Dynamic Battery Model for Vehicle to Grid Appraisal

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Abstract

This paper initially reviews some previous work with respect to battery modelling [1-5] and describes a dynamic mathematical model of a battery for vehicle to grid connection (V2G) realized in MATLAB Simulink. The model takes into account the nonlinear characteristic of battery capacity versus discharge current which is not normally accounted for in standard modelling techniques. Two different charging regimes are implemented in the model e.g. charging with constant current and charging with constant voltage as well as their combination. The model of variable load that has been developed allows the simulation of aggregated V2G units in the power network alongside the various conventional domestic loads.

Keywords: Battery model, battery charge, state of charge, V2G-vehicle to grid

1 Introduction

The accurate modelling of batteries [1], where the nonlinear characteristics are taken into consideration, can still create problems in terms of precise determination of battery parameters [2-3]. More latterly, there has been interest in development of dynamic battery models due to complex battery electrical parameters which are related to battery exploitation and aging [3-4]. The challenge is to implement a relatively simple model but yet which describes accurately battery terminal voltage which is function of battery discharge current and manufacturer‘s data characterising battery type [5-6].
Recently there has been increased interest in use of electric vehicles and plug-in hybrid electric vehicles as possible energy storage for power system. The highly distributed energy storage can provide fast response to the electricity supplier and can be used for: load levelling, peak shaving, area regulation, local voltage stabilization also can be seen from supplier side as equivalent of spinning reserve. Distributed battery storage increases power system stability, security and supports integration of renewable energy generators in the power network.

2 Battery Model

The battery model is described by algebraic equations (1-3) which are inserted in Matlab/Simulink as parameterized functions. These algebraic expressions are used in the simulation to compute the output variables (namely: voltage, state of charge SOC capacity) as a function of current. The battery voltage is described by equation [7]:

$$V = V_0 - p\frac{C}{C - \int_0^t idt} + v_e \exp(-c_e \int_0^t idt) \qquad (1)$$

where V battery voltage, V_0 no load voltage, p polarization constant, C battery capacity, v_e battery exponential voltage, c_e battery exponential capacity, i battery current. The battery state of charge is calculated using formula [7]:

$$SOC = 100\left(1 - \frac{C}{\int_0^t idt}\right) \qquad (2)$$

Parameters p, v_e, c_e characterize battery type and they are determined from discharge characteristics.

2.1 Battery Capacity as a Function of Discharge Current – Peukert's Equation

The stored charge in battery that can be delivered at constant current to a load at pre-defined cut-off voltage defines battery capacity in Amp-hours. Peukert tested several different lead-acid batteries at different discharge current rate. He found that the relation between capacity and discharge current can be described by simple equation:

$$C = {c}/{I_d^{(p-1)}} \qquad (3)$$

where I_d is the discharge current, C is capacity at discharge current of I_d, c is capacity at discharge current of 1A, p is Peukert coefficient. For example a peukert coefficient of $p=1$ means that the available total capacity of the battery does not depend on the discharge current rate, which is not true for lead-acid batteries, which have typically $p=1.3$-1.4. Equation (3) enables to calculate accessible battery capacity at different discharge current. The simulated battery in this paper is used in REVA G-Wiz [8]; 48V lead-acid with capacity of 200 Ah and Fig. 1 indicates the capacity given by:

$$C = 200 I_d^{-0.269} \qquad (4)$$

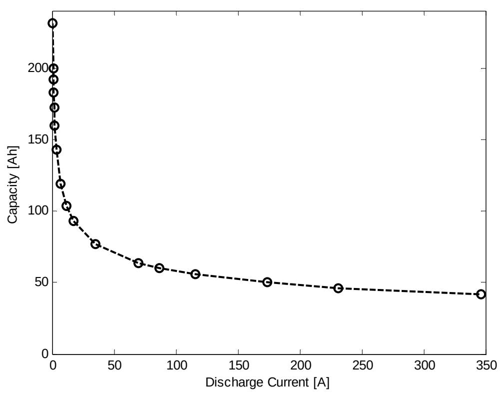

Figure 1: Variation of battery capacity as a function of discharge current.

3 Numerical Battery Model

The dynamic battery model has been developed using Matlab/Simulink package and the internal circuit of battery is presented in Fig. 2. The model represents lead-acid battery; however the model is parameterized and is universal for different types of batteries when parameters and characteristics are set for that type of cell. As mentioned, the battery model implements the nonlinear characteristic linking battery capacity to the discharge current. The nonlinearity is described by Peukert's equation. The battery current is constantly monitored; this allows the actual battery capacity to be continuously calculated. During a typical simulation, a variable load is connected to the battery model and the battery capacity determined automatically. The 'Var Capacity' blocks are used to evaluate the actual battery capacity, delay block have been used to avoid computation errors and provide correct capacity when switching from discharge to charge process occurs. The capacity is saved in memory block Mem2 therefore the battery can be charged with the same amount of energy that was used during discharge cycle.

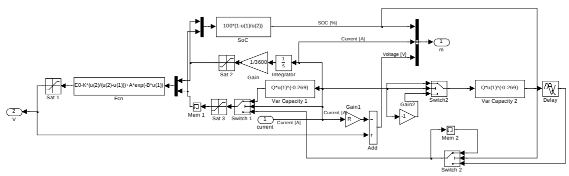

Figure 2: Matlab/Simulink of battery model which implements variation of capacity as a function of discharge current.

The battery model will be used to define load profiles and it is a part of development of power system model with implemented V2G concept. This load profile will represent a typical electric vehicle power demand and also will be used in a definition of electric bus power demand. The battery can be discharged through variable resistive load controlled by clock. An example of variable load is shown in Fig. 3; it has been implemented as a number of resistances connected in parallel which can be switched on or off independently or in required pattern to represent demanded load profile.

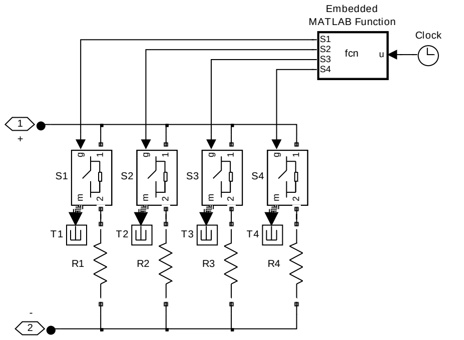

Figure 3: Matlab/Simulink model of variable load controlled by clock.

The battery charger shown in Fig. 4 has been modelled by current source and voltage source connected in parallel and controlled with SOC signal. The relay signals allow only one source to deliver power at one time. The voltage source delivers power at limited voltage to ensure that the battery is fully charged while at the same time avoiding overcharging. For this reason the charging method switches from constant current to constant voltage before the cell voltage reaches its upper limit.

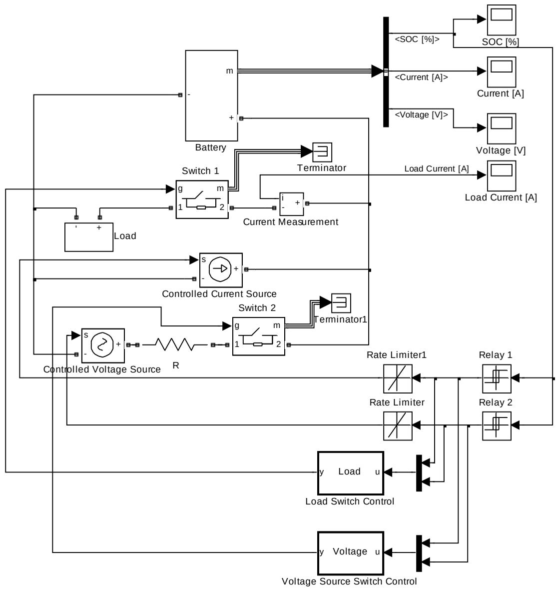

Figure 4: Matlab/Simulink model of battery charger.

4 Simulations results

The modeled battery is 48V lead-acid with capacity of 200Ah and is used in electric car REVA G-Wiz [8]. Fig. 5 shows battery voltage profile for discharge and charging process. The battery is discharged with variable load until SOC reach 50% then is charged with constant current of 20A until SOC reach 90% after that constant voltage is applied until battery is fully charged. Fig. 6 and Fig. 7 show corresponding battery current and SOC profile respectively. The model differs from previous described in [2-3] in such way that the SOC is instantaneously monitored to limit the depth of discharge and to determine the charging regime (constant current/voltage). Constant current charging process is used at the start of charge to limit the maximum current when battery is discharged; constant voltage is applied near the end of charge to limit generation of heat and gasses which can damage the battery. The essence of charging process is to detect when the reconstitution of the active chemicals is complete and to stop the cycle before any damage occur while maintaining the cell temperature within safe limits. Detection of the cutting-off point and termination of charging process is critical in preserving battery life.

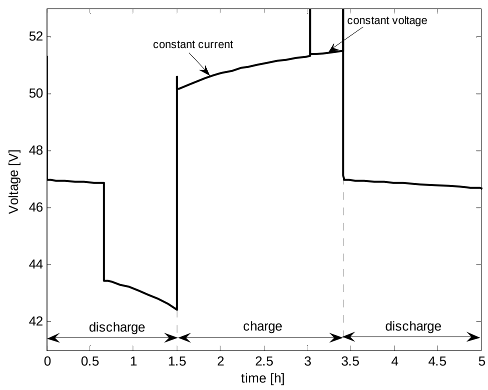

Figure 5: Battery voltage profile for discharge and charge cycle.

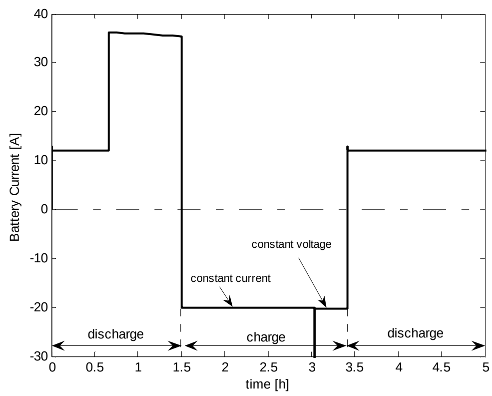

Figure 6: Battery current profile for discharge and charge cycle.

During the discharge process the state of charge of battery changes rapidly this is due to the fact that the battery capacity differs with load current. The battery can deliver more power if loaded lightly for long time and it decreases exponentially when heavy loads are applied. The battery model has been tested with simple load profile and the load current is shown in Fig. 8. The additional load is applied by switching on number of resistances into the battery circuit.

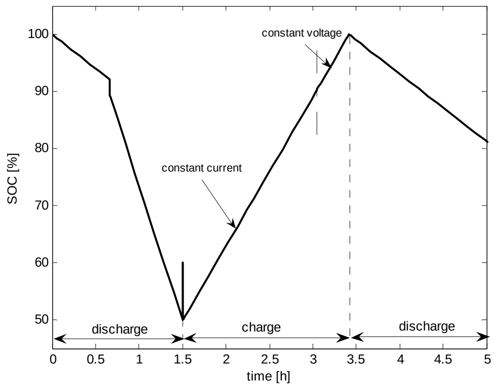

Figure 7: Battery state of charge profile for discharge and charge cycle.

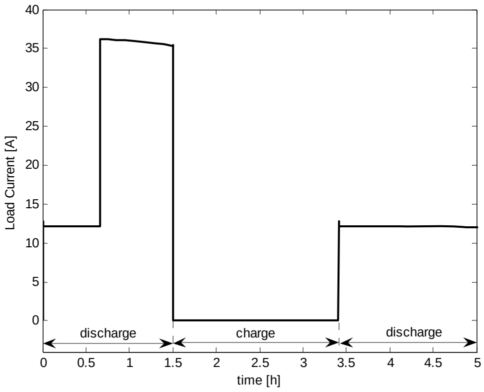

Figure 8: Load current profile for discharge and charge cycle.

5 Battery Aggregation

The aggregation of batteries in Matlab/Simulink model is planned by replacement of several batteries by one with capacity equal to sum of capacities of all batteries. The available on the market AC Propulsion unit is designed for safe charging from existing 110V to 240V outlets at rates up to 20kW. The unit can deliver from battery storage power back into the power network at rate of 20kW. In the considered simulations the power which can be delivered will be limited to 20kW per battery. Fig. 9 shows example of aggregated battery model.

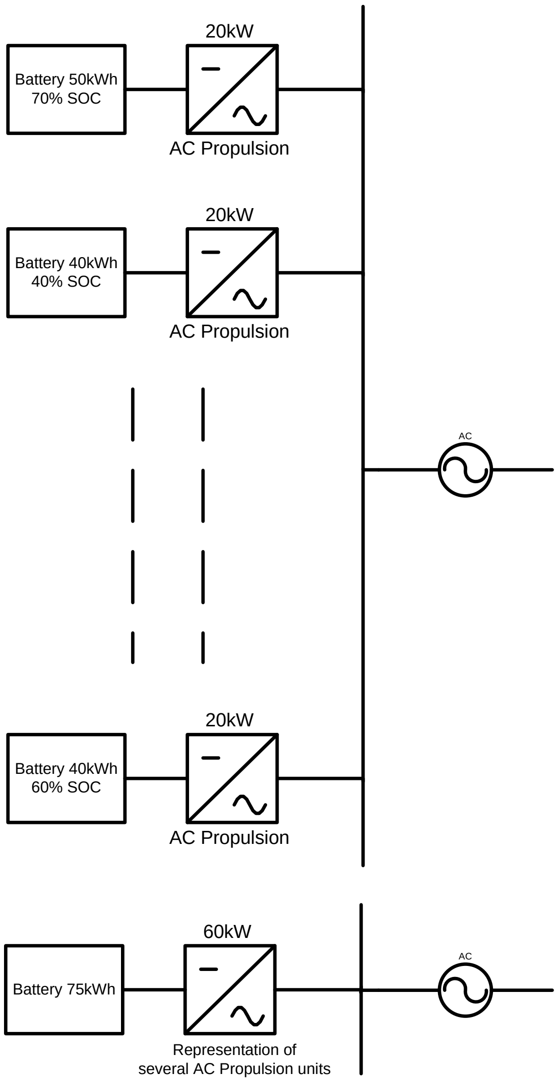

Figure 9: Model of aggregated battery.

The capacity of three batteries replaced by one has been calculated as follows:

- Capacity available for grid support

$C_{V2G}=0.7x50+0.4x40+0.6x40=75kWh$

- Capacity required to recharge batteries

$C_{G2V}=0.3x50+0.6x40+0.4x40=55kWh$

Fig. 10 shows possible power profile which can be used for grid support. The power that can be delivered from each battery is limited to 20kW therefore the maximum power available for grid support from three batteries is 60kW then is reduced to 40kW from two batteries and 20kW when only one battery is available.

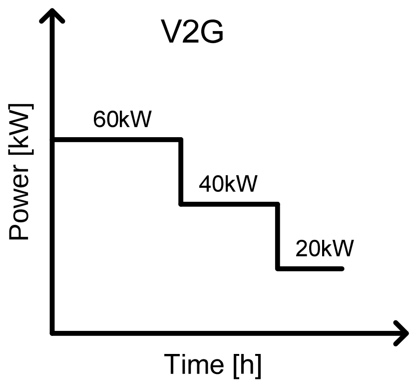

Figure 10: Power available for grid support.

6 Conclusions

The paper has presented dynamic battery model and battery charger topology based on constant current/voltage charging regimes. The arrangement allows simulating battery charge discharge cycles and can be used in determination of load profiles for V2G concept. The model implements non-linear battery characteristic and provides relatively simple tool for battery simulations over long period, 24h profile can be solved in a matter of seconds. The proposed parameterised MATLAB Simulink battery model allows simulating battery terminal voltage for different discharge currents with reasonable accuracy.

Acknowledgments

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