Losses in AWG 2/0 and 4/0 Cables

Background:

High power applications require that the cables used have adequate current carrying capability. An appropriate American Wire Gauge (AWG) size should be selected. The lower the AWG number the larger the cross sectional area of the wire and the greater the current carrying capability, but also the heavier and more costly the cable. For electric vehicle traction power cables, sizes AWG 00 (a.k.a. 2/0, or spoken as "two ought") and AWG 0000 (a.k.a. 4/0, or spoken as "four ought") are commonly used cables.

Selecting the appropriate size cable involves two considerations. One consideration is the voltage drop due to cable resistance while conducting large currents. The other consideration is the heating of the cable due to the resistive losses of the cable. Voltage drop reduces the available battery voltage applied to the controller and thus to the traction motor. When this is excessive it reduces top speed and maximum horsepower available from the motor. Cable voltage drop is a function of the AWG size and also directly a function of length. Generally, both 2/0 and 4/0 cable have very small voltage drops at typical lengths (say 10 feet of less). But the caveat remains; do everything reasonable to keep total cable length (both positive and negative cables) as short as possible.

The heating of the cable does not depend on length of cable, assuming that the cable is not coiled or folded back on itself in a confined space. This would make the heating worse. And this would also contradict the caveat given above for voltage drop. Heating loss goes up dramatically for smaller cables since the cross sectional area goes down. Smaller cables have higher resistance, producing more heat, and also less surface area, which reduces the cable's ability to dissipate the heat. These two factors combine to raise the temperature of smaller cables much more than larger cables.

Analysis:

A few assumptions are made to simplify the analysis. It is assumed that the total path length of the cable is 10 feet (i.e. 5 feet positive and 5 feet negative cable) and that the maximum current applied, even for short times (a few seconds) is 1000 Amperes. The voltage drop for a different cable length is proportional to actual length, ex. 20 feet of cable would have twice the voltage drop. The voltage drop for a given length of cable is also proportional to a different current, ex. 500 Amps gives half the voltage drop.

Table 1, below, lists some parameters for 2/0 and 4/0 cable. The first three columns are AWG stranded wire specifications. AWG specifies the cross sectional area, and thus the resistance per foot, for each gauge of wire. For large stranded cables there are several physical configurations for the stranding in the cables. The different stranding produces cables of slightly different diameters. In the diameter column are listed the range of diameters for the three 'fine' strand versions of the respective cables that would probably be used for electric vehicles because of their greater flexibility compared to the 'course' stranded configurations. From these ranges of diameters a nominal diameter (0.48" for 2/0 and 0.64" for 4/0) was chosen for each cable to allow calculation of a single value for cable surface area.

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Table 1: Cable parameters and calculated values.

AWG	Diameter	Ohm/1Kft	$V_D^\dagger$/10ft	$W_D^\dagger$/ft	Area/ft	$W^\dagger/in^2$
2/0	0.47" – 0.53"	0.0779	0.78V	78W	18 in^2	4.3 W/in^2
4/0	0.60" – 0.66"	0.0490	0.49V	49W	24.1 in^2	2 W/in^2

† at 1000 Amps. of current

The fourth column is the calculated voltage drop produced by ten feet of each cable size at 1000 Amps. 1000 Amps may seem too high for some electric vehicle applications, but peak power levels for traction motors can be four or five times their continuous duty ratings. Controllers often handle 1000 Amps or more. While this will not be the steady condition for the vehicle, it can exist for several seconds or even a minute or more. This is long enough to generate significant heat in the cable. Analysis at 1000 Amps gives some safety margin and removes the need to account for changes in cable resistance with temperature. Cable resistance increasing slightly as cable temperature increases. The increased resistance causes greater power dissipation, which causes greater heating than if the cable was at the original test temperature.

The fifth column is the power in watts dissipated by each foot of cable at 1000 Amp current. Treating the outside of the stranded copper as a cylinder allows a surface area per foot to be calculated for each cable size based on the selected "nominal" diameter for each cable. This is listed in column six. Column seven is the result of dividing the power dissipated per foot by the surface area of the copper to determine a "heating factor."

Conclusion:

It can be seen from column four of Table 1 that the voltage drops for both cables (at 10 foot length and 1000Amps) are very small compared to the voltage available by the battery pack. Based on voltage drop, 2/0 is just as usable as 4/0 cable. (Note: Generally voltage drop due to short cable itself are insignificant, BUT voltage drops at connection points, i.e. battery posts, controller terminals, etc. can be several times larger. Make sure all connections are made tightly between bright shiny copper. Even small amounts of dirt, oil, or tarnish can degrade overall cabling performance.)

From column seven of Table 1 it is seen that heating factor is more than twice as much for 2/0 than for 4/0, even though it takes six size differences in gauge to result in half the cross sectional area of the cable.

But is this a reason not to use 2/0 cable? It is difficult to give a definite answer with what is known. Actual temperature rise at the surface of the copper inside the insulation of the cable is the critical parameter. This temperature should not exceed the allowed temperature of the insulation, with some safety margin (don't want to melt the insulation and expose the copper). Temperature rise depends on how well the heat can be conducted into the surrounding air. The specifics of the cable insulation, the ambient conditions of the cable, and even the surface of the copper all affect how the heat will be dissipated and thus the actual copper temperature.

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An opinion is that 2/0 cable could get quite warm with hard driving. In comparison, a common 60W light bulb has a surface-heating factor of about 3 and gets too warm to hold in your hand. But then again that is continuous heating, whereas the 1000 Amps for the electric vehicle is intermittent. Please note that it is not the temperature on the outside of the insulation (the part you can touch) that matters, but the peak temperature at the surface of the copper under the insulation.

If you have already purchased the 2/0 cable, you might try it (the experimental approach) and after a period of hard driving, check the cable (ideally in a place where it gets the least amount of cooling) and see if it feels very warm or if the insulation feels soft or smells ‘cooked.’ If so, then consider changing out the 2/0 for 4/0. In contrast, your driving demands on the vehicle may be mild and the cable you selected may have insulation with a higher temperature rating, so 2/0 could be suitable. But 2/0 potentially could be a problem, so check it when the car is built to be sure you don’t have a problem.

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