Drive Selection for Electric Kart

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Abstract

In this paper the parameters for choosing an electric drive for an electric kart have been analyzed. The advantages and disadvantages of different electric drive configurations had been shown while focusing on development of academic research prototype for future use in student education.

Keyword

Electric vehicle, electric kart, electric drive, DC motor, AC motor, power electronic converter.

Introduction

The idea of personal electric vehicles is becoming more popular in recent years. Electrical vehicles are energy-effective, fuel-saving and emission-less transportation [2]. It is the frontline of civil research and advancement, and it is attracting much of the world wide academic attention and research funds.

In light of the growing importance of this field and the lack study model in the faculty, it was decided to set out and develop an electric vehicle that will serve for both educational purposes and research as well as to inspire and serve as a basis for future developments and advancements into this growing, important academic field.

Because of mounting convenience, mechanical and economical reasons a small one-man kart model was selected over a full size car. The aim of the model is to be as simple as possible mechanically and to allow modular and upgradable design of the electrical system.

Out of the general desire to simplify the mechanical aspects of the project, it was decided that each of the rear wheels of the kart will be directly connected to separate motor, which might add some complexity to the control but also allow great many further features, for example the implementation of an electronic differential, which might not be especially important for a small kart, but it is an obvious part of any full size car.

1. Parameters of the Drive System

Any equipment (not only electrical) is estimated from the point of view of its supply, load and specific features. In the context of choice of electric drive the supply is an autonomous electrical energy source, load is estimated through its mechanical parameters (weight, top speed, acceleration and output power) while the specific requirements mostly regards the power electronic converter of the drive. In this section main parameters are defined.

1.1. Supply

The voltage source of an electric vehicle is most typically a battery of some sort. Easily accessible and reasonably cheap batteries are lead-acid 12 V batteries. Such batteries can be connected in series to achieve a higher voltage, however due to their weight and size it was decided to settle for a total of two batteries giving 24V/50 Ah. Further development of the vehicle includes also installation of some more capacitive energy source like a fuel cell but this topic is not included in this report.

1.2. Weight

The most critical parameter of a drive system is the weight it needs to move.

For some of the main components of the kart the weight is already known:

- Chassis
- Batteries
- Passenger (estimated average weight)

A significant part of the overall weight of the kart is the weight of the motors. The weight of the motors is greatly dependent on the type of the motor used for the same power rating of a motor, the weight can vary significantly (for example a permanent magnet DC (PM DC) motor can be two times lighter than a series excited DC motor).

Typical power-to-weight ratio of different motors types are given in Table 1. This parameter shows how much power can be drawn from electrical machine per one mass unit.

<table>
<thead>
<tr>
<th>Special purpose PM DC</th>
<th>PM DC</th>
<th>DC series excited</th>
<th>AC Squirrel-cage</th>
<th>Special purpose AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>0.14</td>
<td>0.09</td>
<td>0.17</td>
<td>0.75</td>
</tr>
</tbody>
</table>

According to Table 1, and the approximate power of the motor, the probable weight of the motor is assumed to be about 20 kg. This gives a total weight for the kart of around 200 kg.
1.3. Top Speed

As it was mentioned above one of the main goals is to match the performance of the combustion engine. The top speed is chosen to be 60 km/h, in order to show reasonable performance in comparison to commercial karts, while still aiming to design a model for academic research, which involves certain safety limitations.

If the wheel diameter is known to be 0.29 m then the motor rotational speed can be calculated as:

\[ n = \frac{V}{\pi D} = 1099 \text{ rpm}, \]  

where \( n \) is the rotational speed of the wheel, \( V \) – the top velocity and \( D \) is the wheel diameter. The resulting velocity is less common for industrial motors, and for this reason it was decided to use a gearing mechanism with a ratio of 3:1 which means the top speed of the motor should be 3297 rpm.

1.4. Power

The required power of the motor can be calculated from the parameters derived in the previous sections.

Assuming the kart is moving at constant maximal acceleration, from 0 km/h to top speed, the maximal power can be calculated according to:

\[ P = \frac{W}{t} = \frac{F \cdot s}{t} = \frac{m \cdot a \cdot s}{t}, \]  

where \( m \) is the mass of the kart, \( a \) – the maximal acceleration of the kart, \( s \) – the distance passed during the acceleration to top speed and \( t \) is the time that that acceleration took.

The time \( t \) is chosen to be 6 seconds following empirical assessment.

The distance \( d \) can be calculated according to:

\[ s = V \cdot t - \frac{a \cdot t^2}{2} \]  

Acceleration \( a \) can be calculated according to:

\[ a = \frac{V}{t} \]  

Combining equations (3), (4) and equation (2) gives:

\[ P = \frac{mV^2}{2t} = 4.6 \text{ kW} \]

In order to simplify the selection of the motor it was decided to take this maximal power into account as the rated value. Then the motor must be chosen with rated power higher than the calculated one in equation (5) in order to over come possible inaccuracies in the given parameters of different elements in the kart and also losses in the system that are not appearing in the above calculations.

2. Electrical Drives

With the different parameters selected, the next step is to choose the drive system for the electric kart. There is no definite best solution for an electric drive system. So, different configurations of the drive should be analyzed in respect to needed performance of the system.

The analysis includes DC motors with permanent magnet and electric excitement, AC squirrel-cage motors, AC permanent magnet synchronous motors and suitable power electronic converter for each machine.

2.1. DC Machines

DC machines are the oldest machines introduced in the market, but even though, they still show good characteristics. DC machines can be driven with simple and efficient circuits with low number of components, and are widely available.

Downsides of DC machines are their relatively high maintenance needs (due to wearing out of the brushes), their relatively high weight and the effect of sparking of the collector can exclude them from being used in many environments.

The most common DC machine for vehicle applications is the series excited motor whose characteristic curve is shown in Fig. 1. Such characteristic curve can support an stable operation of the motor at any mechanical load above 25% of its nominal load. The motors torque is proportional to the squared current through the motor which is important when handling overload situation.

![Fig. 1. Characteristic curve of series excited DC motor](image)

Another DC machine architecture which is growing more popular due to improvements in magnets technology is the permanent magnet DC motor whose characteristics are similar to those of the separate excitation motors (Fig. 2.). The permanent magnet motor has some good properties in respect to the series excited motor, such as a lighter weight and also a higher efficiency due to the lack of an electric excitation.
DC machines are available in low rated voltages which are suitable for personal electric vehicles (like the kart) that are likely to run on low voltage batteries. Since the voltage source for the kart is, as mentioned, most likely to be a DC voltage source, then the use of a DC machine is much simpler. If there is no need for regenerative braking then a simple buck-boost circuit, using only one switch, is sufficient to control the motor. The control strategy in this case is voltage PWM that is done through commutation of the converter’s switch.

The kart described in this paper includes regenerative braking. Hence, a more sophisticated circuit should be chosen (such as a full bridge converter or split-πi converter). This will require more switches and more complicated control, thus increasing the size and cost of the whole system.

### 2.2. AC Machines

AC machines are very common industrial machines. AC drives have no built-in mechanical commutation device like the brushes in DC machines. This almost removes the need of maintenance and allows a completely sealed package that allows working even in hazardous environments. AC machines usually have slightly higher efficiency than DC machines and also a better power-to-weight ratio (especially for high power rates).

However, when they are fed from a DC supply and when there is a need for a good control over the motors speed, AC machines requires an inverter since their speed is controlled by the frequency of the applied voltage not by its magnitude. The need for an inverter is posing a complexity of the control system and its cost as well as decreasing the overall safety of the drive.

In addition, AC machines most commonly have high rated voltage, and it is harder to find an AC machine with a rated voltage low enough to use without boosting the batteries voltage.

The described kart includes only a basic gearing and does not allow un-loading the motor for start-up. That is why when choosing an AC machine for the kart it is reasonable to prefer a squirrel cage motor over a synchronous motor since the design of the kart does not include any velocity feedback device.

Such choice is defined by the start-up characteristics of synchronous motors.

### 2.3. Practical considerations

On the one hand the AC machines have better efficiency and higher reliability. They are also less expensive. This is especially evident on large power rate motors. At the power rates discussed in this article for the mentioned kart (under 10 kW), the difference is getting less significant.

However, as can be seen in Table 2, even the simplest power converter for AC machine has a significantly higher part count and thus a more complicated control and higher costs.

#### Table 2. Optimal number of switches needed per machine

<table>
<thead>
<tr>
<th>Voltage source matches rated motor voltage</th>
<th>Regenerative braking</th>
<th>DC</th>
<th>AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 2 is written under the following assumptions:

1. An AC machine is a 3 phase one. This means a full bridge, consisting of 6 switches, is necessary for controlling the speed of the machine. Single phase AC machines exist, however they are rare and less successful.

2. Changing the voltage source voltage can be done with a simple step-up DC/DC converter which requires a single switch.

The number switches is taken as indicator for the complexity and cost of the control circuit since it is one of the more expensive components and definitely requires the most control effort.

### 3. Selected system

Compiling all the parameters, a DC motor was chosen:

- Manufacturer Mars Electric LLC
- Part number ME0709
- Rated power 7 kW
- Nominal voltage 72 V
- Rated torque 20.3 Nm
- Loaded speed 3300 rpm
- Nominal current 114 A
This motor was chosen mainly due to its good power/weight ratio, accessibility and rather low price.

The electrical drive system was chosen to fully support the above mentioned motor (boost-up the battery voltage to 72V) and allow the regenerative braking. Another reason is avoiding the use of transformer due to its large weight and cost.

A split-Pi converter was chosen since it gives all the above qualities with minimal switch count (4). It has relatively simple design and high theoretical efficiency of 96% [6]. Split-Pi is essentially a boost converter followed by a buck converter. The circuit (Fig. 4.) allows bi-directional current flow which in turn allows regenerative braking [5] that suits the kart needs.

4. Conclusions

This paper offers a set of considerations and parameters to take into account when approaching the task of choosing a drive system for a small scale electric vehicle, in this case – electric kart.

As a result of the described process the drive system was premeditated in order to eventually develop a fully functional prototype for academic research.

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