Dual Source Railway Vehicles

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Abstract— The paper deals with research activities about technical aspects of dual source railway vehicles on the Czech railway traffic system. The thought vehicle uses for powered traction equipment the catenary and traction battery system. The battery system design is based on the traction and vehicular simulations.

1. INTRODUCTION

The multisource railway vehicles are solving at Department of Electrical and Electronic Engineering and Signaling in Transport. Research activities are focused on the traction and propulsion computer simulations and on the real measurement of the experimental vehicle. The paper discusses a design of dual source railway vehicle (DSRV) with the trolley collector and the battery. It is expected that this vehicle will be operating in the Czech district.

The designed vehicle has a lot of advantages unlike conventional one. Among these advantages we might include operation in a short section without an electric line, elimination of combustion engine, using a principle of regenerative braking and recharging battery under catenary. Recharging in a station is not necessary. This realities lead to more effective vehicle using [5–7].

2. CONCEPTION OF DSRV

This research goes by way of the battery position analyses in the vehicle powered by catenary. In this case it is talking about DSRV, because there are the collector and the battery. This vehicle can be operating in short sections without catenary that are ordinary in the Czech Republic.

The electric equipment described by Fig. 1 was designed on base of a metropolitan railway vehicle. For this vehicle is 750 V a typical value of voltage in DC link. This is very advantageous because there is the battery inside DC link. The battery has to be connected to the DC link by converter and the isolating transformer when the voltage will be higher than 1000 V. Furthermore, the electric equipment must be constructed for a high voltage. This solution is more expensive and more complicated in comparison with the 750 V DC link technologies. If the battery would get high

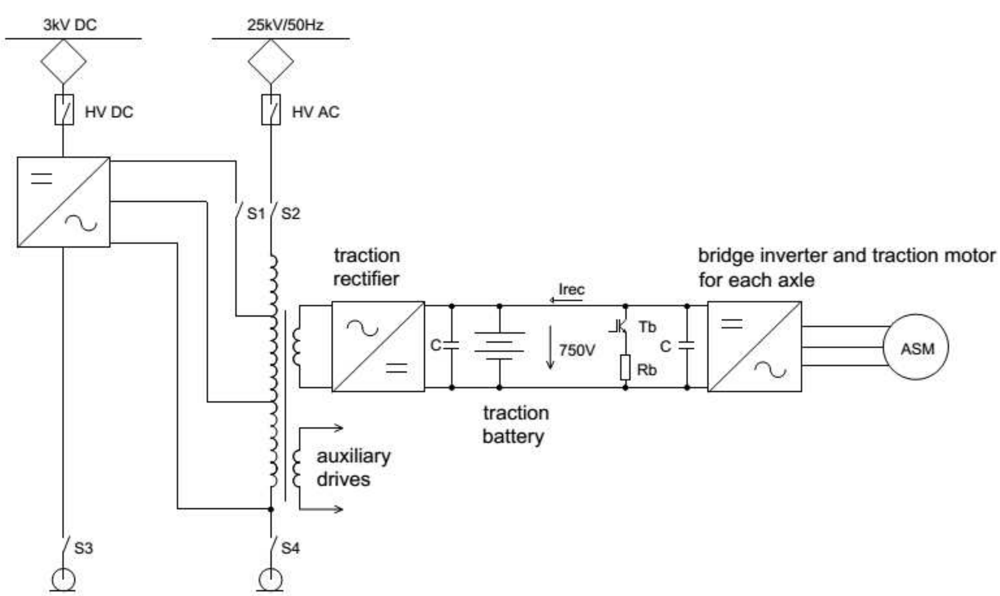

Figure 1: Two power supplies railway vehicle.

voltage on the ports she will be destroyed. It would be very dangerous situation for the passengers and staff. Furthermore, the conception that is in Fig. 1 has higher efficiency. The vehicle that is described above is powered from the catenary with 25 kV 50 Hz and 3 kV DC. The value of an alternate voltage is changed by a transformer and rectified by a rectifier. The DC voltage is led to the transformer through an inverter that creates an alternate voltage. The accumulator can be charged in the same time when traction inverters are consuming an electric energy from the DC link in case of intelligent control. The energy from regenerative braking can be saving to the accumulator or returning to the trolley wire. Energy storing to the battery is naturally preferable because the vehicle works with a higher efficiency [8, 9].

3. DESIGN AND DIMENSIONING OF THE BATTERY SYSTEM

The most restrictive equipment of DSRV is the accumulator of energy — the battery. This element determines the main parameters of non-electrified track — DSRV output power and range. It is necessary to design a battery for this track which will comply with these parameters: energy, power, safety and life time.

It seems that the best way for DSRV is to use electrochemical battery based on lithium (Li-ion). Li-ion batteries are the most modern one, because they have a lot of benefits in comparison with other batteries (Lead acid, NiMH, etc.). The main benefits are for mobile applications higher volumetric and mass energy density. Another benefit is relatively high nominal voltage around 3.2 V/cell because of the big potential difference between negative carbon electrode and positive lithium electrode. The disadvantages of Li-ion batteries are higher price and necessity of supervisor management system (BMS — battery management system). The Li-ion technology based on LiFePO4 was selected for the proposal of traction calculations. This is the most used and safe technology nowadays [4, 9].

3.1. Ideological Proposal Design of Battery System

The battery system design is based on the knowledge of required energy for non-electrified section, required circumference wheel power and required converter DC link voltage. To achieve the needed voltage it is necessary to calculate the number of cells connected in series:

$$n_{\text{cells}} = U_{\text{dclink\_nom}}/U_{\text{a\_nom}}[\text{-}, V, V] \tag{1}$$

where n_{cells} is the number of cells in battery, $U_{\text{dclink\_nom}}$ is the voltage of converter DC link and $U_{\text{a\_nom}}$ is the nominal cell voltage. The next step is to determine the battery capacity in connection with track energy intensity and required power.

The traction drive chain consists of: traction converter, traction motors, transmissions and wheels. The battery contains internal resistance and the supply of electro motoric voltage. If the required circumference wheel power is known, the power from the battery (battery ports) is calculated as:

$$P_{bp} = P_{\text{wheel}}/\eta_{\text{drive}}[W, W, \%] \tag{2}$$

where P_{ab} is the required power on the battery ports, P_{wheel} is the required circumference wheel power and η_{drive} is the total drive efficiency. Next step is to calculate the current from the battery ports:

$$I_{bp} = P_{bp}/U_{\text{dclink\_nom}}[A, W, V] \tag{3}$$

where I_{bp} is the current from the battery ports. Every traction battery contains internal parasite resistance which becomes energy loss. The energy loss depends on value of charging and discharging current. The efficiency of charging and discharging is reduced. During research activities it was determined on battery TS-LFP40AHA 40 Ah that internal resistance of LiFePO4 technology is not dependent on depth of discharge (DOD) and also the value of charging/discharging current. The nominal battery capacity should be measured by standard CSN EN 62660-1 at discharging current of magnitude 0.3 C (current corresponding to 0.3 multiple of battery capacity). It means that if the battery is discharging by the current 0.3 C, the measured capacity of this current is equal to the catalog capacity. It is not possible to declare the compliance of this standard nowadays. For this reason it is necessary to determine the methodology which would make energetic safe solution. The model of DSRV uses for the simulation the capacity from catalogue which is used as internal capacity. It means that the energy from the battery is used for energy losses on internal battery resistance and traction work.Dependence of charging and discharging on current from battery with capacity 1000 Ah (WB-LYP1000AHA) was described in [16]. The defining is based on available parameters from manufacturer. After approximations is possible to express equation for efficiency as:

$$\eta_{\text{char\_dischar}} = -0.0094 \cdot I_{bp} + 100[\%, A] \tag{4}$$

where $\eta_{\text{char\_dischar}}$ is the efficiency of charging and discharging. For the required battery capacity is possible to use this equation:

$$C_{\text{acu\_nom}} = A_{\text{wheel}} / \left(U_{\text{dclink\_nom}} \cdot \eta_{\text{drive}} \cdot \eta_{\text{char\_dischar}}\right) [Ah, Wh, V, \%, \%] \tag{5}$$

where $C_{\text{acu\_nom}}$ is the required battery capacity and A_{wheel} is the required circumference wheel energy. For the increasing of energy and power reserve is necessary to increase energy capacity by at least 25%.

$$C_{\text{acu\_real}} = C_{\text{acu\_nom}}/0.8 = C_{\text{acu\_nom}} \cdot 1.25[Ah, Ah] \tag{6}$$

where $A_{\text{acu\_real}}$ is the total battery capacity. Battery capacity meets energy requirements now. Now it is necessary to check if it is possible to give the battery a full traction load. In general this condition must be met:

$$I_{bp} \leq 3C[A, Ah] \tag{7}$$

where $3C$ is triple capacity — it is the current maximal allowed for LiFePO4 technology. If the condition is not met, the capacity has to be increased.

3.2. Design Validation in the Context of DSRV

The design of vehicle battery system needs the detailed knowledge of driving cycle — energy claims and work part of traction characteristics. The next premise for sophisticated battery system design is represented by the comprehensive set of technical parameters about exact type of battery. If is not possible to find out or measure the required parameters, the calculations must be done with a big reserve of energy and power.

4. SIMULATION OF DSRV AND OPERATING

The primary problem of DSRV design is a calculation necessary battery capacity. The valid capacity value is obtained if the numeric simulation for the required tracks is used. All simulations were done by Matlab.

The ground of simulation model was calculated the train motion equation. All the tractions calculations are solved with 20 ms period that was verified during testing of simulation model. At first the model loads parameters of the track and rail vehicle. The main parameters of the track are locations of gradient changes, speed changes and stations. The vehicle is characterized by the traction characteristic and the braking characteristic. In the next step model needs dates about a propulsion system for solving energetics calculations. The valid information about propulsion system is obtained after analyses of energy flows inside a propulsion chain. For the valid value of the accumulator capacity and the power dimensioning simulation model needs dates about auxiliary consumption. The air-conditioning and the heating are the significant components of the total auxiliary consumption.

After loading important parameters the program will calculate the traction force. In the next step the program compares the traction force Ft [N] with speed of the train v [kph] and computes the actual power ($P_{\text{wheel\_act}} = v \cdot F_T$) on circumferences of wheels. The consumed energy E [kWh] can be determined by integration of infinitesimal elements of the power. The mathematical operation of the integration is transformed to the summation in the simulation model. The energy increments are calculated by multiplication an actual power $P_{\text{wheel\_act}}$ with a period of the simulation T [ms]. The mentioned principle describes the Equation (12).

$$E_n = E_{n-1} + P_{\text{wheel\_act}} \cdot T \tag{8}$$

The results are graphically presented as progresses after the simulation. The graphs describe the changing values during the vehicular ride. The energy in the battery is calculated from the traction energy and the efficiency of the propulsion system. Fig. 2 and Fig. 3 demonstrate the interpretations which come up from the simulation algorithms.

For a better transparency, simulation results were given to the average of 15 tracks that were passed by eight axels DSRV vehicle. The vehicle weight was 110 t with included 115 passengers. The capacity of the battery was specified to the value 750 kWh. Than weight of lithium cells is 8 t. With this battery the vehicle should be able to pass 50 to 80 km ride. Note that the battery is

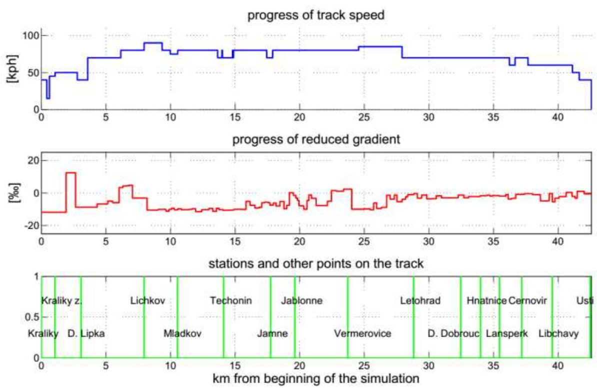

Figure 2: Examples of input quantities.

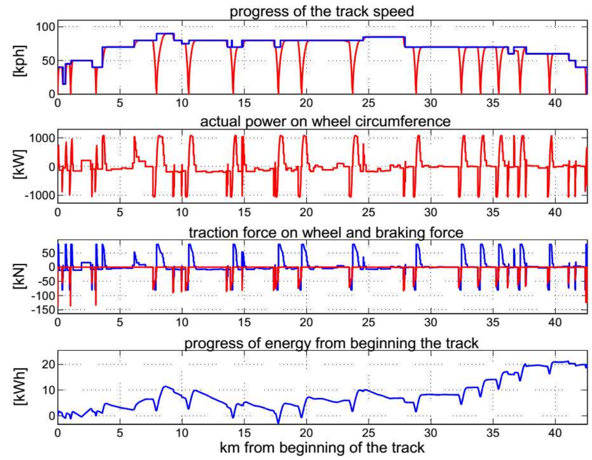

Figure 3: Examples of output quantities.

designed with 50% DOD. Note that the length of the ride depends mainly on the gradient. These same simulations were repeated for the dieselelectric railway vehicle, the clearly electric railway vehicle, the battery railway vehicle and the dieselelectric railway vehicle with a catenary collector.

It was followed that the vehicle of the DSRV type is more effective for an operation than other vehicles designed for the nonelectric section operation. Furthermore, the DSRV might be suitable for a clearly electricity operation after an irreversible death of the battery.

5. CONCLUSION

During the research activities it has noticed many contributions of the collector/battery DSRV against the conventional collector/combustion engine vehicle. In the comparison of the cost of electric energy and the fuel wins the electric energy. Therefore, the clearly electric operating vehicle is cheapest. On the second hand the operation of a vehicle powered by the combustion engine is the most expensive. The average way is to use DSRV with a battery. Therefore, the maintaining vehicle with the battery is cheaper than the maintaining vehicle with the combustion engine. Furthermore the energy from braking can be partly returned to the battery. Next an advantage is covered in more effective traffic flows. DSRV goes on the track with and without catenary. Consequently the people cannot change the train. The electric buses get more and more popularity around the world. The railway has to respond fast on this trend for keeping customers.

ACKNOWLEDGMENT

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