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Driving System for Electric Vehicles: Modelling and Simulation

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Abstract – **The paper presents a system level overview of an electric vehicle power train. After a brief review of the available power train architectures, a particular one is constructed along with its control circuit, using popular simulation software. Finally, the results for typical driving cycles are plotted.**

Keywords – **Electric Vehicles, Bidirectional power converters, EV system level simulation**

I. Introduction

The ongoing strive for sustained transportation requires an increasing electrification in all its current technologies. This so called Transportation 2.0 parading, calls for continuously increasing investment in electrified transport [1]. However, to achieve such goals the design engineers must have a broader understanding of the key enabling technologies involved. To gain a better understanding of the factors involved to achieve the ever stringent design specification the designer must seek a system level overview of the whole vehicle.

The system level construction of pure electrical vehicle, which is the ultimate goal in a fully electrified transportation, allows the designer to look at different confronting issues that need to be addressed to achieve an optimum working design. The first step in such an endeavor usually involves the construction of a full system model with varying levels of detail for the different components. The results obtained for the system behavior allows the identification of some of the possible optimizations and design faults in the different subsystems, which than can be independently solved during their detailed design. The system level simulation of a pure electric vehicle is the primary topic in this paper.

The paper is organized as follows: section 2 presents a brief literature overview and comparison of the available power train architectures, concentrating on the ones that can support a hybrid energy source. Then, in section 3 a full system block diagram for the investigated design is given, with description of the separate subsystems involved. In section 4 the full system is simulated for a typical driving cycle involving acceleration and braking and the different waveforms are given. Finally, in section 5 a brief overview of the work is presented, along with some possible future iteration.

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II. EV Topology Overview

The design of a pure electric vehicle with a hybrid energy storage system consisting of a supercapacitor (SC) and battery is investigated in this paper. The great diversity of possible power train architectures does not allow for their full comparison, but the most popular types are shown in Fig. 1 [2], [5]. Their advantages and disadvantages are summarized in TABLE 1. In the particular realization a cascade configuration is chosen.

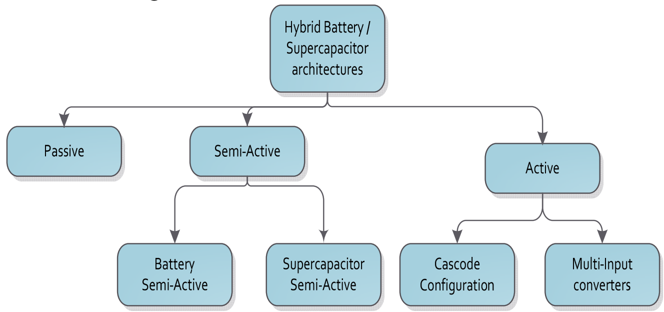

Fig. 1. Battery/Supercapacitor power train architectures

TABLE 1. EV POWER TRAIN ARCHITECTURES COMPARISON

Type	Advantages	Disadvantages
Passive	Simple realization and control	Equal battery and SC voltage, Similar current profile for SC and battery
Battery Semi-Active	Requires only one additional power converter, adds a degree of freedom in choosing battery voltage and control its current profile	The supercapacitor needs to be at the same voltage as the motor
SC Semi-Active	Requires only one additional power converter, adds a degree of freedom in choosing the SC voltage	Braking energy absorbed by the battery is not directly controlled
Cascode configuration	Relatively simple control for active configuration, independent control of battery charge/discharge profile	Increased losses for the battery power flow path, also requires separate control of two additional converters
Multi-Input Converters	Minimizes the total amount of power switches or filter elements for the same degrees of freedom in power control	Increased control system complexity

III. System Level Description

To simulate an electric vehicle on the system level the designer must at least model the power source, electric motor, the vehicle dynamics and the power converters with their control circuits that manage the conversation between the energy source and the motor. A full system level overview of an EV is shown in Fig. 2, where the black blocks are minimum requirements for a full system simulation. For this reason their implementation will now be separately explained.

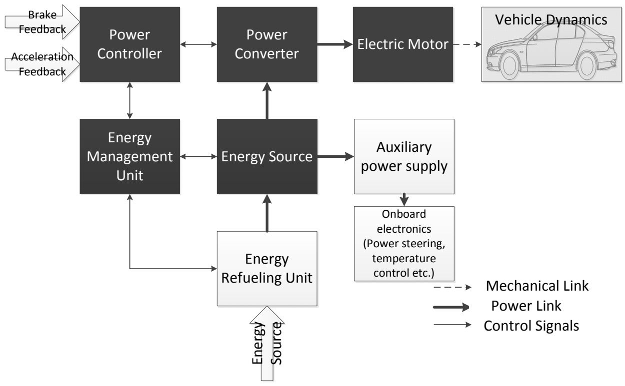

Fig. 2. System level overview of a EV

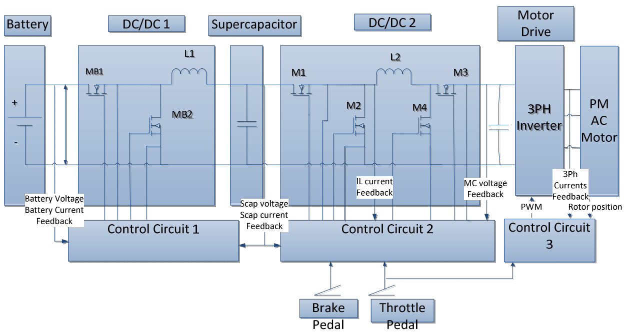

Fig. 3. Power train topology

A.Power Electronics

The power electronics in such an implementation consist of the main converters connected between the energy source (hybrid in this case consisting of a supercapacitor and battery) and the motor, along with its control systems that ensure proper energy management of the whole vehicle.

As noted in Section II the model in question will use a cascade configuration, which is shown in Fig. 3. The first converter with the accompanying control system are responsible control the voltage of the supercapacitor as a function of the vehicle speed in order it to be able to capture the kinetic energy in case the vehicle needs to slow down. The used two-quadrant converter allows the current to reverse direction boosting the voltage between the SC and the battery for a possible battery charging, if the voltage on the SC is higher than needed. The block diagram of the control circuit is shown in Fig. 4, and the Stateflow realization in Fig. 5.

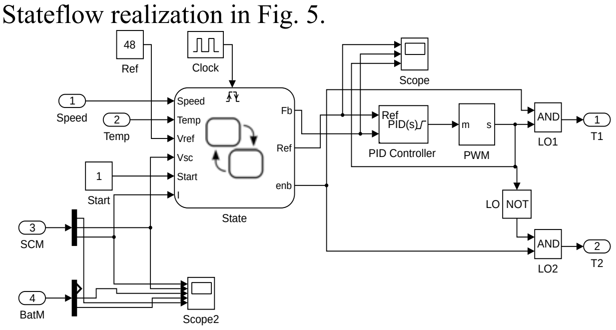

Fig. 4. Control circuit 1

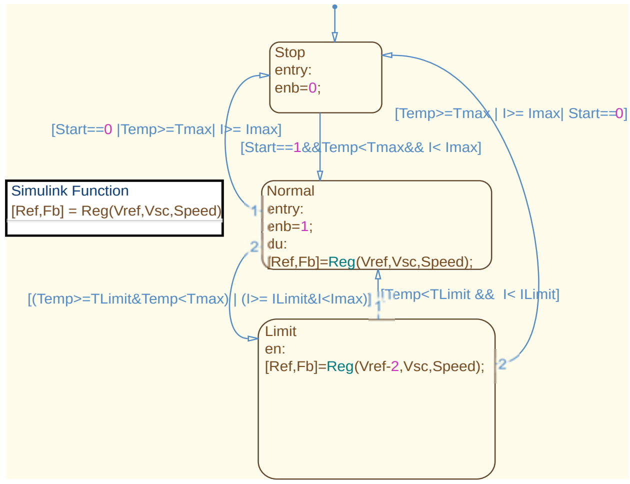

Fig. 5. Control circuit 1 state diagram

The second converter connected between the SC and the inverter is a noninverting buck-boost converter [3],[4]. When the vehicle is accelerating energy must be supplied to the motor from the hybrid energy source, and when the vehicle is braking energy is supplied from the generator.

In the first case the voltage at the input of the motor controller must be used as a setpoint, and the converter allows either buck or boost operation. The control system uses a current peak control algorithm to stabilize the voltage. In this case the output of the voltage control loop (PID2) is multiplied by the current, that is needed to achieve the desired torque (Iref) and this is the current reference used by the peak current controller.

During regenerative braking the control circuit uses the motor current as the setpoint in order to achieve constant braking torque. The control system then uses a hysteresis controller (Relay 2).

The block diagram is shown in Fig. 6, while Stateflow realization due to its size will not be shown. However, the main idea behind its realization is to set one of the possible operation modes of the power converter under consideration (shown in TABLE 2), the possibility of the a third operating regime where part of the cycle the converter is used as a boost and the rest as a buck is not investigated.

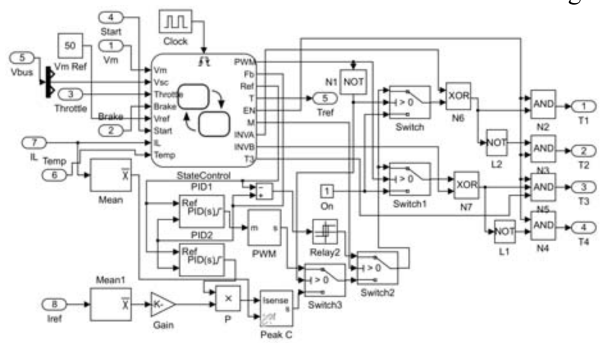

Fig. 6. Control circuit 2

TABLE 2. TRANSISTOR OPERATION IN DIFFERENT MODES OF OPERATION

Mode / Function	Acceleration	Regenerative Braking
Boost	M1-On, M2-Off M3,M4- PWM	M1,M2-PWM M3- On,M4-Off
Buck	M1,M2-PWM M3- On,M4-Off	M1-On, M2-Off M3,M4- PWM

B. Power Source

The topology under investigation uses a hybrid energy source consisting of a battery and supercapacitor. The battery is optimized for long-term energy balance, so its dynamics can be neglected for the short term acceleration or braking times that will be considered. This motivates the decision to model it as a perfect voltage source, and lump its internal resistance with the resistance of the power converter that connects it to the supercapacitor.

The supercapacitor is modeled in its simplest form as a voltage dependent capacitor and an equivalent series resistance.

C. Motor

The motor used is a permanent magnet AC machine, due to the reduced driving requirements. The machine along with its inverter is control in the dq frame with torque setpoint given form the acceleration pedal. After the currents corresponding the torque are transferred back to abc domain, a hysteresis controller is used to track them. The control system is shown in Fig. 7.

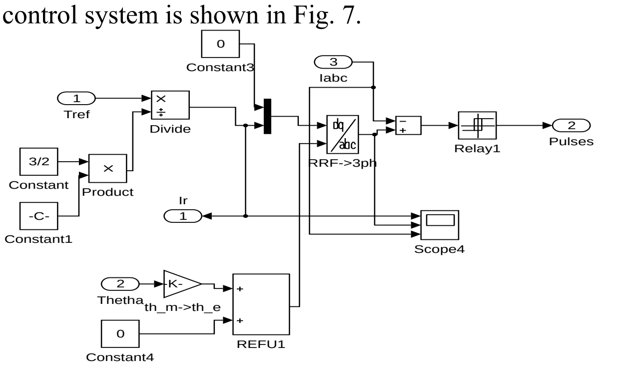

Fig. 7. Control circuit 3

A. Vehicle Dynamics

To simplify the full model the vehicle subsystem only considers a two dimensional model in which the second Newton law of motion is used to calculate the vehicle acceleration, while accounting only for the rolling resistance force, aerodynamic drag force and the grading resistance force, which are being subtracted from the traction force [5].

IV. Simulation Results

The full simulation diagram is shown in Fig. 8, while the power circuit in Fig. 8. Due to the large number of simulated elements and the large difference in the time constants in the mechanical and electrical subsystem the simulation step needs to be small to account for the PWM control of the power transistors, but the simulation time must be long to appreciate the vehicle speed changes.

This leads to very long simulation time of the whole system and the inability to achieve solution for long periods of time on a normal desktop computer. For this reason some simulation parameters are scaled allowing an minimization of the simulation time, and proper use of initial condition of the vehicle speed and supercapacitor voltage are implemented in order to obtain mechanical responses and test the validly of the overall control system.

The overall system behavior in case of full throttle from standstill to 100km/h and then a braking cycle is shown in Fig. 10.

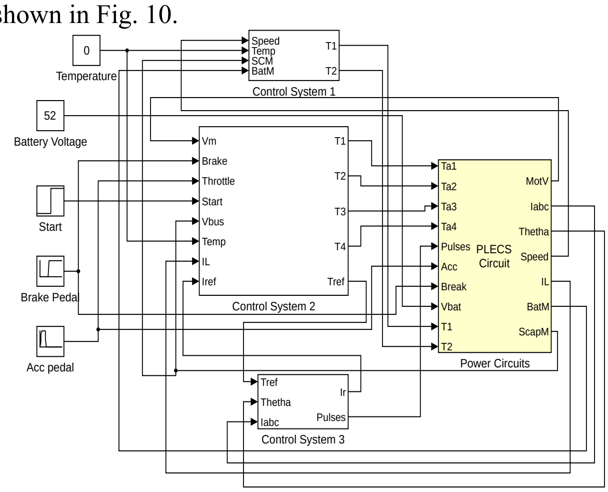

Fig. 8. Simulated circuit overview

V. Conclusion

The system level design and simulation of an electric vehicle with a hybrid energy source was the primary goal of this paper. To achieve this goal the various power train topologies were compared for achieving the goal set. After choosing an appropriate topology the system level overview of the control system were shown, together with the accompanying state level design. The complete system was than implemented using a popular software package that allows system level simulation. Finally, the various waveforms obtained for rapid acceleration and braking were shown for some parameters that allowed computation in a limited time due to the very time consuming simulation on a typical computer.

Acknowledgments

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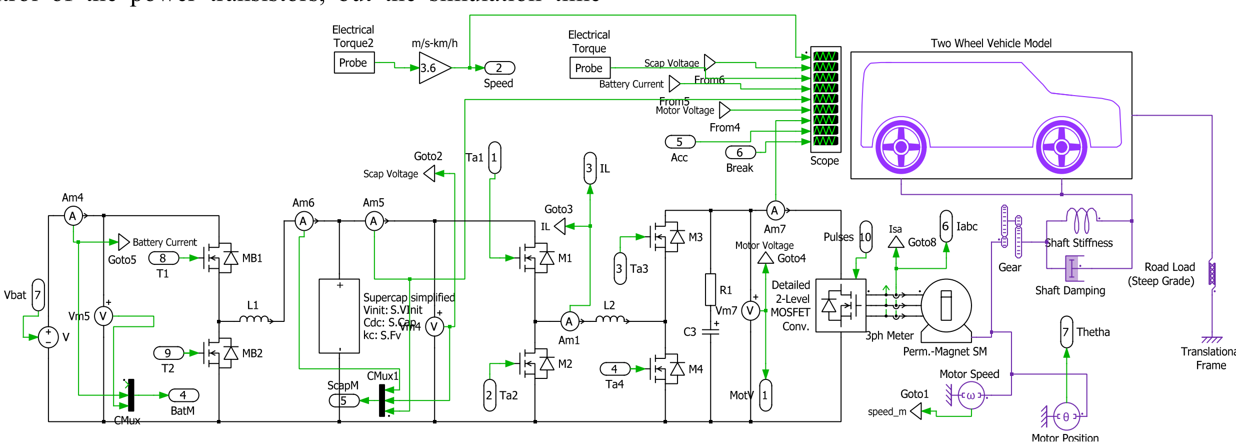

Fig. 9. Simulated power circuit

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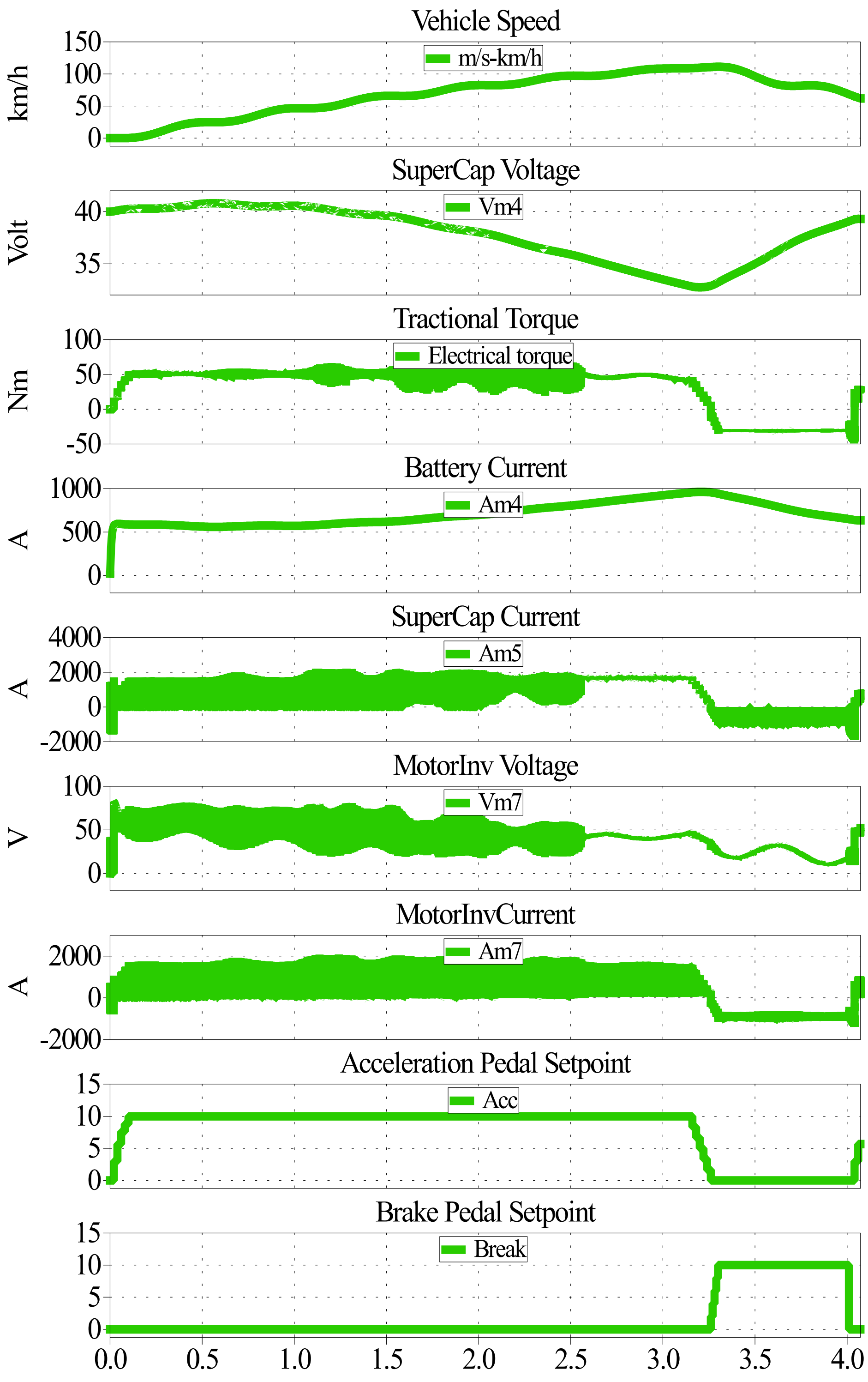

Fig. 10. Electric vehicle waveforms for an acceleration and braking cycle