ENERGY MANAGEMENT IN HYBRID ELECTRIC VEHICLE FOR SUSTAINABLE DEVELOPMENT IN GLOBAL ECONOMY.

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Abstracts

Sustainable energy development is a key issue to global development. Energy is a driver to economic growth and development. The current increase usage of fossil fuels driven by the transport sector is not only a threat to economic stability and energy security of the globe, but also poses risks to health as a result of increasing toxic emissions and climatic changes that alters the environmental conditions. Hybrid electric vehicles (HEVs) and electric vehicles (EVs) are alternatives aiming to replace conventional vehicles that consume fossil fuel and emit CO2 and toxic pollutants. The barrier to these technologies is the battery technology and its required electrical and thermal management to ensure efficient and safe operations. This paper presents Lithium ion battery Pak thermal model incorporated with HEVs power train to serve as a basis to investigate new battery management strategies.

Keywords: *HEV –hybrid electric vehicle, SOC- state of Charge, EV- electric vehicle, BMS Battery management system*

Background to the Study

Sustainable energy is the key to global economic development. Energy is central to human development and a key driver as well as consequence of economic growth. Until recently countries part of the Organization for Economic Cooperation and Development (OECD) accounted for larger energy consumption than the rest of the world with a significantly smaller population. The world energy consumption is set to increase by more than 60% between 2010 and 2040 with non OECD countries accounting for almost 50% of such forecasted increase (IEO, 2013), see Fig 1.Similarly, energy consumption due to transportation is forecasted to increase in non OCDE countries by 2.2% per year between 2010 and 2040, with most of the growth being in Asia (IEO, 2013).By contrast, OCDE countries are forecasted to be able to reduce transportation energy consumption by 0.1% per year. Ambitious targets have also been set in the EU initiated 2050 Roadmap framework to reduce gas emission by 40% in 2030,60% by 2040 and 80% in 2050.

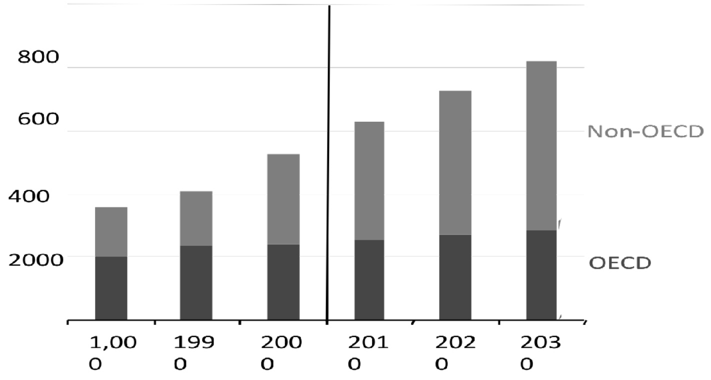

Fig.1. World Energy consumption projection. (reproduced from IEO, 2013)

The main source of energy used in transportation is liquid fossil fuel. The increased demand for liquid fossil fuels can, to some extent, be accommodated by advances in drilling technologies including horizontal drilling, multi-stage hydraulic fracturing; better production and transportation solutions to exploit deep water resources. The exploitation of previously inaccessible regions has to be balanced with associated higher cost and risks to the environment.Increase usage of fossil fuels increases toxic emissions as well as greenhouse gases, leading to higher health risks and climatic changes that alters the environmental conditions. There is therefore a political and economic incentive in reducing liquid fuel consumption.

In the past, the main drivers for reduced consumption were increased taxation as well as government incentives to promote fuel efficiencies through greenhouse and toxic gas emissions targets. Such measures have led to more efficient internal combustion engine (ICE) design and the uptake of stop start technology. However these gains in efficiency have been counter balanced by losses due to the increase mass of vehicles required to meet safety standards such as EURO NCAP as well as accommodate new features on vehicles. A solution for further reduction is to combine ICE with other power sources such as electricity. Current solution involving both ICE and electrical power include hybrid electric vehicles (HEVs), Fuel-cell hybrid electric vehicle (FHEV), plugin hybrid electric vehicle (PHEV),Fuel cell vehicles, Electric vehicles (EVs) and vehicle to grid (V2G) (Savacool & Hirsh , 2009). Most commercial vehicles are HEV with a few small EV. One of the advantages of EV or HEV is the generation of electricity by braking with the electric motors used as a generator through a process known as regenerative braking,instead of losingenergy as heat on tire drum (Sovacool & Hirsh, 2009).

The different types of EVs are expected to lead to lower vehicle operating costs, reduced local CO2 emission, and the ability to support and contribute to the grip through the integration of renewable energy. The most significant positive CO2 impact is expected in countries using renewable energy sources e.g. wind, solar, water, where EV batteries could be charged at night when there is low demand and yet available 'green' energy. There is however still to date many scientific and commercial issues to resolve to realize the potential benefits of EVs. This paper will only focus on one such aspect: the EVs battery technology.

To use electricity it is necessary to store it. Battery technology is therefore a cornerstone to the development of hybrid or fully electric vehicles. Battery for transportation operations are required to be able to deliver high energy peaks, have high energy density and low charge loss, high operating voltage and long cycle life. The current battery of choice for EV or HEV is nickel-metal-hydride. However, Li-ion battery technology is seen as the future due to its capability to deliver sufficient power and energy with a low self-discharge rate (Tan, et al., 2011; Erdinc, et al., 2009; Park & Jung, 2013; Chacko & Chung, 2012;Murashko, et al., 2013). Whilst the operating temperature for Li-ion is relatively large [-20, 60]oC while charging and [-50, 60]oC while discharging (Tan, et al. 2011), the best performance in term of power availability and battery longevity can only be obtained by operating the battery in the range 20oC to 40oC (Park & Jung, 2012).This is due to

(i) poor low temperature performance leading to a permanent reduction in capacity,
(ii) capacity reduction for temperature above 50oC,
(iii) safety issues associated with the increased temperature due to thermal runaway (Bandhauer, et al. 2011; Park & Jung, 2013).

The risk associated with thermal runaway occurs when a battery cell internal temperature reaches a threshold between 73°C to 85°C (Bandhauer, 2011). If the battery cannot dissipate energy effectively heat-generating exothermic reactions are triggered that elevate the cell temperature further. Additional exothermic battery material decomposition can then lead to battery degradations which themselves lead to further increase in temperature at a even higher rate resulting in thermal runaway from temperatures in the range 130-190 degrees(Bandhauer, et al. 2011). Thermal runaway can result in temperatures ofthe order of 500°C-700°C or lead to explosive reactions (Bandhauer, et al. 2011).

To ensure robust, efficient and safe battery operation as well as extend the life of batteries, appropriate battery management systems (BMS) have to be used.The BMS is required to deliver power and manage the battery state of charge (SOC) as well as provide safe battery operation. Monitoring of SOC is the key factor in managing the battery efficiently (Xu, et al. 2012). The issue is that the SOC cannot be directly measured and has to be estimated taking into account temperature, battery capacity, and internal resistance. Monitoring and managing the cells temperature within the battery pack is the main challenge in terms of safety of operation, battery degradation and thermal runaway. The aim of battery thermal management system (BTMS), which is part of the overall BMS, is to maintain the temperature in the range 25°C to 40°C with temperature difference between cells being kept small e.g. 5°C (Sato, 2001). The challenges include the potentially significant temperature increase when higher power is extracted from the battery pack and long heat-up time within the cell (Chen, & Evans 1996; Chacko & Chung , 2012). BTMS use heating or cooling systems to maintain an optimal temperature. The most common cooling solutions involve air or liquid as heat transfer fluids (HTFs), with the former exploiting existing air conditioning unit being cheaper, less expensive and easier to maintain than dedicated liquid cooling systems. Liquid cooling is however more efficient with large battery packs (Park and Jung, 2013). Passive cooling systems involve different battery designs, with the use of laminated cross sectionbeing effective to suppress battery temperature rise, and/or new material able to absorb and convert thermal energy such as phase change material (PCM) (Karimi et al, 2013, Rao et al 2011). To evaluate the benefits of different BTMS it is necessary to perform simulation studies with large and complex models, whereas to implement control solutions there is a need for simplified models able to be used in real time. The aim of this paper is to review existing thermal models before describing the implementation of a thermal model within the MATLAB/Simulink environment. The challenge for the model is to capture the interactions between SOC, temperature variation, capacity fading and available power. The paper is organized as follows, Section 2 presents the Lithium ion characteristics, Section 3 presents the battery mathematical model used in theMATLAB/Simulink model, Section 4 presents the simulation results and Section 5 concludes the paper.

Battery thermal modelling

Battery cells characteristics

Battery cells are constructed using a range of packaging or structure as well as materials for anode and cathode and different chemistry for the electrolytes. Current battery structures include coin cell, cylindrical (or spirally wound) cell, pouch cells with multi-stacked-layer (coffee-bags), prismatic; current cathode material include graphite, hard carbon,graphitized carbon fiber and current anode material include LiNiCoAlO2, Li1.06Mn1.89Al0.05O4,LiMn2O4,LiCoxNiyMnzO2 (e.g. LiCo02Ni0,8O2),LiCoO2, Li1.156Mn1.844O4 (Benger, et al. 2009, Bandhauer, et al. 2011).Currently electrolytes based on organic carbonates, such as ethylene carbonate (EC), propylene carbonate (PC), and dimethyl carbonate (DMC) are flammable but exhibit high conductivities over a wide temperature range. Damage to the cell can however trigger spontaneous heat-evolving reactions, which can lead to fires and explosions (Smith B, 2012). The latter have prompted most of the research to focus on the packaging of the electrolyte. However in (Ding et al, 2013) alternativesmart multifunctional fluids were investigated shear thickening fluid electrolyte are investigated for their ability to provide both good conductivity and mechanical protection due to shear thickening effect under pressure or impact. Additional damage can be caused by the heat generated within the battery during charge and discharge with the potential to lead to thermal runaway.

Influence of depth of discharge (DOD)

The depth of discharge (DOD) is the percentage of battery capacity to which the battery is discharged (Husain, 2011). The discharge capacity of battery depends on the rate of discharge, denoted C-Rate, and the temperature (Gao & Dougal, 2002) and is related to state of charge (Husain, 2011). The depth of discharge influences the current density with the current density modeledas a function of the potential difference between the positive and negative electrodes with the polarization characteristics of the electrodes modeled as polynomial function of the DOD(Tiedemann and Newman, 1979; Newman and Tiedemann, 1993).

Thermal behavior

There are four sources of heat produced in battery operation.In this work, the most commonly used thermal model is used. It is based on thermodynamic energy balance and models the heat using two terms relating to i) electrical power including over-potential due to ohmic losses in the cell, ii) entropic heat such that the heat generation inside the battery is given by (Chancko & Chung, 2012;Rao, et al. 2011):

$$q_{gen} = I(V_{oc} - V_{op}) - IT\frac{dV_{oc}}{dT} \qquad (1)$$

where Voc is open circuit voltage of battery, and Vop is operational voltage, I is the current and T is the temperature. The other two sourcesof heat, taken into account in Bernadi et al (1985), namely the mixing effects due to the non-uniform reaction rates in the cells as well as the heat from material phase change are not included. This work uses (1).

The electrical model for each cell uses two RC equivalent circuits (Yuanet al., 2013).The approach to heat generation in the inner cells of the battery pack can be determined theoretically by considering three mediums within the battery cells as

i) The volumetric energy dissipation on the cells, by knowing the specific heat capacity and the area and volume of the cells.
ii) Electrostatic energy transfer between poles (Electrodes) specific heat capacity and the volume occupied. This is new approach instead looking at the electrochemical state, the paper look at the electrodynamics of charges involve.
iii) Heat surface, heat dissipation.

where Mc is the mass of the cell, Cpc is the specific heat capacity of the cell, h is the heat capacity of the cell, A is the area of the cell plate, is change in temperature, Me is the mass of electron species (electrolyte), Cpe the Specific energy of the species (Rao, et al. 2011).

The rate of temperature with time can be determines through the following

$$\frac{dT}{dt} = q_{gen} - h * A * \Delta \frac{T}{M_c C_{cp} + M_e C_{ce}} \qquad (3)$$

A battery system has two electrodes immersed in electrolyte which contribute to the heat effect and are characterized by a chemical potential (4)andan electrostatic galvanic potential Crompton, (2000) (5)

$$V_i = V_i^0 + RT\ln\left(\frac{a_i}{a_i^{ref}}\right) \tag{4}$$

$$\bar{V_i} = V_i + V_e \square E_e \tag{5}$$

where V_i^0 is Standard potential of the species this for case of Li-ion is (-3.04V), R is gas constant (=8.314 J/mol), a is activities of species (mol/m3), and Tis the temperature (2°5 C) ambient, F is faradays constant (=96485 C/mol),Eis the electrostatic potential, Ve – is velocity of ionic species.The electric potential energy E_e s the work done in moving charge species from one electrode to the other.

$$W.d = E_e = \int_0^Q \frac{\triangle Vdq = \frac{1}{2}Q^2}{C} \tag{6}$$

$\triangle V$ -is electric potential of electrode with respect to species as part of equation 4, as

(7)

where P –Species solution pressure, while P o -is Osmotic pressure

$$P_o = kMRT \tag{8}$$

where k - Van't Hoff factor, M- is the Molarity of species (Crompton, 2000).
Based on the above theory it is possible to view the working of the cells, after having e.m.f of a cell on open circuit at a particular temperature coefficient of e.m.f (dE/dT).
The heat change accompanying cell reaction is modeled as:

$$\triangle H = nF\left[E_e - T\left(\frac{dE_e}{dT}\right)\right] \tag{9}$$

The following assumptions were made in the study of this paper.

(i) Cells arrange in the battery are identical in shape and properties
(ii) Uniform Charge density of the species within cells
(iii) Negligible enthalpy
(iv) Battery simulation

The thermal battery model were generated from the mathematical heat generation model using Matlab/Simulink, with an input signal of charging /discharging current and ambient temperature from signal generator block (Hurai, et al. 2012).A power train model was incorporated with the battery model to account for realistic demand on the battery, see Figure 2-3. The model generated the current input to the battery model were as shown in figure 3. The latter is the dynamic loading (discharge current) that current drawn from the battery, with battery terminal voltage response.

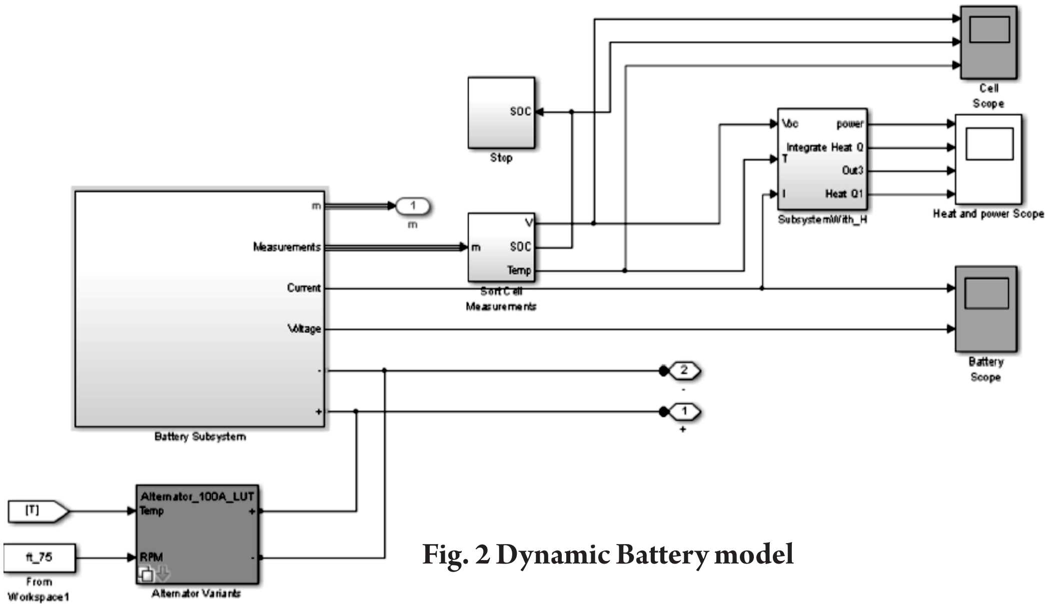

Fig. 2 Dynamic Battery model

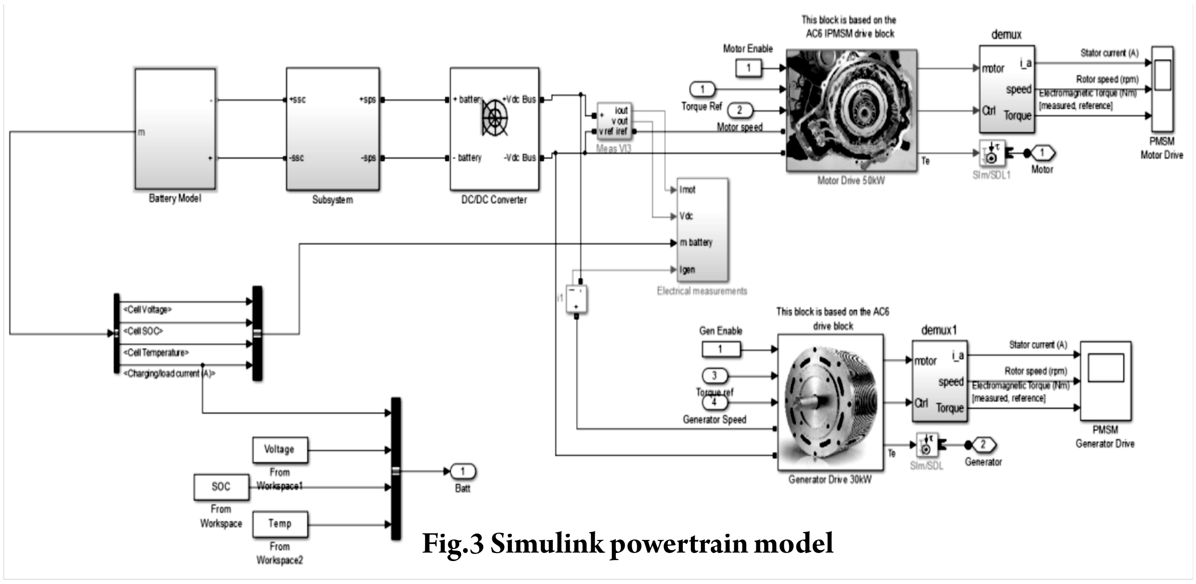

Fig.3 Simulink powertrain model

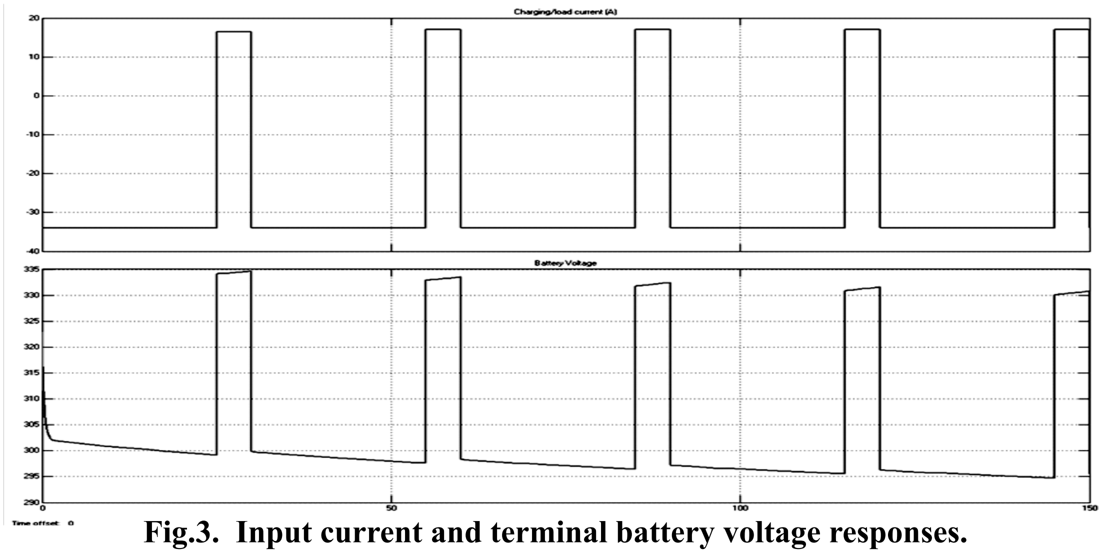

Fig.3. Input current and terminal battery voltage responses.

Results and discussion

The results shown in fig.4 reflect the non-linear dynamics of the battery model given the Voltage, SOC of the change during loading (discharge current). The shape of the response is similar to that in (Chacko and Chung, 2012).The SOC for each cell decreases proportionality with the load current.The effects of temperature in the battery model indicates an increase in charge and discharging current, thus the higher rate of discharge the higher is the temperature, in turns affects both the battery capacity and SOC.

Conclusions

This paper has summarised issues connected with the use of liquid fuel in transportation systems. It has presented a potential solution to reduce liquid fuel consumption in term of use of hybrid or hybrid electric vehicle. The paper has however highlighted that to ensure that the expected benefits of EV are realised appropriate infrastructure as well as battery technology and thermal battery management is required. The paper has presented work in progress on a thermal battery model.It has presented a short mathematical description of the system and aMATLAB/Simulink implementation.

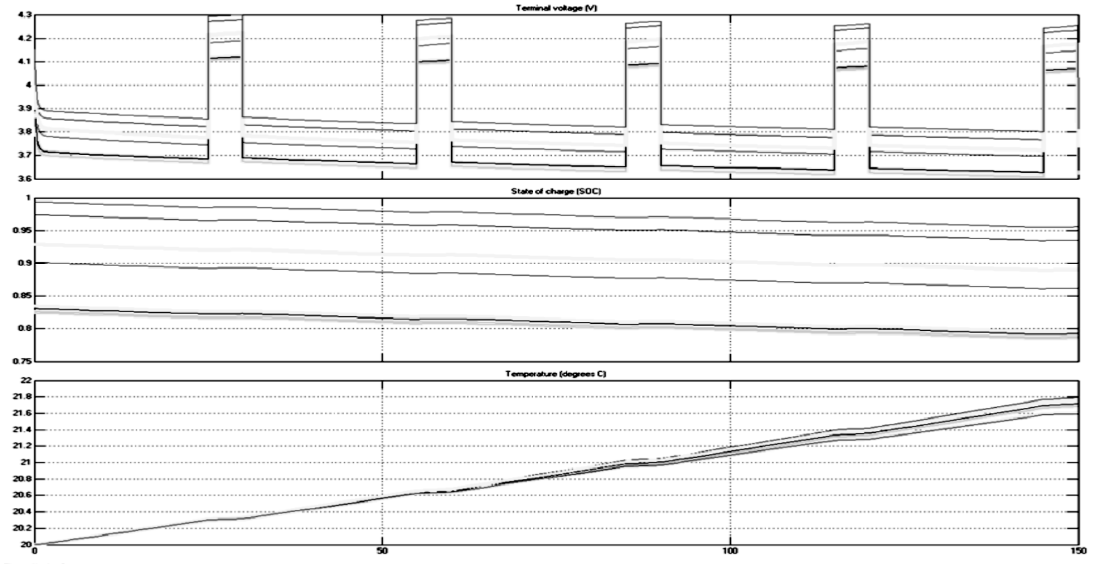

Fig.4 Terminal Voltage, SOC, and Temperature generation in the cells

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