

DC Motor Power Supply for Electric Kart

Kristaps Vitols (Doctoral student, *Riga Technical University – RTU*), Nadav Reinberg (*Master student, RTU*), Ilya Galkin (*Professor, RTU*)

Abstract – The aim of this paper is to provide thumb rules for developing power supply for an electric kart with a DC motor. Article includes consideration of battery system and designing process of power converter. A battery selection flowchart is introduced. Converter operation in buck mode is tested and evaluated. Needed improvements are discussed.

Keywords – electric kart, EV, buck and boost, battery selection

I. INTRODUCTION

The idea of personal electric vehicles is becoming more popular in recent years. Electrical vehicles are energy-effective, fuel-saving and emission-free. 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 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 and important academic field [6]. Because of mounting convenience, mechanical and economical reasons a 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 connected to separate motors, which have already been preselected [5]. The purpose of article is to develop motor controller power part, in order to use the kart in experiments with different control methods like use 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.

II. BATTERY SETUP

Today most available types of batteries that are used in electric vehicles (EV) are: lead-acid, nickel-metal hydride and lithium ion batteries (lithium-ion, lithium polymer, lithium iron phosphate). The lead-acid batteries are the oldest type of rechargeable batteries. They have low cost, high durability, require less maintenance and also can provide needed power for an EV, but they have low energy-to-weight ratio and low energy-to-volume ratio. Nickel-metal hydride batteries have greater energy-to-weight ratio and greater cycle durability, but lower charge/discharge efficiency and greater maintenance compared to lead-acid batteries. Lithium batteries are most expensive, but they have higher energy-to-weight ratio, high

charge/discharge efficiency, and good cycle durability. Yet they require more complex maintenance [4].

Main criterion for battery selection is the load – motor. The kart motor is selected to be a DC motor, with rated power 7kW at nominal voltage of 72V. Motor nominal current is 120A. It was decided to set the maximal motor current same as nominal, because it is enough with both motor rated power to achieve reasonable kart performance. Although DC motors are not highly efficient and are hard to maintain, despite they were selected because of their simple control. Motor parameters were used to determine the battery.

If multiple batteries are used then they are connected in series, in parallel or in a matrix setup. In series connection the battery pack voltage is the sum of all the individual batteries in the pack. Battery pack series connection is efficient to achieve needed nominal voltage if all units have same parameters and age. In the case if one of the battery pack units is faulty then either the needed voltage will not be supplied or the batteries will not supply power at all. Series connection usually is equipped with balancing scheme and has a complicated charging device (especially for lithium type batteries). A cheap and convenient solution can be achieved by using lead-acid batteries in serial connection. In current case, six 12 volt batteries would give 72 volts in total. All pack can be charged together with one charger, however it is recommended to charge batteries individually.

Use of parallel connection can give high current, but this setup requires step-up converter to reach motor nominal voltage. In turn, this increases the design complexity, cost and also requires large conductors and inductors. Losses are higher due to the high current. On the other hand only one charger is required in parallel connection and it can charge all the paralleled batteries simultaneously. There is one more important drawback. In order to detect a faulty cell it is necessary to take the setup apart and test each cell individually. In some cases such actions are hard to perform.

There is another possible connection – series and parallel connection. In fact each battery pack generally is a matrix of basic battery cells, combined in series to achieve higher voltage and in parallel to achieve higher current capabilities. Connecting several of such battery packs in an array is common practice in many power appliances, particularly in electric vehicles, where the battery packs require large voltages and ampere hour ratings. This solution requires more batteries, as a result costs and overall weight is increased.

III. BATTERY SELECTION

To ease the process of battery selection, a specially developed flowchart (Fig. 1.) can be used.

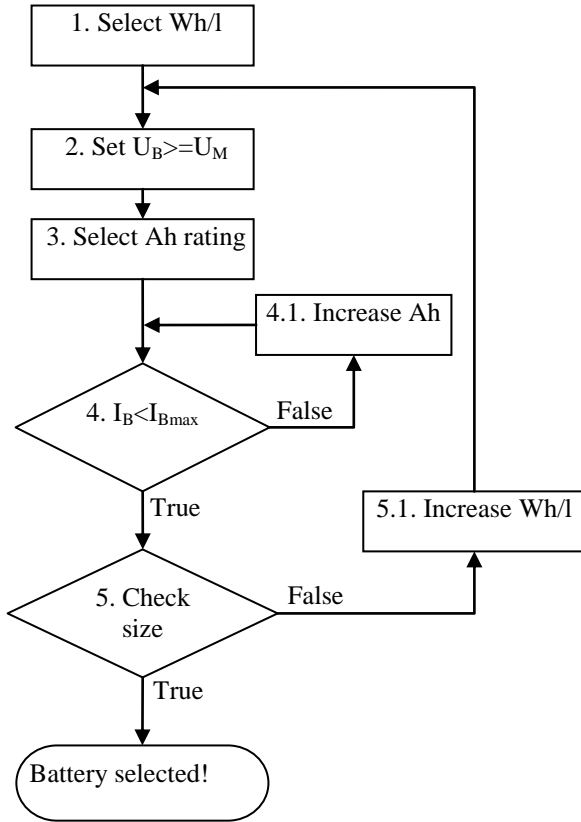


Fig. 1. Battery selection flowchart.

Selection process is explained in the following text:

1. The first step in selecting a battery is to choose battery energy to size (Wh/l) ratio. Generally there is only little difference of Wh/l ratio among one battery type. To get different power ratio, it is necessary to pick different battery type. The main drawback of just picking battery with the best ratio is that batteries with higher Wh/l are more expensive. Thus it is recommended to begin with lower energy batteries and if they do not fit – increase Wh/l ratio.
2. As concluded in second chapter, the most fitting solution is to connect batteries in series. The voltage that is needed to achieve with series connection is the same or higher than motor nominal voltage. In this step the needed amount of batteries is decided.
3. In third step battery Ampere-hour (Ah) rating is chosen. First, Ah rating directly shows the energy amount, second Ah rating correlates with the maximal current that can be drawn from battery: higher Ah – higher max current.
4. If the chosen energy rating does not provide necessary current, then the Ah rating has to be increased.
5. Last but not least, battery pack mechanical properties must be evaluated. Since kart does not have a lot of free space, battery size might become a problem. If so, a return to the first step is necessary: higher Wh/l ratio

must be selected. Battery weight can be taken into account in a similar manner.

The selected battery pack size can be smaller than available battery compartment space. In that case it is recommended to increase each cell Ah rating in order to get higher capacity battery pack. More capacity will provide more range to the kart.

Using given flowchart a battery pack was selected for the kart. The series connected pack was constructed of six high discharge rate valve regulated lead acid batteries rated 12V 22Ah nominal each. Battery maximal discharge current is 300A.

IV. CONVERTER DESCRIPTION

Power controller is the device usually referred to when discussing EV motor control. Typically power controller consists of a power converter and controller board, which measures input signals and produces appropriate control signals for power converter switches. The main purpose of power converter is to achieve user defined speed by precise delivery of the necessary power to the motor and as well regenerate kinetic energy back to the battery when vehicle is braking. The kart is equipped with permanent magnet DC (PMDC) motors. Since there is no excitement winding, the control of motor and regenerative braking is fairly simple. A buck and boost circuit (Fig. 2.) is sufficient to meet the requirements mentioned above.

Operation of kart can be divided into two modes: driving and braking. In driving mode the high side switch (VT1 and VT11) is controlled with PWM signal from control board. The low side switch (VT2 and VT22) turned off. The circuit works as a buck converter. In braking mode high side switch is turned off and low side switch is controlled with PWM to boost motor back EMF voltage and charge the batteries.

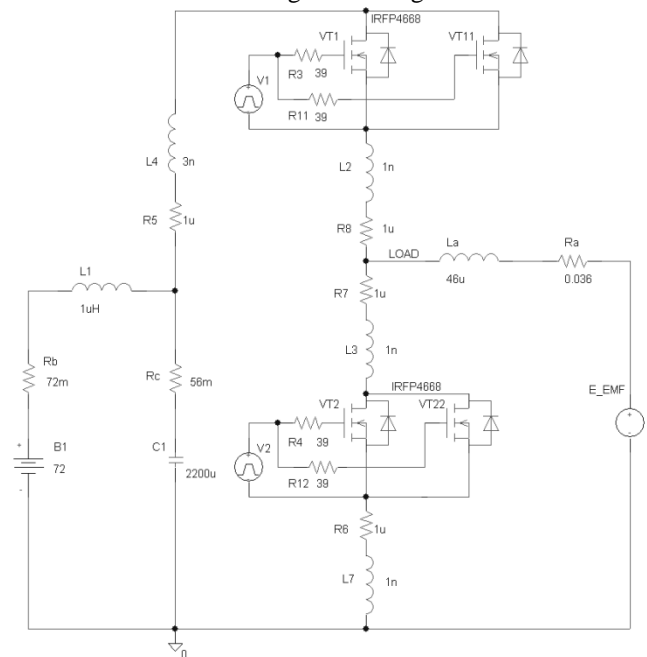


Fig. 2. Converter circuit in Orcad Schematics.

V. PRACTICAL CONSIDERATION

Despite the fact that converter circuit is rather simple, there are some issues regarding specific converter. The converter input current will reach 120A at max power. At such current rates voltage overshoots produced by leakage inductance and conduction losses become important issues.

The analysis of the converter begins with assessing the losses of the selected switch. A MOSFET switch was selected since for the planned switching frequency (50 kHz). IGBT switch was not chosen due to lesser performance at such frequency.

The switch losses are composed of two components: the conduction losses, which are the result of the switch resistance (R_{DSon}) while conducting the rated power; the switching losses which arise from the transient process on the device.

Hence, with a chosen switch (IRFP4568) and the known rated characteristics, the switch losses are calculated as instructed in [2]. Total switch losses are $P_1=154W$. The result suggest that the chosen switch can dissipate the power it is expected to be loaded with, as the datasheet of the device state the maximum allowed power to be applied on the transistor is 327W. However, this value is given assuming an ideal heatsink, which can take any amount of energy without a change in temperature. In a real case, the heatsink thermal resistance to the ambient should be evaluated and then the junction temperature can be calculated. Taking an optimistic value for the heatsink to ambient thermal resistance of $R_{\theta CA}=0.8\text{ }^{\circ}C/W$ (assuming some sort isolation will be needed), a value for the junction temperature T_J can be calculated to be $230^{\circ}C$

The conclusion is that the switch will fail even for this thermal resistance value. There are several ways to treat this:

- Apply external cooling devices like fans or water cooling. This will give limited result and is probably not sufficient in this case.
- Choose switch rated to higher current. Such transistor will have lower R_{DSon} and therefore lower losses. However the selected switch already has a rather small R_{DSon} value and a device with a meaningfully smaller one can be expected to be very expensive.
- Reducing switching frequency will reduce the switching losses. However this will also increase converter passive component size and complicate the control of it.
- Reducing the transistors gate resistance, will reduce the switching losses significantly, but will increase the drain voltage overshoots.
- There is the option to connect and control two identical transistors in parallel. This way the overall conduction losses are reduced as the equivalent R_{DSon} of the paralleled transistors is half the original and the switching losses are divided between the two switches.

The down side to applying the last suggestion is the required symmetry when implementing. If a time difference will occur between the two gate pulses then for that time period the full current load will be applied on the transistor that will conduct first. Unequal line inductances at the drain or source of the transistors pair will have a similar affect, as one

transistor will take the current load faster than the other. This will result in unbalanced thermal load between the transistors and at extreme cases will over-load one of them and shorten its lifetime [1].

To decrease this effect, precautions should be taken during layout of the board. In particular, the conducting lines between the bus voltage and the transistors drain and also between the bus bottom rail and the transistors need to be as geometrically symmetrical as possible, in order to equalize the parasitic inductances they induce, and the lines from the gate driver to the transistor gate should be as equal in length and width as possible in order to equalize the gate resistance and propagation time of the signal.

VI. CONVERTER SIMULATION

In order to get a better understanding of proposed converter operation, it was simulated using Orcad PSpice simulating software. Circuit was simulated at 50% duty cycle. In the simulated circuit several parts were improved to better match their real life models. Source battery B1 is in series with its internal resistance resistor R_b with value $72m\Omega$. Half bridge decoupling capacitor C1 is in series with its equivalent series resistor R_c with value $56m\Omega$. Since model for the transistor used for actual converter was not available, another similar model was used. Both switches in simulation circuit are made of a pair of IRFP4668 model transistors. The chosen transistor model is fairly similar to actual transistor. The R_{dson} resistance is $5m\Omega$ higher and there are minor changes in other parameters. Simulation still gives a good look at actual problems, like voltage overshoots produced by leakage inductance (Fig. 3.). Motor was modeled with its measured armature inductance in series with armature resistance and back EMF.

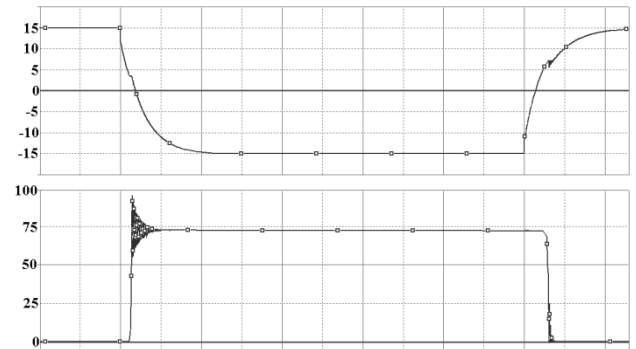


Fig. 3. Top: Switch Gate-Source voltage, bottom: Switch Drain-Source voltage ($1\mu s/div$).

Simulated MOSFET drain-source turn-off transient has voltage oscillations, which increase transistor off-state voltage by 26V. These oscillations are caused by leakage inductance. Transistor gate voltage has rather slow rise and fall time, which can be improved by changing gate resistor value. Decreased gate resistor would decrease switching time thus lower the commutation losses. The drawback is that faster transient will have larger voltage overshoot.

VII. EXPERIMENTAL RESULTS

Some experiments were done to inspect converter operation. Experiment was done with setup shown in Fig. 4. Batteries B were connected to the converter. Converter was constructed according to previously mentioned practical considerations. Actual motor M was connected to the converter output. To load the motor a permanent magnet three phase synchronous generator G was used. Load was set to 1250W using variable resistors R connected to the generator terminals.

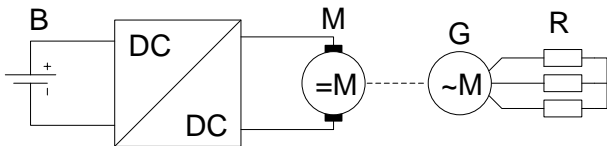


Fig. 4. Experimental setup scheme.

Same as in simulation 50% duty cycle was used to observe switch voltage (Fig. 5.).

Experimental results differ from simulated. Voltage overshoots on the transistor are larger; voltage spike at turn-off reaches 116V. This can be explained with excessive leakage inductance. Voltage ringing is observed at turn-on transient as well.

At set output load, battery current and voltage was measured to get converter input power: 1,93kW. When motor and generator losses are added to output power it is possible to determine converter efficiency. Converter output power is 1,77kW. Estimated converter efficiency is 92%.

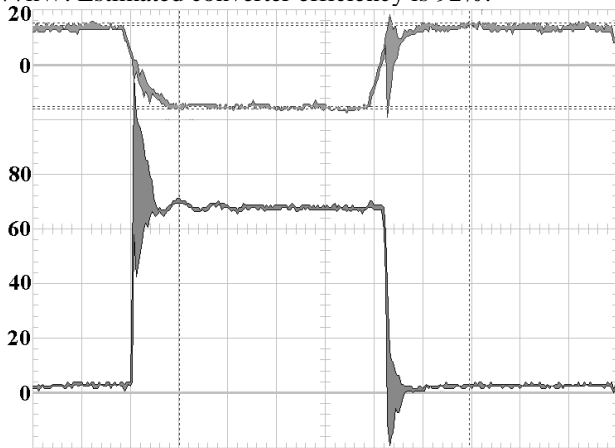


Fig. 5. Top: Switch Gate-Source voltage, bottom: Switch Drain-Source voltage, (2 μ s/div).

VIII. CONCLUSIONS

Different battery types and battery connections were discussed in order to produce effective kart battery selection algorithm. With minor improvements this algorithm could be used for different applications as well.

General application-specific buck and boost converter thumb rules were introduced. These recommendations should be further improved to gain better converter qualities.

Proposed converter was simulated and experimentally tested. Due to leakage elements, experimental model had voltage overshoot problems. Switch drain peak voltage reached 116V. A snubber circuit should be incorporated in design to protect switch elements.

Converter efficiency was calculated to be 92% at 1,77kW output power, but these results are not feasible due to the battery discharge. Experiment should be repeated with better decoupling capacitor and a snubber circuit as well as at different loads.

Further examination of converter is necessary. Output power should be increased to nominal value. Regenerative mode should be tested as well.

REFERENCES

- [1] Application Note AN-941, "Paralleling HEXFET Power MOSFETs", www.irf.com/technical-info/appnotes/an-941.pdf, [Accessed April 14, 2010].
- [2] Dusan Graovac, Marco Purschel, Andreas Kiep, MOSFET Power Losses Calculation Using Data-Sheet Parameters, Application Note, http://www.btipnow.com/library/white_papers/, [Accessed April 14, 2010].
- [3] Carl Blake and Chris Bull, IGBT or MOSFET: Choose Wisely, International Rectifier, www.irf.com/technical-info/whitepaper/choosewisely.pdf, [Accessed April 14, 2010].
- [4] Sandeep Dhameja, "Electric vehicle battery systems", Newnes, 2002.
- [5] K. Vitols, N. Reinberg, A. Sokolovs, I. Galkin, "Drive Selection for Electric Kart", Topical Problems in the Field of Electrical and Power Engineering, Parnu, Estonia, 2010.
- [6] J. Van Mierlo, J. Timmermans, P. Lataire, P. Van den Bossche. "Project oriented education: Build your own electric go-kart", EPE, Dresden, 2005.

Kristaps Vitols has received his bachelor and master degree in the field of electrical engineering at Riga Technical University (in 2008 and 2010, respectively). He is currently working toward the Ph.D. degree in electrical engineering at Riga Technical University. The thesis is focused on converter development for electric vehicles.

Currently Kristaps Vitols is employed in Riga Technical University, Department of Power Electronics and Electrical Technologies as a lab assistant. His research interests include motor drives and electric vehicle development.

He is an IEEE member.

Nadav Reinberg has received his bachelor degree in the field of electrical engineering at The Technion, Israel's Institute of Technology. He is currently working toward a master degree in electrical engineering at Riga Technical University. The thesis is focused on control and development of power converters for electric vehicles.

The working experience of Nadav Reinberg includes 5 year of practical engineering job at research and development department of "Kollmorgen-Servotronix" from the Danaher motion corporation, in the field of digital board development for Servo drives applications.

Ilya Galkin received his Bachelor's (1994), Master's (1996) and Doctor's (2001) Degrees in the field of electrical engineering at Riga Technical University. The main research field includes design and applications of matrix converters. In particular it regards integrated designs with the matrix converters, smart control of their semiconductor switches, thermal and conductor's design. Another research field includes smart power supplies for various applications.

The working experience of Ilya Galkin includes 6 year of practical engineering job at research and manufacturing enterprise "Lasma" (Latvia) in the field of elaboration and development industrial automatics, as well as 14 years of research and educational job at Riga Technical University. At the given time he is professor at the Department of Power Electronics and Electrical Technologies of RTU-EEF-IEEL.

Ilya Galkin is IEEE member since 2006 in societies of Power Electronics, Industrial Electronics, Automatic control and Education.