Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 10, October-2019

Energy Management Strategy for Improving Battery Life in an Electric Vehicle

Toshik Audichya
College of Technology and Engineering,
Udaipur, India

Jai Kumar Maherchandani
Electrical Engineering Department,
College of Technology and Engineering (MPUAT),
Udaipur

***Abstract* - Electric Vehicle are getting popularity as a cleanest and eco-friendly vehicle. But the Battery Life is still a hurdle in the acceptance of Electric Vehicle. The battery life is mostly affected by the driving conditions, transient load demands, high starting current etc. This paper proposed an Energy Management Strategies for a Photovoltaics /Battery /Ultracapacitor based Hybrid Electric Vehicle. The proposed strategy is implemented with the help of MATLAB/Simulink. The simulation results show that use of PV Power. PV Power to meet the steady-state load requirement and Ultracapacitor for sudden peak power demand reduce the stress on battery and to improve the battery life.**

Keywords – Electric Vehicle, Battery Life, Ultracapacitor, Photovoltaic array, energy management strategy, State of Charge (SOC), Hybrid Electric Vehicle (HEV) etc.

I. INTRODUCTION

An Electric Vehicle (EV) is a vehicle which is powered by an electric motor and battery instead of getting power from an Internal Combustion Engine (ICE). The EV gets power from batteries through which the vehicle's electric motor is powered. The batteries used in it are rechargeable can be charged by the electricity available in the locality (House/Private Supply + EV Charging Station). They are simpler in working structure and robust than the traditional petrol or diesel engine powered vehicle. When it comes to environmental impact, the EVs are the cleanest and eco-friendly vehicle.[1] They create hardly any noise pollution due to the absence of heavy machinery parts of an internal combustion engine i.e. clutch, gears etc. Also driving an Electric Vehicle is very easy as they are based on automatic transmission. However even though such pros of an Electric Vehicle still the commercialization of the industry haven't gone purely on Electric Vehicle due to limiting factors such as battery life, travel range, charging time and charging station availability [3] - [6], and its competition with traditional gasoline vehicle on basis of availability, fuel-stations, price etc. Various factors which affect the battery life are cycle of a battery i.e. State of Charge (S.O.C), Charging and Discharging cycle, shelf life etc. Although due to technological advancement and increasing dependencies have led to an increase in the exceed capability and its efficiency.

As the main hurdle in revolutions of Electric Vehicle is the energy source which provides high peak power and high energy density with relatively small shelf size. Currently, the only viable solution to this issue is to have a Hybrid Energy Storage System (HESS). The combination of the battery with the Electrochemical Double Layer Capacitor (E.D.L.C.) or Ultra-Capacitor or Super-Capacitor is also a type of HESS. [3] – [8] Thus, the hybridization of Battery with an Ultra-Capacitors can be a solution for the bottleneck issue of high peak power requirement. [2]

For an Electric Vehicle which has only one source of energy can be made more proficient by using multiple sources of energy such as a Hybrid Electric Vehicle i.e. a type of an Electric Vehicle which is based on the principle of combination of two energy sources to power the vehicle. The Photovoltaic (PV) array also can be used as a power source in an Electric Vehicle to give supplementary power backup to a battery. It can handle steady-state load conditions in a vehicle and help in improving battery life by reducing stress on it by fulfilling load demand conditions.[10]

The HEV was developed to overcome the disadvantages of both ICE vehicles and the pure battery-powered Electric Vehicle. It helps the battery to compensate with low energy density, high peak power and increasing the vehicle's range. [7] The hybrid-electric system of batteries and Ultra-Capacitor supports the battery by high peak current, saving and improving Battery State of Health (S.O.H.) and State of Charge (S.O.C.) by supporting in high and variable load condition by saving its charging/discharging cycle and its shelf life. By compensating battery during transient loads the Ultra-Capacitor makes system optimum & maintaining battery's life and PV array supplies in steady-state. [7] - [10] With the energy management strategy of storage systems the performance of the Electric Vehicle could be improved.

II.ELECTRICAL MODELLING OF COMPONENTS

The mathematical modelling of battery, Ultra-capacitor, PID controller and PV array is presented. These components are used in the MATLAB/Simulink model to evaluate the energy management strategy for battery life improvement.

A. BATTERY THERMAL MODEL

A battery is an electrochemical cell that converts stored chemical energy to electrical energy while energy discharges. It is an energy storage device in which electrochemical reaction occurs and it produces electricity as an output which can be recharged repeatedly and used again. The basic unit of a battery is battery cell and cells can be arranged in series or parallel to get the required output voltage. Batteries are widely preferred for energy storage medium due to their high specific energy density proportional to smaller volume size. There specific power rating can go up to several KWh.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

Currently, the lithium-ion battery is preferred over lead-acid, nickel-metal hydride and nickel-cadmium battery due to high specific energy and size ratio, low charging time and maintenance-free system. The lithium-ion is a current battery technology used in the modern vehicle due to its specific characteristics and sub-par features. The battery consists of a single electrochemical unit which is known as battery cell and this cell can be connected in series or parallel topology. The Fig.1 shows the battery equivalent circuit.

Where the voltage is a function of charge and has the following relationship:

$$V = V_0\left(\frac{SOC}{1-\beta(1-SOC)}\right) \tag{1}$$

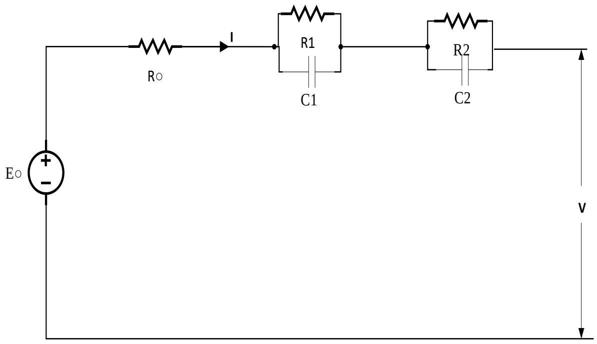

Fig. 1 Battery equivalent circuit

Where,
- *SOC* (state-of-charge) is the ratio of current charge to-rated battery capacity.
- V_0 is the voltage when the battery is fully charged at no load, as defined by the Nominal voltage parameter.
- β is an exponential constant capacity of the battery.

B. DC-DC CONVERTER

DC-DC converters are mainly used to change DC electrical voltage from one level to another including unregulated DC input voltage to a regulated output voltage. AC converter is used to get DC voltage of some level plays a specific DC voltage at output level with minimizing the loss. These DC converters are chosen as the transformers can't work on the DC side. Here, the efficiency can't make to be equal to 100% as the output power is always lower than the input power. The dc-dc converters are mainly divided into three type buck converter, boost converter, and buck-boost converter. The DC-DC converter used in the proposed model is boost converter.

Modelling of the boost converter

Let us consider a simple model of a boost converter with no internal resistance and consider all components as ideal and don't consume energy.

a. When the switch is closed.

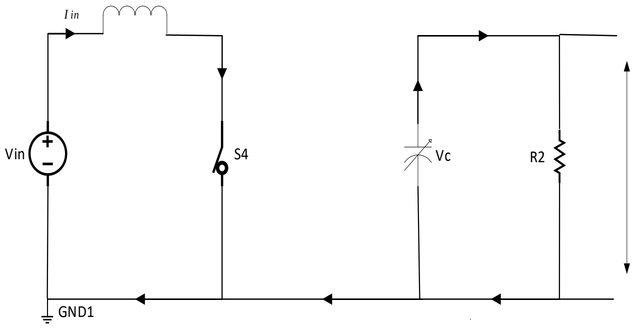

Fig.2 Boost converter Switch ON

When the Boost converter is switched ON, as shown in Fig.2.

From KVL,

$$L\frac{di}{dt} = V_{in} \tag{2}$$

From KCL,

$$C\frac{dV_c}{dt} = \frac{-V_C}{R} \tag{3}$$

Where i_L = inductor current.

The i_L = inductor current is equal to $i_L = i_{in}$ (Input current).

v_c = Voltage Capacitor.

$v_c = v_{out}$ (Output Capacitor).

Let us consider state variable:

$$x_1 = i_l(i_{in}),\ x_2 = v_c(v_{out}) \tag{4}$$

$$\begin{pmatrix}\dot{x}_1\\ \dot{x}_2\end{pmatrix} = \begin{pmatrix}0 & 0\\ 0 & \frac{-1}{RC}\end{pmatrix}\begin{pmatrix}x_1\\ x_2\end{pmatrix} + \begin{pmatrix}\frac{1}{L}\\ 0\end{pmatrix}V_{in} \tag{5}$$

$$V_0 = [0\ 1]\begin{pmatrix}i_L\\ v_C\end{pmatrix} \tag{6}$$

That is: - $\dot{x}_1 = A_1 + B_1 u$

b. When the switch is open.

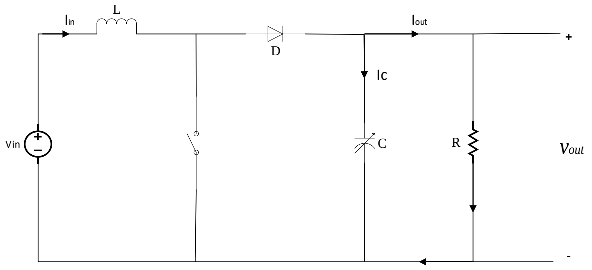

Fig.3 Boost converter Switch OFF

When the Boost converter is switched OFF, as shown in Fig.3.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

From KVL, we get

$$L\frac{dl}{dt} = V_{in} - V_C \tag{7}$$

From KCL, we get

$$C\frac{dV_c}{dt} = i_L - \frac{V_C}{R} \tag{8}$$

In State Space equation form:

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \end{pmatrix} = \begin{pmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} \frac{1}{L} \\ 0 \end{pmatrix} V_{in} \tag{9}$$

$$V_0 = [0\ 1] \begin{pmatrix} i_L \\ v_c \end{pmatrix} \tag{10}$$

That is: - $\dot{x}_1 = A_2 + B_2 u$

During discontinuous conduction mode

From KVL,

$$\frac{di_L}{dt} = 0 \tag{11}$$

From KCL,

$$\frac{V_C}{R} + C\frac{dV_c}{dt} = 0 \tag{12}$$

In state space form:

$$\begin{pmatrix} \frac{di_L}{dt} \\ \frac{dV_c}{dt} \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & \frac{-1}{RC} \end{pmatrix} \begin{pmatrix} i_L \\ V_c \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \end{pmatrix} V_{in} \tag{13}$$

$$V_0 = [0\ 1] \begin{pmatrix} i_l \\ v_c \end{pmatrix} \tag{14}$$

C. ULTRA- CAPACITOR

Ultra-capacitor/Super-capacitor is a very high energy variant of a conventional capacitor with greater specific energy density *(Wh/kg)* than conventional capacitors. It also possess higher power density *(W/kg)* than the most available traditional batteries. Such property of capacitor allows them to produce high power transiently. However, they store power lower than battery but produce power at a higher rate. Ultra-capacitor have a double electric field which is generated when it charged and behaves as a dielectric, it doesn't have dielectric material like ceramic aluminum oxide or polymer films to separate its electrodes. Instead, here a physical barrier made of carbon. The surface area of activated carbon is higher to allow the absorption of ions. When the activated carbon is with electrolyte. Positive and Negative ions tend to form between the infused solution electrolyte. The capacitance of Ultra-capacitor is defined as the ratio of charge (Q) to the applied voltage (V).

Here, C is directly proportionally to surface area (A) of each electrode and directly proportionally to surface area (A) of each electrode.

$$Q = C * V \tag{15}$$

$$C = \frac{(\epsilon\ A)}{d} \tag{16}$$

ϵ = dielectric constant of free space and constant of the insulating material between the electrodes and non-permeable separator.

The energy E stored in an Ultra-capacitor is directly proportional to its capacitance.

$$E = \frac{1}{2}CV^2 \tag{17}$$

One of the considering factor in Ultra-Capacitor is the internal resistance, however reducing equivalent series resistance (R_{ESR}) increase the power density.

Two factors which creates the voltage imbalance in the serial string of Ultra-capacitor are

- The fluctuation of the nominal capacitance of capacitors.
- Fluctuation in self-discharge performance or in the leakage current discharge.

Here, Fig.4 shows the simple circuit for Ultra-capacitor. Its circuit consist of capacitor, a series resistor, and parallel and series inductor.

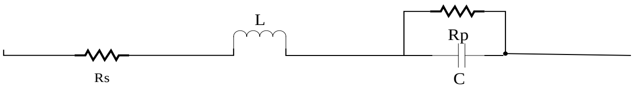

Fig.4 Simple circuit of Ultracapacitor

And fig.5 shows the equivalent circuit of ultracapacitor consists of a capacitor, a series resistor, and parallel and series inductor.

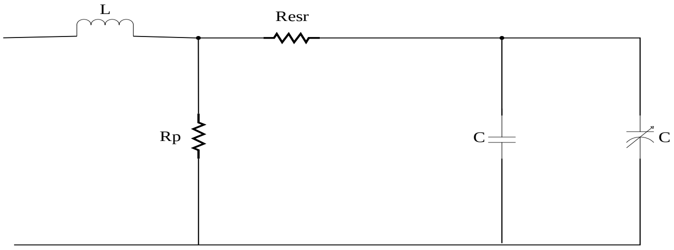

Fig.5 Equivalent circuit of Ultracapacitor

R_{esr} = equation series resistance, which contributes to energy loss during charging and discharging of Ultra-capacitor. While L as an inductor whose value is very small.

D. SOLAR PV MODELLING

A number of solar PV modules are connected together to give the desired voltage and current. The modelling of Photo-Voltaic includes a non-linear I-V relationship and it is best explained by a current source across a diode. The output of the PV module is influenced by the solar radiations, ambient temperature, and area of PV modules. The Fig. 5 shows the Double Exponential Model. The output power of the PV module is given by P_o.

$$P_o = \eta A_m G_t \tag{18}$$

$$I = Iph - I_{d1}\{\exp[\frac{q(V+IRs)}{KT}]-1\} - I_{d2}\{\exp[\frac{q(V+IRs)}{AKT}]-1\} - \frac{V+IRs}{Rp} \tag{19}$$

Where,

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

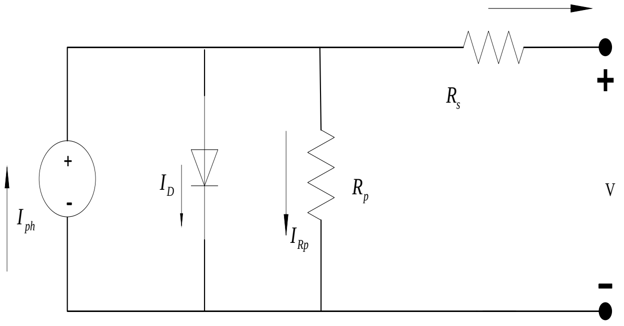

Fig. 6 Double Exponential Model

I_{ph} = Photo generated current
I_d = Reverse saturation current
V = Output Voltage
I = Output current
R_s = Series resistance
R_p = Parallel resistance (leakage current)
q = Electron charge
T = Temperature of the PV cell (°C)
K = Boltzmann constant

E. RULE BASED ENERGY MANAGEMENT STRATEGY

The proposed rule-based energy management strategy which is rule based has been shown in Table – 1. The following conditions have been applied on the MATLAB/Simulink model and results have been studied accordingly. Where P_{PV} is PV array output power in W/m^2, P_{load} load power and $P_{battery}$ is output battery power.

Table -1 Rule Based Energy Management strategy

Conditions	Action	Charging
$P_{PV} > P_{load}$	If PV power is greater than load demand, it meets the load steady state demand. The Ultracapacitor supplies in the transient load conditions.	Excess PV power is used in charging the battery and ultracapacitor. If the SOC level of battery and ultracapacitor is at normal level or low level.
$P_{PV} < P_{load} < P_{PV} + P_{battery}$	PV power + Battery power fulfils the load demand. Ultracapacitor supplies the load in transient condition.	The battery charges the ultracapacitor, as the available PV power is utilized in supplying the load.
No P_{PV} or $P_{PV} = 0$ **and** $P_{load} > P_{battery}$	As no PV power is available. The complete load demand is fulfilled by battery power until it reaches to a critical value. Ultracapacitor supplies the load in transient condition.	The battery charges the ultracapacitor till the battery reaches to low SOC level.

III. RESULTS

The simulations are carried out by taking different cases along with a specific value of PV Power at constant temperature. The different loads are taken to characterize Electric Vehicle. The proposed energy management strategy is implemented in a MATLAB/Simulink where PV power and supercapacitor reduces the stress on the battery by sharing the load and transient phase respectively. The PV shares the load in steady-state condition and also charges the battery and Ultra-Capacitor when sufficient power is generated by PV. Ultra-capacitor mainly works in the transient phase to meet the sudden load demand and reduce the stress on battery.

Fig.7 (a) shows the PV Power output near to. The load power requirements is 800Watts and PV power is generating nearly 1000W consistently, the PV is capable enough to supply the load demand and also charges the battery and Ultra-capacitor. At the initial, sudden transient in the system are present and Super-capacitor comes into the role and handles the transient power which only occurs for few milliseconds. When enough power is supplied to the load by PV and still power is left. It is supplied to the battery and Ultra-Capacitor for charging. If the SOC level of battery is at normal level or low level. It is observed in Fig.7 (c) battery power is going down to negative 200 Watts as its getting recharged.

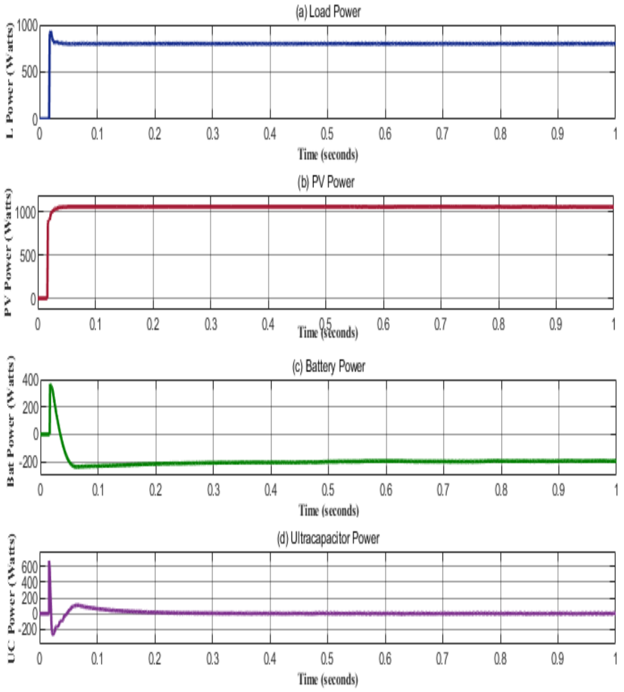

Fig.7 (a) Combined Power load demand, (b) PV Power, (c) Battery, (d) Super-capacitor in (Watts)

Fig.8 shows the (a) battery voltage in volts, (b) current in ampere, (c) state of charge in (%) and (d) Power in watts respectively. Battery, state of charge gets increased as PV charges the battery when it sufficiently supplies to the load and battery, also the Ultra-capacitor gets charged along with it. In battery, the initial state of charge is taken at 95%. From fig 8 (c), it is clear that battery state of charge does get

(This work is licensed under a Creative Commons Attribution 4.0 International License.)

improved by the help of PV as its state of charge increases from 95% to 95.015% and increases with time.

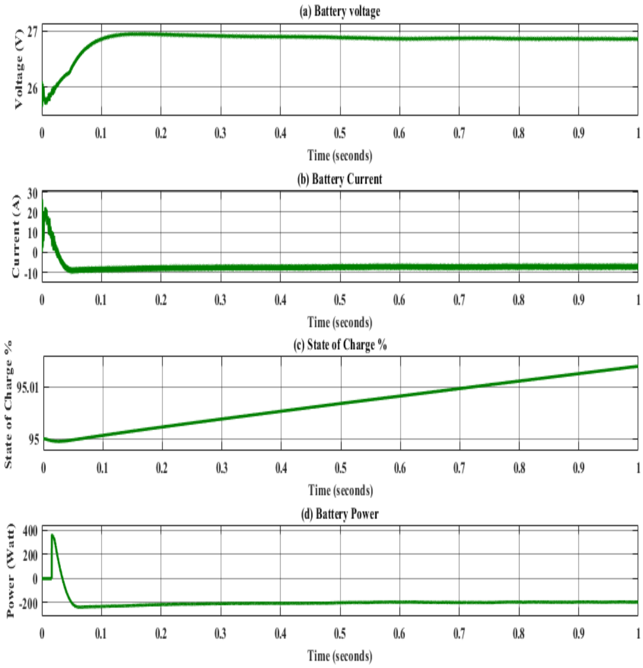

Fig 8 All battery waveforms (a) (voltage (V), (b) current (A), (c) Soc(%) and (d) Power (Watts))

Here, PV shares the steady state load with battery and supercapacitor meets the sudden load demand on the battery and reduces stress on the battery and improve its battery life. If the load demand is lower than Power generated by PV then the excess PV power charges the battery and supercapacitor. If PV power generates lower power than required load power, then battery and PV combined power fulfils the load demand. Also, in conditions when no PV power is available the then battery alone fulfils the load demand.

IV.CONCLUSION

The presented work is carried out for battery life improvement of an Electric Vehicle. An energy management strategy for a PV/Ultracapacitor/battery powered Electric Vehicle is developed. On the basis of the simulation results and the performance analysis carried out. It can be concluded that PV shares the load and fulfils the load demand when it is it is generating more than the load demand; it charges the battery and supercapacitor. When PV output power is lower than the load demand the battery and PV power both will fulfils the load demand. A dynamic model of the proposed strategy has been successfully developed.

The simulating results shows that the proposed strategy reduces the stress on the battery and enhance battery life. It is clear that the battery state of charge does get improved by the help of PV, ultracapacitor helps battery by supplying high peak current in transient load condition. The rule-based strategy can be further improved by applying Artificial intelligence techniques.

V. REFERENCES

[1] Aderemi, B.A., Zau, A.T.P., Chowdhury, SP.D., Olwal T.O., Abu-Mahfouz, A. M. 2018. Hybrid Battery Technologies with Battery Management System in Power and Energy Sectors. *2018 IEEE PES/IAS PowerAfrica* held at Cape Town, South Africa during June 28-29, 2018. pp. 716-721.

[2] Akar, F., Tavlasoglu, Y., Vural, B. 2017. An Energy Management Strategy for a Concept Battery/Ultracapacitor Electric Vehicle With Improved Battery Life. *IEEE Transactions on Transportation Electrification* 2017 3 : 191-200.

[3] Cao, J., Emadi, A. 2012. A New Battery/Ultra-Capacitor Hybrid Energy Storage System for Electric, Hybrid, and Plug-In Hybrid Electric Vehicles. *2009 IEEE Transactions on Power Electronics* **27** : 122-132.

[4] Chan, C.C., Bouscayrol, A., Chen, K. 2010. Electric, Hybrid, and Fuel-Cell Vehicles: Architectures and Modeling. *IEEE Transactions on Vehicular Technology* **59** : 589-598.

[5] Cheng, Y. Cui, S., Chan, C.C. 2009. Control strategies for an electric variable transmission based hybrid Electric Vehicle. *In : Proceedings of IEEE Vehicle Power and Propulsion Conference* held at Dearborn, MI, USA, 2009, pp.1-7.

[6] Gu,B., Cha, S.W. 2017. A study of energy consumption in battery/super capacitor hybrid system based on optimized driving strategy. *2017 International Conference on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA)* held at Surabaya, Indonesia during October 12-14, 2017. pp. 52-55.

[7] Jian, C., Emadi, A. 2012. A New Battery/Ultra-Capacitor Hybrid Energy Storage System for Electric, Hybrid, and Plug-In Hybrid Electric Vehicles. *IEEE Transactions on Power Electronics* **27** : 122-132.

[8] Joshi, R.P., Deshmukh, A.P. 2006. Hybrid Electric Vehicles: The Next Generation Automobile Revolution. *2006 IEEE Conference on Electric and Hybrid Vehicles* held at Pune, India during December 18-20, 2006. pp. 1-7.

[9] Park, J., Murphey Y.L., Masrur M.A. 2016. Intelligent Energy Management and Optimization in a Hybridized All-Terrain Vehicle with Simple On-Off Control of the Internal Combustion Engine. *IEEE Transactions on Vehicular Technology* **65** : 4584-4596.

[10] Pancholi, G., Yadav, D.K., Chaturvedi, L. 2017. Energy Management Strategies for Hybrid Electric Vehicle Using PV, Ultracapacitor and Battery. *2017 IEEE Transportation Electrification Conference (ITEC-India)* held at Pune, India during November 13-15, 2017. pp.1-6.

[11] Zhang, R., Tao, J., Zhaou, H. 2018. Fuzzy Optimal Energy Management for Fuel Cell and Supercapacitor Systems Using Neural Network Based Driving Pattern Recognition. *IEEE Transactions on Fuzzy Systems* **27** : 45-57.

(This work is licensed under a Creative Commons Attribution 4.0 International License.)