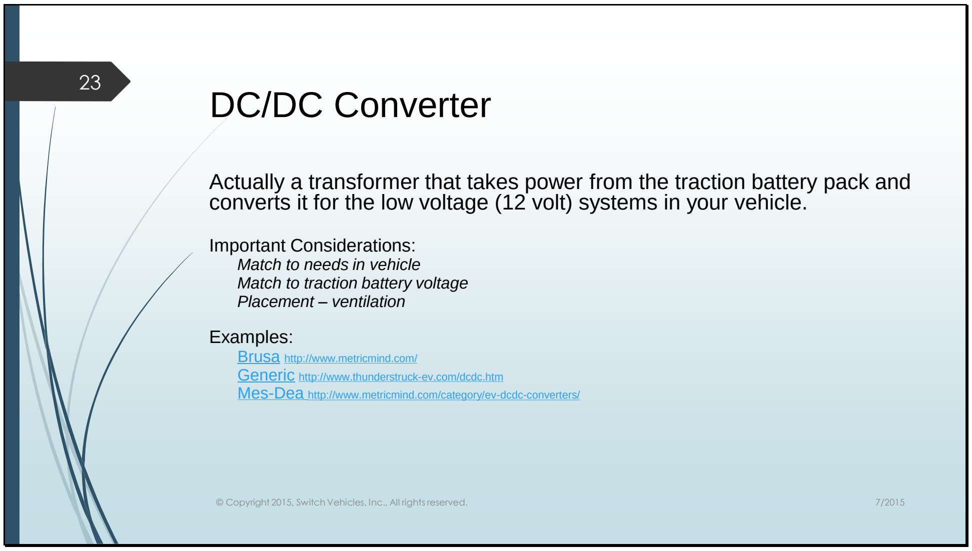


DC vehicles require an “Emergency Disconnect” it was described in detail when we discussed the Main Contactor. In a DC vehicle the emergency disconnect is usually a high capacity fuse opened when the driver pushes or pulls a lever. In an AC vehicle it is usually the main contactor.

Any safety device installed in an EV must be rated for the total voltage and TOTAL current output of the battery pack. As discussed previously.

The Ac vehicle we are building will utilize an inertia switch to automatically cut power to the main contactor to act as an emergency disconnect.

Slide 23



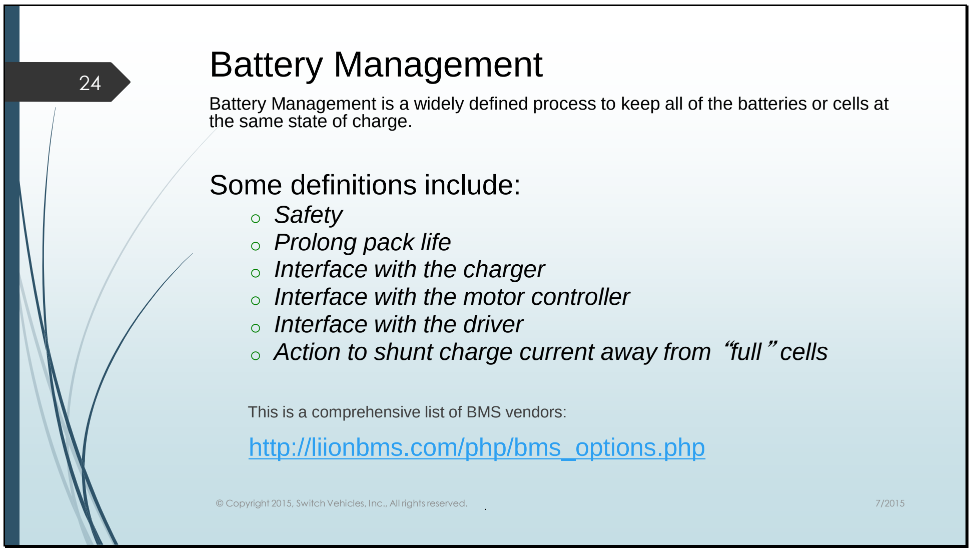
The DC to DC converter does the job of the alternator and must be sized in the same manner when determining the amount of watts are required for the low voltage system. For instance if you have a rather low demand, just headlights, running lights and a radio you would be able to use a 30amp DC to DC converter. If you added a 500 watt amp and a sub-woofer you would need a much higher output for your DC to DC converter.

On the intake side the input voltage range of the DC to DC converter must match the traction battery. Usually DC-DC converters are designed to work within specific voltage ranges. Common sizes range from 48-72 volts or 72-120 volts, some are 100-200 volts and then some are 240-440 volts with a variety of outputs and features.

Placement – ventilation and vibration. All DC to DC converters have large heat fins to dissipate heat, remember heat is a euphuism for lack of efficiency, but they all have fins and need air circulation. Some will even have cooling fans to provide more air flow.

So plan to mount your DC-DC converter on rubber and in an area where you may get some air flow.

Slide 24



Cells or batteries in an EV are connected in series to increase voltage. Cells charged in series will deviate in relative state of charge over time. It is important to monitor each lithium cell and control the charge and discharge cycles to prevent cell damage or fires.

Safety – there are two main justification for the BMS – prevent fires and cell damage while charging or discharging
And prolonging the pack life. The battery is generally the most expensive component and needs to be protected as such.

Interface with the charger – the BMS MUST be able to turn off the charger when a SPECIFIC cell reaches a full state of charge to prevent cell damage and possible fire.

Interface with the motor controller – the BMS MUST be able to power off the motor controller when a specific cells reaches the low voltage cut off to prevent over discharge, cell damage and possible fire.

Interface with the driver – The BMS should tell the drive what is going on with the battery pack. Warn by exception and even intervene if required.

Action to shunt charge current away from “full” cells – by balancing the cells the BMS can maximize pack life improve range and keep the pack as healthy as possible for as long as possible