THERMAL BATTERY CONTROL FOR HYBRID ELECTRIC VEHICLE HEV

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Abstract:

In recent years there has been increasing interests and demands on hybrid electric vehicle (HEV) as one of the option for greener technology. One of the major issues on the vehicle technology is the batteries system. In order to overcome the critical issue of concern in batteries, the research study introduces new battery thermal cooling and control (Fan-pad battery, FPB) system invited from building industry. The work is associated with improving battery performance; Longevity or life cycles through appropriate state of charge (SOC) and thermal control. The study presents the application of logic SOC control mechanismwith cross beaming techniques design in controlling the airflow into the battery cells, the paper achieve in maintaining the SOC as well as temperature variation within the operational limits of the battery cell (25oC to 45oC). The simulation studies were carried out to evaluate the cooling performance of the proposed fan -pad system and compared with existing cooling solutions based on Phase Change Material (PCM), air only andPCM plus air. The proposed fan-pad system achieved higher cooling power than the alternative cooling method. It improves cooling by 3oC compared to PCM plus air and 12oC compared to air-cooling.

Key word: State of Charge (SOC), Internal combustion engine (ICE), Hybrid electric Vehicle (HEV). Energy Management (EM)

1 INTRODUCTION:

With the increased concern about the global green house emissions and electric longevity in electric vehicle (HEV) drive, many studies are on going for efficient electric energy usage in hybrid electric vehicle (HEV)[1].

As a major trend of new transportation, electric vehicle and on-line electric vehicle (OLEV) were among recent technology in which the vehicle receive electric power wirelessly from the installed power cable laid on the road as alternative to improve the electric energy storage [2]. However, these still involve critical issues such weight and cost.

However, for HEV commercial applications it is important for HEV battery system design not to over design the cooling system and unnecessary complicated control hardware. Hence the interest here is to emerge a thermal management that requires less component and cost implications in maintaining the cells(battery) temperature and thermal profile within the desired range[3].

This paper analyzes the cooling performance of Fan- Pad battery (FPB) thermal management, a technology transfer for evaporative cooling used in the building management to the automotive industry, the system uses evaporative pad that allows passive cooling by the mixture of air and water. The paper shows system (FPB) capability to replace the conventional thermal managements used for LI-ion batteries in HEV as compared with phase change material (PCM) only, PCM plus air and air only. This comparison is carried out for various drive cycle airflow under same ambient temperature and same cell parameter.

It is important to note that the passive thermal management of Li-ion battery pack studied in this work uses vehicle speed by types of drive cycle speed as air speed in to the cooling system, the fan blade are used for airflow guide during vehicle drive to the pad through the cell pack thus Power less Fan when vehicle is under drive conditions and fan powered when at rest (static).

2. Battery electric circuit model

Battery systems exhibit complex non-linear behaviors. The level of model complexity depends on the area of battery system applications. Pattipati et al. 2011b classifies the battery electrical models in terms of equivalent circuit, electrochemical, fractional discharge, dynamics, data based and factors affecting battery performance. Dynamic models describe the instantaneous terminal voltage as a function of charge and discharge current. Electrochemical models, e.g. (Fuller, et al, 1994; Domenco, et al. 2010; Paul, et al. 2002), describe the power characteristic of battery by the mathematical representation that describes the inner actions of the battery e.g. based on modification of the Peukert equation (Omar, et al. 2013) for Li-ion batteries. Such method is demanding, computationally intense and inappropriate for run-time applications or system-level modeling(Saw, et al. 2014). Data types are mostly used to interpolate system parameter over a wide range of conditions (Pattipati, et al. 2011b). Equivalent circuit models describe the battery as a combination of resistors and capacitors, in Thevenin's equivalent circuit as shown in Figure 1.

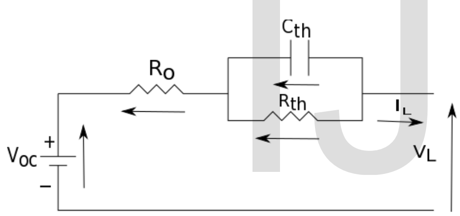


Fig.1. Thevenin's electric circuit model

Thevenin's equation is given as

$$V_L = +\frac{V_{th(t)}}{R_{th}C_{th}} - \frac{I_{L(t)}}{C_{th}} + \mathrm{V_{oc}} - \mathrm{I_L}(t)\mathrm{R_o}(1)$$

Where V_L is the load voltage, I_L is the load current, V_{oc} is the no load voltage, R_o is the internal resistance , R_{th} , C_{th} are the branch Therenin's resistance and capacitance respectively.

Daowd, et al. (2010), introduce model parameter estimation of the battery using the PNGV battery equivalent circuit.

2.1 State of charge (SOC) Estimation

The battery state of charge (SOC) is an important parameter that reflects the performance of the battery systems. Accurate estimation of SOC not only protects battery but can prevent overcharge or discharge and improves battery life. SOC is an important parameter for control strategy [8]. The SOC of a battery can be defined as the remaining capacity of the battery or the remaining charge in the chemistry of the system as shown by equation 2 [9].

$$SOC = \frac{Q_t}{Q_n} \qquad (2)$$

The modified form of coulomb counting method in defining SOC is as defined in the following equation [10].

$$SOC(t) = SOC(0) + \int \frac{I(t)}{Q_n} \mathrm{d}t \qquad (3)$$

Where Q_n and Q_t are nominal and current battery capacity, I(t) is the current flow, is the current state of charge and SOC(0) is the initial state of charge of the battery.

3. Battery State of charge control

HEVs technology requires at least two independent driving power sources (ICE and electric storage) and an energy management (EM) for the control ofdriving power sources to ensure a reliable andenjoyable driving experience [11]. In this study the energy management (EM) focuses on the battery storage however it does not include the electric drives (Inverters, electric machine) and ICE. The battery is charged with the ICE. Charging the battery results in increases of both SOC and temperature. Discharging the battery occurs mainly to provide the motoring power then the vehicle is in electric mode. Discharging the battery results in a decrease of the SOC and an increase in the battery temperature. This implies that the battery temperature may limit the ability of the vehicle to recover energy by charging the battery.

The study in this paper presents a developed SOC control under vehicle operation simulating under American drive cycle FT 75 and New European drive cycle NEDC respective speed cycle response shown in Figure 2 a and b respectively

ISSN 2229-5518

(a)

(b)

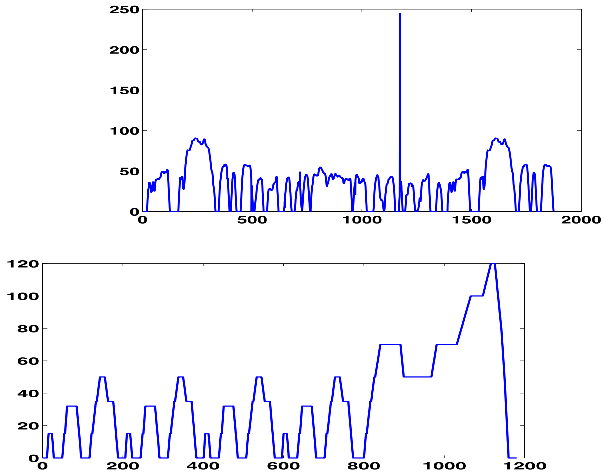


Fig.2 (a) American FT 75-drive cycle (b) New European drive cycle

The battery current demand by the vehicle in this study was derived from the vehicle dynamic model and the drive cycle speed.

Vehicle power train components constitute of various driving force components, these includes general vehicle dynamics (Tire rolling force, vehicle dimensions, transmission and aerodynamic resistance), ICE, Electricmotor, Generator and lastly the storage (battery).

3.1 Vehicle Dynamic

Consider a moving vehicle shown in Figure 3, with various force dynamics. From the findings of the electric torque and power required by motor, will leads the computation of load current demands by energy storage (battery). The forces and power required by the entire power train depends on the driving pattern that can be captured by drive cycles scheduled speed.

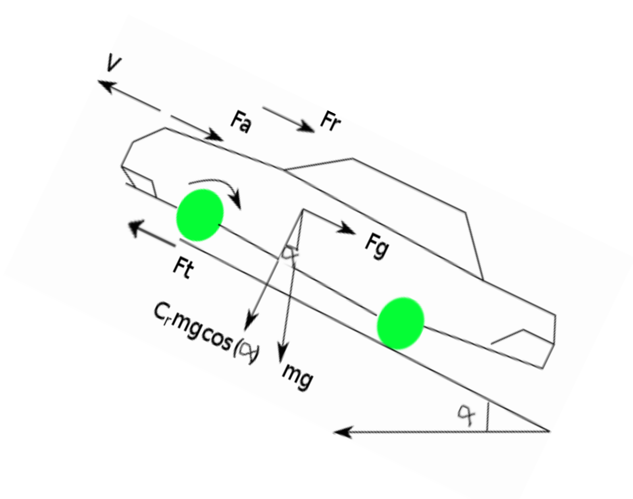


Fig. 3. Vehicle dynamic forces resolution

The process of finding the forces on the moving vehicle, Newton's postulate was applied in this study second law of motion thus reasons of vehicle movement depends on the resulting forces acting the entire vehicle system as in Figure 3, the governing equations describes by opposing forces namely 'Ft' as traction force, 'Fg', gravitational force, 'Fa' aerodynamic resistance force, 'Fr' as the rolling force (ALCALÁ et al. 2014; Nyberg 2013; Wei 2012).

$$F_r = C_r mgcos(\alpha) \quad (4)$$

$$F_g = mgsin(\alpha)(5)$$

$$F_a = {}^1/_2\, C_d A \rho_a v^2 \quad (6)$$

Total force

$$m\frac{dv}{dt} = F_t - F_g - F_a - F_r \quad (7)$$

It follows that the traction force is :

$$F_t = m\frac{dv}{dt} + mgsin(\alpha) + {}^1/_2\, C_d A \rho_a v^2 + C_r mgcos(\alpha) \quad (8)$$

Where m is the mass of the vehicle, g is the gravity, ρ_a the density of air , v the speed of the vehicle which usually depends on the driven speed patterns, Cd is the drag coefficient, Cr is the rolling friction coefficient, A is the front area of the vehicle and α is the road inclination angle as shown in Figure 3.
The torque required cranking the engine, τ_{crank} [N.m] that can overcome the engine's inertia. J_{eng} [Kg.m2] is given by:

$$\tau_{crank} = J_{eng}\frac{d\omega_{eng}}{dt} + \tau_{lt} + \tau_{tr} \quad (9)$$
9

Where τ_{crank} - is the torque required to crank the engine, ω_{eng} -is the angular speed of the engine [rad/s], J_{eng} - is the engine's inertia in (kg.m2), τ_{lt} - is the lumped torque [N.m] and τ_{tr} - is closed throttle torque of the engine [N.m].

However for HEV and electric vehicle (EV) utilizes electric motor as the prim mover of the vehicle, thus the motor convert the electric energy from the battery to mechanical propulsion power for the vehicle (Wei 2012). The force mechanism demonstrated in Figure 4.

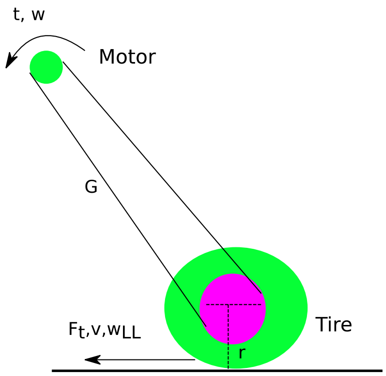


Fig. 4. Torque transmission system

The motor torque demand τ_t is related to the force applied on the vehicle through the tire of radius 'r' and the transformation ratio G : On the assumption that transmission ratio is 1:1 Given by equation

$$\tau_t = {F_t r}/{G} \qquad (10)$$

This is demanding torque on the motor; hence the inertia moment (J) of the entire mass of the vehicle M could be computed through the tire radius (r) and transformation ratio given by equation 11

$$J = \frac{Mr^2}{G^2} \qquad (11)$$

The total power required by the electric motor (Pelec) is given by the product between the torque τ_t in equation 10 and the angular speed ω as in Figure 4 and η is the efficiency of the motor (Wei, 2012).

$$P_{elect} = \begin{cases} (\tau_t - \tau_m)\omega\eta, & \tau_t < 0 \\ \frac{(\tau_t \tau_m)}{\eta}\omega, & \tau_t \geq 0 \end{cases} \qquad (12)$$

However the electric motor parameter used in the study is as shown in table 3.1

TABLE 0-1 VEHICLE DESIGN PROPERTIES

Vehicle properties	Values
Mass	1325 Kg
Distance from CG to front axel	1.35 m
Distance from CG to Rear axel	1.35 m
CG from ground	0.5m
Frontal Area ' A'	2.57 m2
Drag coefficient ' Cd'	0.26%
Rolling friction 'Cr'	0.1
Tire rolling radius 'r'	0.3 m

TABLE 0-2 ELECTRIC MOTOR PROPERTIES

Motor Parameter	Values
Efficiency	94 %
Max. angular speed	50 rpm
Max. power	70 KW
Max. bus voltage	400V

3.2 Battery Energy demand (current)

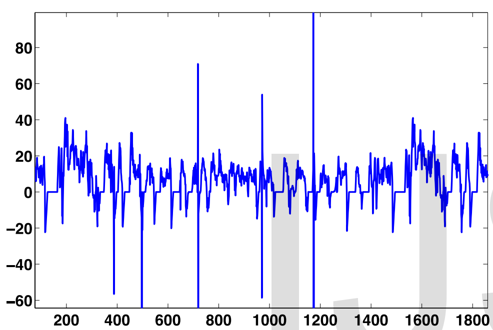
HEV electric traction power mode is governed by the motor angular speed (ω), motor torque τ_t and the total power of the motor (P_{elect}) derived from the traction force (Nyberg, 2013). However the current demand (I_{dem}) by the motor to provide the required traction force for the vehicle, thus this is required on the battery pack for the electric drive mode of the vehicle computed from the demand electric power given in equation 12. Therefore current demand is given by

$$I_{dem} = \frac{P_{elect}}{V_{batt}} \quad (13)$$

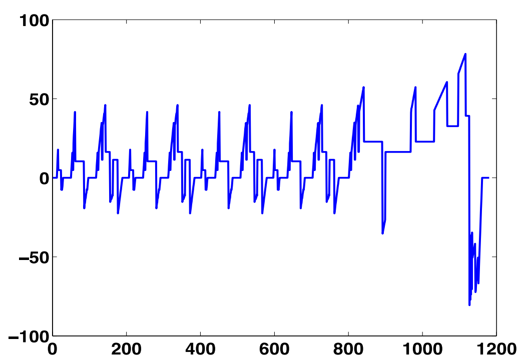
Thus

$$I_{elec} = \frac{\tau_t \omega}{V_{bat}} = \frac{F_t r}{V_{bat}\, G} = \frac{(m\frac{dv}{dt} + mgsin\,(\alpha) + {}^1\!/_2 C_d A \rho_a v^2 + C_r mgcos\,(\alpha))}{V_{bat}\, G} \quad (14)$$

Where α is the road inclination angle with the vehicle, A is the front area of the vehicle and ρ_a is the density of air and 'v' is the driving speed based on the drive cycle speed as FT 75 or NEDC in Figure 2. The simulated current demand response computed for the drive cycle is depicted in Figure 5.



(a)



(b)

Fig.5. Current demand (a) for FT 75, (b) for NEDC

Figure 5 shows the charging and discharging current demand on the HEV battery pack for FT 75 (-70 A to 70A) at average while for NEDC (-50 A to 50A) .

3.3 SOC Logic control

HEV propulsion mechanism works in two modes Internal combustion Engine (ICE) mode or Electric mode (Battery powered). In this study the energy management (EM) focuses on the battery storage however it does not include the electric drives (Inverters, electric machine) and ICE. The battery is charged with the ICE, charging the battery results in increases of both SOC and temperature. Discharging the battery occurs mainly to provide the motoring power then the vehicle is in electric mode. Discharging the battery results in a decrease of the SOC and an increase in the battery temperature. This implies that the battery temperature may limit the ability of the vehicle to recover energy by charging the battery.The study developed a control system to control the state of charge under operation by logical switching to the driving power train from electric mode to internal combustion engine (ICE) mode. An alternator unit developed in SimscapeTM that serves as a charging unit when ICE drives the vehicle modeled the power provided by the ICE. The control logic for ICE/Battery mode of operation and battery charge/discharge is shown Figure . While illustrates the control logic implemented in MATLAB/Simulink as described in Figure 6.

```
if Temp<=45
    If SOC >= 65     % vehicle can run on battery power
        Discharge  = ON % ICE if OFF
        ICE = OFF
    else             % battery should be charged
        Charge = ON
        ICE = ON
    end
else % battery temperature too high, need to use ICE
    Charge = OFF % ICE is ON
    Discharge  = OFF % ICE is ON
    ICE = ON
end
```

Figure 6. code representation of the SOC control logic to switch between ICE and battery

The logic use based on SOC and battery temperature.

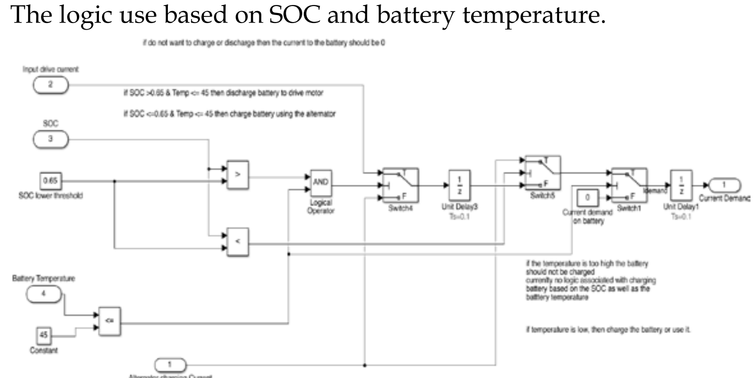


Fig.7 Simulink SOC control

Having described the control logic for the battery/ICE switching to maintain a SOC higher than 65%.

3.4 Simulation Results

The result shows SOC maintained higher than 65% for the tested drive cycles American FT 75 and NEDC as indicated in Figure 8 and 9.

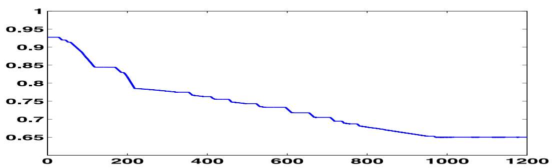


Fig. 8. SOC control from current demand for American FT 75 drive cycle

Figure 8 shows the switching actions between the two-hybridmodes ICE and Electric mode this could also be seen from the current demand on the battery shown in Figure 5 (a). the controller logic maintain the % SOC much higher than 65% as compared with the response by the demand current due to NEDC drive cycle shown in Figure 9.

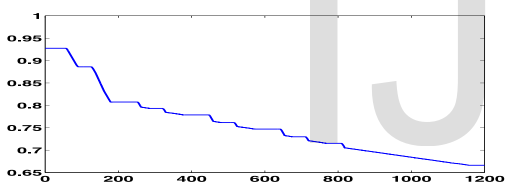


Fig. 9. SOC control from current demand for NEDC drive cycle.

The current demand response by the NEDC is less stressful in terms of multiple charging discharging rate, but with same control range above 65%.

4.0 PAD BATTERY THERMAL COOLING

Pad thermal system of cooling is an evaporative cooling widely used in hot and dry regions where it is mostly applied to enclosed surfaces. Evaporative cooling is produce by passing atmospheric air through wetted pad that acts as heat exchanger. The resulting water evaporation results in a temperature reduction of the air passing through the pad (Khah and Fla, 1989). The system requires small amount of energy to produce cooling [15], however requires less power compared to air conditional systems and it is considered to be effective, economical, healthy and environmentally friendly cooling system [16].
The cooling system idea was invited from building cooling technology , classified into two major forms. Direct evaporated cooling (DEC) and indirect evaporative cooling (IEC).

Direct evaporative cooling (DEC) involves air coming into direct contact with water. The system however adds moisture to the air stream, where the output air temperature reduces to its wet-bulb temperature under adiabatic saturation condition [16]. In DEC system the dry bulb temperature decreases while the wet bulb temperature remains the same, principally the system transformssensible heat to latent heat, where heat is absorbed by the water as it evaporates from medium (Pad) and leaves the system at lower temperature [17].
The indirect evaporative cooling (IEC) provides cooling to the processed air without any additional moisture to the primary air stream [16], [18]. The system involves a secondary air stream that goes through the heat exchanger, were it cools the primary airstream circulated by a blower. In an IEC both the dry-bulb and the wet-bulb temperature are reduced.
The wet-bulb temperature (T_{wtb}) is thelowest temperature achievable by evaporatingwater into air to bring the air into saturation. The dry-bulb temperature (T_{db}) is the air temperature measured by an ordinary thermometer.
For the direct evaporative cooling the efficiency (∈) of the pad otherwise known as effectiveness is usually 90% [19].
Thus efficiency of an evaporative pad is given as

$$\in = \frac{(T_{db} - T_{ac})}{(T_{db} - T_{wtb})} \qquad (15)$$

4.1 Cooling design

The study introduces two series directional cross beaming cooling flow techniques to achieve unification of battery cells temperature by free airflow to the HEV battery pack by vehicle speed through two channels to battery pack as depicted in Figure 10.

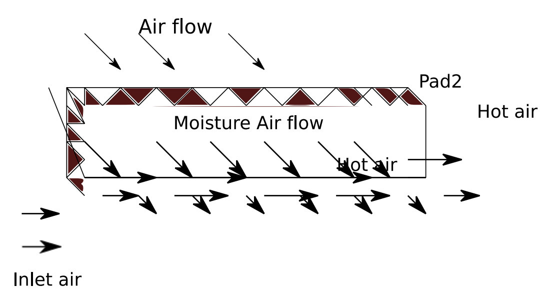


Fig. 10 Cross airflow cooling

Uniform cell cooling is necessary for the prevention of cell degradation that could lead to voltage variations among cells in the pack, these results to non-uniform rates of discharge thus accelerate cell degradation that could lead to cell explosion[20]. The setup result in a two directional cooling using direct system under adiabatic processes the air across the pad materials tends to evaporate the water surface thus maximizing cooling efficiency through the increase in heat transfer coefficient [21].

4.2 Mathematical Pad cooling model

The air-cooling mass flow rate depends on the area of the Pad, generated from continuity equation given as:

$$m_{ai} = \rho_a A_i v \qquad (16)$$

Where v is the air speed, ρ_a is air density and A_i is area of cooling pad in m2 however the convective heat transfer coefficient $h_i$can be computed from Nusselt number by

$$N_u = \frac{h_i\, l}{\sigma}$$

Where l is the length of pad, σ is thermalconductivity of air. Therefore

$$h_i = \frac{N_u\, \sigma}{l} (17)$$

And the Nusselt number [15] given by

$$N_u = 0.1 \left(\frac{1}{l}\right)^{0.12} R_e^{0.8} P_r^{\frac{1}{3}} \qquad (18)$$

Where R_e is Reynolds number and P_r is Prandtl number, also given as

$$R_e = \frac{vl}{\vartheta}$$

And

$$P_r = \frac{\vartheta}{\alpha} \qquad (19)$$

Whereϑ is the kinetics viscosity, v is the air speed α is the thermal diffusivity given as

$$\alpha = \frac{\sigma}{\rho C_{pa}} \qquad (20)$$

Where σ is thermal conductivity of air, C_{pa} is specific heat capacity of air

The battery change in temperature in the pack during vehicle operations are modeled under energy conservation law as [22].

$$M_c C_{pc} \frac{dT}{dt} = Q_g - Q_r \qquad (21)$$

Where Q_g is the heat transfer by the conduction from cells in the pack of Mass M_c in kg,C_{pc} is specific heat capacity of the cells (J/kg. C), T is temperature and $Q_r = (Q_{p1} + Q_{p2})$ is the rate of heat removed by the contribution of the two directional pads Q_{p1} and Q_{p2} thus the mass heat transfer by pad

$$Q_{pi} = h_i A_i (T - T_o) \qquad (22)$$

T_oIs the temperature of the individual pad in °C

The heat generated in the battery cells Qg given by the electrochemical energy is represented as

$$Qg = \left[I(v_i - V_{oci}) + IT_{ci}\frac{dV_{oci}}{dT_{ci}}\right] (23)$$

where I is the total current flow, v_i is the load voltage, V_{oci} is the open circuit initial battery cell voltage and T_{ci} is the cell temperature [23].

Temperature coming out of the individual pads expressed as output temperature T_{oi} given as

$$T_{oi} = \frac{Q_{pi}}{C_{pui}\, m_a} + T_{wb} + [T_a - T_{wb}] \exp\left(\frac{-h_i A_i}{m_a C_{pui}}\right) \qquad (24)$$

Thus the total cooling temperature contributed is given as

$$T_{pad} = \sum_{i=1}^{2} T_{oi} \qquad (25)$$

Where T_{wb} is the wet bulb temperature of air entering pad, T_a is the ambient air temperature, T_{pad} is the total pad cooling temperature.

4.3 Simulation results

The model was develop under MATLAB® and SimulinkTM simulation environment to investigate the dynamic behavior of the proposed cooling technique for HEV batterypack. Simulation result under NEDC drive is indicated in Figure11

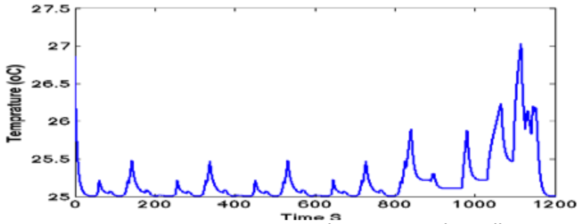


Fig.11 Pad Cooling temperature under NEDC drive

The cells cooling temperature response under the NEDC drive reflects a control of temperature within the best operational temperature level of Lithium-ion battery (20oC– 45oC)

4.3.1 Comparison of cooling systems with Pad cooling

The cooling model was validated with the existing battery cooling system Air-only and liquid cooling simulated under NEDC with similar cell parameter. The systems cooling were compared as when vehicle is under driving condition results depicted in Figure 12.

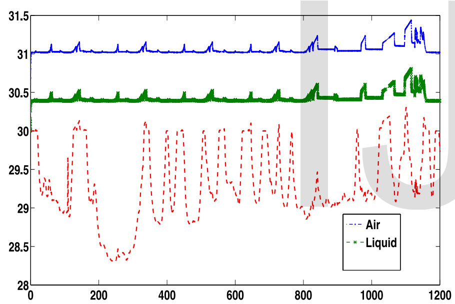


Fig.12 Cooling system comparison with pad system

The comparison of the systems capabilities highlighted that the pad thermal cooling approach had advantages over the other techniques considered in this study for the particular simulation carried out. The system approach is simple, relatively cheap and should results in lower maintenance costandlower energy consumption than other techniques.

It can be seen that the evaporative pad cooling has more cooling power resulting in cell temperatures approximately 2oC lower than air-cooling and 0.6oC lower than liquid cooling system. However the Pad system is simpler, cheaper, lower maintenance cost, uniform cooling and it improves the thermal conductivity of air.

5.0 CONCLUSION

Battery pack design together with battery management systems play a key role in maintaining the battery state of charge as well as battery temperature within operational limits. Key to the longevity and health of the battery is the ability to manage effectively the battery cells temperature variations associated with the charge and discharge during normal vehicle operations. Battery pack packaging is designed to help the thermal management systems keep each cell within the pack at a similar temperature. This study has investigated three aspects linked with battery pack thermal management.

The first is the technology transfer from the building industry to the automotive industry in terms of thermal management. Having identified the relative merits of the current cooling techniques based on air, liquid, phase change material and combination of thereof in systems such as Heating, ventilation and air conditioning, the research has resulted in the proposal for a new and simplified pad evaporative cooling system.

The overall outcome of the work is to have demonstrated that alternative battery cooling could be developed based on the learning made in other industries such as the building industry. Being able to provide a simple yet effective battery cooling system marks a significant step towards maintaining optimal battery performance.

REFERENCES

[1] M. Shams-Zahraei, A. Z. Kouzani, S. Kutter, and B. Bäker, “Integrated thermal and energy management of plug-in hybrid electric vehicles,” *J. Power Sources*, vol. 216, pp. 237–248, 2012.

[2] M.-H. Park, E.-G. Shin, H.-R. Lee, and I.-S. Suh, “Dynamic model and control algorithm of HVAC system for OLEV® application,” *Control Autom. Syst. (ICCAS), 2010 Int. Conf.*, pp. 1312–1317, 2010.

[3] R. Sabbah, R. Kizilel, J. R. Selman, and S. Al-Hallaj, “Active (air-cooled) vs. passive (phase change material) thermal management of high power lithium-ion packs: Limitation of temperature rise and uniformity of temperature distribution,” *J. Power Sources*, vol. 182, no. 2, pp. 630–638, Aug. 2008.

[4] N. Omar, P. Bossche, T. Coosemans, and J. Mierlo, “Peukert Revisited—Critical Appraisal and Need for Modification for Lithium-Ion Batteries,” *Energies*, vol. 6, no. 11, pp. 5625–5641, 2013.

[5] L. H. Saw, K. Somasundaram, Y. Ye, and a. a. O. Tay, “Electro-thermal analysis of Lithium Iron Phosphate battery for electric vehicles,” *J. Power Sources*, vol. 249, pp. 231–238, Mar. 2014.

[6] B. Pattipati, C. Sankavaram, and K. R. Pattipati, “System identification and estimation framework for pivotal automotive battery management system characteristics,” *IEEE Trans. Syst. Man Cybern. Part C Appl. Rev.*, vol. 41, no. 6, pp. 869–884, 2011.

[7] M. Daowd, N. Omar, B. Verbrugge, P. Van Den Bossche, and J. Van Mierlo, “Battery Models Parameter Estimation based on Matlab / Simulink ®,” *25th World Batter. Fuel Cell Electr. Veh. Symp. &Exhibition*, vol. 2, no. C, 2010.

[8] H. He, R. Xiong, and H. Guo, “Online estimation of model

ISSN 2229-5518
parameters and state-of-charge of LiFePO4 batteries in electric vehicles," *Appl. Energy*, vol. 89, no. 1, pp. 413–420, Jan. 2012.

[9] W.-Y. Chang, "The State of Charge Estimating Methods for Battery: A Review," *ISRN Appl. Math.*, vol. 2013, pp. 1–7, 2013.

[10] Y. Hua, A. Cordoba-Arenas, N. Warner, and G. Rizzoni, "A multi time-scale state-of-charge and state-of-health estimation framework using nonlinear predictive filter for lithium-ion battery pack with passive balance control," *J. Power Sources*, vol. 280, pp. 293–312, 2015.

[11] M. Ade and a. Binder, "Modeling the drive train for two parallel Hybrid Electric Vehicles in MATLAB/Simulink," *2009 IEEE Veh. Power Propuls. Conf.*, pp. 592–600, 2009.

[12] I. ALCALÁ, A. CLAUDIO, G. GUERRERO, J. AGUAYO ALQUICIRA, and V. H. OLIVARES, "Electric Vehicle Emulation Based on Inertial Flywheel and a Dc Machine," *Dyna*, vol. 81, no. 183, pp. 86–96, 2014.

[13] P. Nyberg, *Evaluation , Transformation , and Extraction of Driving Cycles and Vehicle Operations*, no. 1596. LiU-Tryck,Linkoping, 2013.

[14] L. Wei, *Introduction to Hybrid Vehicle system Modeling and Control*, vol. XXXIII, no. 2. 2012.

[15] M. C. Ndukwu, S. I. Manuwa, O. J. Olukunle, and I. B. Oluwalana, "MATHEMATICAL MODEL FOR DIRECT EVAPORATIVE SPACE COOLING SYSTEMS," *Niger. J. Technol.*, vol. 32, no. 3, pp. 403–409, 2013.

[16] B. Riangvilaikul and S. Kumar, "An experimental study of a novel dew point evaporative cooling system," *Energy Build.*, vol. 42, no. 5, pp. 637–644, 2010.

[17] S. K. Abbouda and E. A. Almuhanna, "Improvement of Evaporative Cooling System Efficiency in Greenhouses," *Int. J. Latest Trends Agric. Food Sci. Vol.2*, no. 2, pp. 83–89, 2012.

[18] A. Mohammad, Th, S. Bin, M. Y. Sulaiman, K. Sopian, and A. A. Al-abidi, "Experimental Performance of a Direct Evaporative Cooler Operating in Kuala Lumpur," *Int.J Therm. &Environmental Eng. Vol. 6,No. 1 15-20*, vol. 6, no. 1, pp. 15–20, 2013.

[19] K. Senawong, R. Suntivarakorn, and T. Radpukdee, "Sliding Mode Control for Humidity and Temperature Control in an Evaporative Cooling System of a Poultry house," *Second TSME Int. Conf. Mech. Eng. 19-21 October,2011, DRC07*, 2011.

[20] Z. Rao and S. Wang, "A review of power battery thermal energy management," *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4554–4571, 2011.

[21] X. Zhao, S. Liu, and S. B. Riffat, "Comparative study of heat and mass exchanging materials for indirect evaporative cooling systems," *Build. Environ.*, vol. 43, no. 11, pp. 1902–1911, 2008.

[22] A. Cordoba-arenas, S. Onori, and G. Rizzoni, "A control-oriented lithium-ion battery pack model for PHEV life-cycle studies and system design with consideration of health management," *J. Power Sources*, vol. 1, pp. 1–18, 2014.

[23] H. Fathabadi, "High thermal performance lithium-ion battery pack including hybrid active-passive thermal management system for using in hybrid/electric vehicles," *Energy*, vol. 70, pp. 529–538, 2014.