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Efficiency improvement of a directly-driven electric scooter with energy management and battery sizing

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Abstract— **This study descriptions the effect of an actual driven pattern on the battery pack sizing and an ultra-capacitor bank to improvement the gross efficiency and driving range of an electric scooter, driven directly by a four-phase axial-flux brushless dc permanent magnet motor. The key improvement of an electric scooter is increasing electric range until the battery discharges to a least threshold. The main part of designing an electric scooter is maximum battery energy storage with an auxiliary ultra-capacitor. This study requires a MATLAB simulation code to estimate the power and energy demands of the electric scooter in variant electric range conditions.**

Choosing the right energy storage system to handle the daily driving needs is essential and vehicle manufacturers are expected to produce EVs with sufficient electric driving range for their customers.

Finally, in this particular work a regenerative braking system restores power to the ultra-capacitors and the ultra-capacitor bank supplies power for an additional acceleration and start-up when the battery required additional energy on short time and also mates prolonging battery life.

Keywords- battery; electric scooter; ultra-capacitor; efficiency improvment ;electric driving range.

I. INTRODUCTION

Rising oil prices because of oil lessening, global warming and the introduction of compulsory standard gas emissions in cities have had a marvelous effect on the maturity of new transportations technologies. By increasing vehicles, descent of energy supply, and environmental pollution, governments and manufactures concentrate on the research of new green energy vehicles. Figure 1 shows forecasting the world oil demand and supply between 1998 and the projection of 2026, which is given by International Energy Agency [1]. However the oil demand is increasing proportionately, the oil supply is decreasing from 2014.

In electric vehicles (EVs), renewable energy is a new option for enhancing vehicle efficiency and is economical with lower toxic gas emission. To achieve the same power and energy density as a combustion engine, fuel cells (FCs) with batteries and ultra-capacitors are combined to provide additional power rapidly during high demand and to overcome the FC start-time. Based on the longer start time and being more expensive, application of FCs with batteries and ultra-capacitors is not much economical. Using only ultra-capacitors with batteries can improve cost and driving range of electric scooter [2].

Nowadays, electric scooters are reasonable as a new vehicle with green energy product and have a good potential industry for many countries. Two-wheeler vehicle motors increasing over half of the vehicle fleet. Asia's 15-18 million scooters in 2006 are expanding at 18% per year. China's scooter expanding at 30% per year and the accounting of two-wheeler vehicle motors is about 77% of vehicle sales in India [3–5]. So the purposeful design of the electric scooter that will answer the needs of most consumers is especially important.

In Taiwan, usually displeasure of consumers is about long charging time (6-8 hours), short driving range, and heavy weights of scooter because of using lead-acid batteries [6].

Li-ion batteries is the better than nickel-based and valve-regulated lead-acid (VRLA) batteries, because of their unique characteristics such as light weight, high energy density, low discharge ratio, and high cell voltage [7]. Battery combined with ultra-capacitor offers flexibility to increasing electric driving range, efficiency, and energy harvesting. By using ultra-capacitor one could use the regenerative braking system to pump the kinetic energy to the ultra-capacitor and improve the electric range of driving.

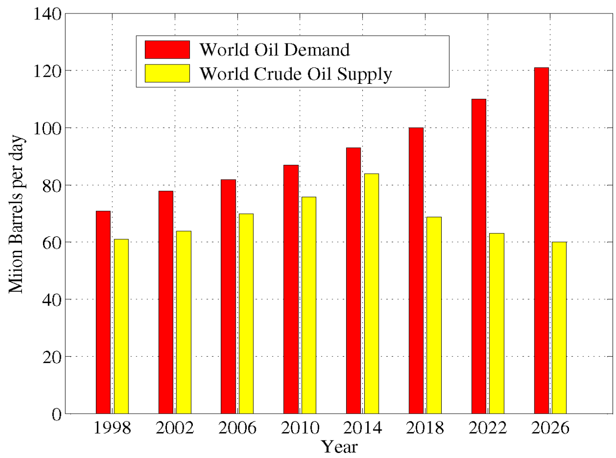

Figure 1. Oil price forecasting based on demand and supply.

II. SCOOTER MODELING AND SIMULATION

The scooter dynamics must be described using a mathematical model to expand an efficient power management strategy system for proposed electric scooter.

Electric scooter must have the ability to overcome the various forces including aerodynamic resistance F_{aero}, the force of gravity on a scooter F_{grad} and rolling resistance F_{roll}. The selected scooter must be able to fulfill consumer satisfaction in various driving conditions. Figure 2 shows a diagram of various forces applied to scooter [8]. The demanded force of scooter wheels F_{wheel}, is:

$$F_{wheel} = F_{aero} + F_{roll} + F_{grad} + ma \quad (1)$$

And the equations of forces can be written as:

$$F_{aero} = 0.5\,\rho\,C_d A_f V^2 \quad (2)$$

$$F_{roll} = C_{rr}\,m\,g\cos\alpha \quad (3)$$

$$F_{grad} = m\,g\,\sin\alpha \quad (4)$$

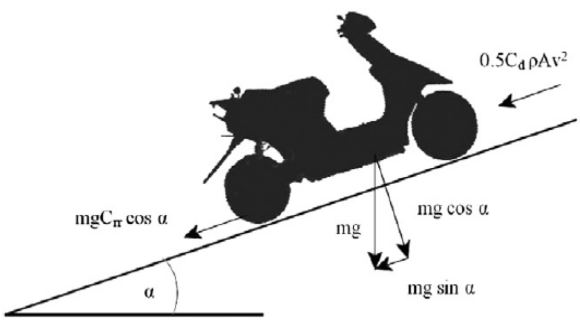

Figure 2. Review of forces in two-wheeler.

where ρ is density of air, C_d is the aerodynamic drag resistance, V is vehicle speed, C_{rr} is the coefficient of rolling resistance, m is total mass of vehicle, rider, passenger, and load, g is the gravitational acceleration, and α is the angle of road slope and parameters for a typical scooter are listed in Table 1.

So the mechanical power of wheels, demanded at wheels can be written as:

$$P_{wheels} = V(F_{aero} + F_{roll} + F_{grad}) + maV. \quad (5)$$

Finally, the required power of source is resulted:

$$P_{output} = \frac{P_{wheels}}{\eta_{drivetrain}} + P_{auxiliary} \quad (6)$$

where $P_{auxiliary}$ is auxiliary systems power such as head lights, signal lights, etc and is about 60 W; $\eta_{drivetrain}$ is efficiency of electric scooter and controller subsystem [9] and is about 80% in this paper.

TABLE I. TYPICAL PARAMETERS OF ELECTRIC SCOOTER [9]

A_f	ρ	C_d	C_{rr}
$0.6\,m^2$	$1.23\,\frac{kg}{m^3}$	0.9	0.014

The mass of electric scooter was 120 kg, which was 20 kg more than "FORTUNE 200e" electric scooter, and the driver weight was 75 kg. Also by using of high efficiency batteries (Li-ion), mass of scooter can be lighter than 80 kg.

Figure 3 shows the instantaneous power requirements and aerodynamic power for an electric scooter at constant acceleration (0.4 m^2) at various speeds.

III. DESIGNED ELECTRIC SCOOTER SPECIFICATIONS

In Malaysia, it is estimated that half of the vehicle are used to travel 20 km below per day and half of them may travel more than 30 km per day [10]. At present, two-wheelers market represents 77% of vehicle sales in India and has the second highest density of two-wheelers in the world. Also it is estimated that the Indian two-wheeler population will go beyond that of China sometime between 2010 and 2020, and will have the largest two-wheeler fleet in the world [8].

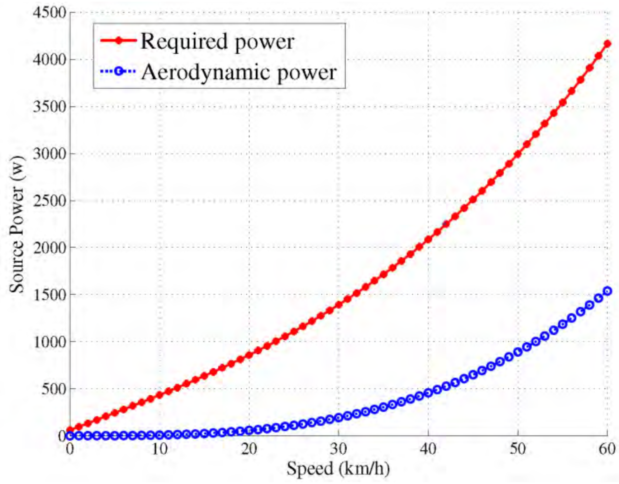

Figure 3. Required and aerodynamic power for variuos speeds.

The average travelled kilometers per day by two-wheeler commuters in Coimbatore city is about 25km and closely 61% of riders drive less than 25km per day. About 32% of riders travel between 25 and 50km per day and only 7% of them travel more than 50km per day [11].

In this paper, designed scooter must be able to meet the needs of most users (50 km per day on single battery charge) and also provides a two-seat advantage in different situations.

A. Matlab simulation using driving cycle

One typical driving cycle must be identified to optimize the energy source of any electric scooter. In this study, the simulation process has been started ECE-47 driving cycle as shown in Figure 4.

In this simulation, the peak power is appraised by feeding the velocity and acceleration values from the ECE-47 driving cycle. For the developed ideal model, the peak required power at ECE-47 is about 3 kW (one-seated) and 3750 kW (two-seated), as shown in Figure 5.

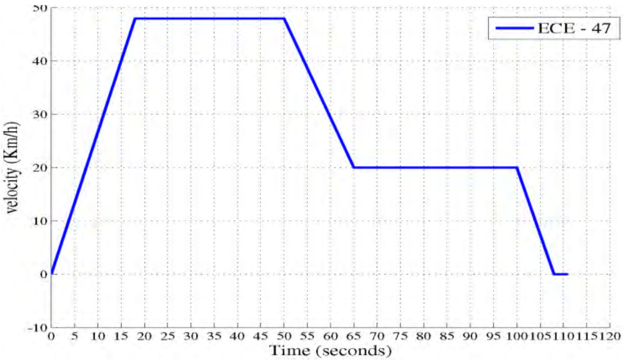

Figure 4. ECE - 47 driving cycle.

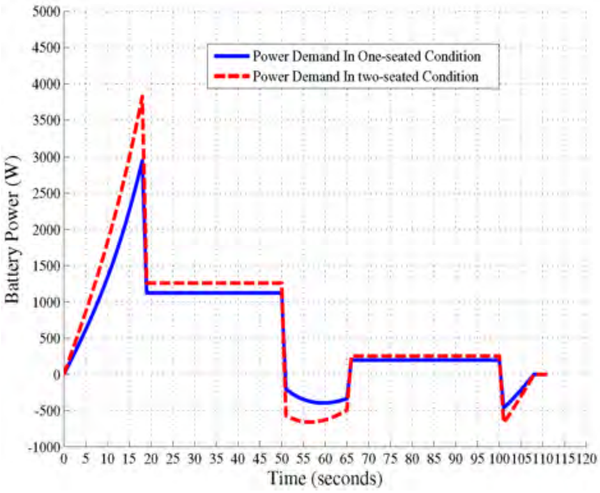

Figure 5. Load power of scooter uder ECE-47 driving cycle.

B. Electric Motor

A multi-objective optimal choice of an axial flux permanent magnet wheel motor is selected. This brushless dc motor has a motor efficiency and high torque-to-weight ratio and also is fitting for in wheel motor applications. The pulse-width modulation (PWM) drive controls this axial flux brushless dc wheel motor with optimum current waveforms.

The number of magnets in the rotor disk of motor is 18, which is sandwiched between two plates of the stator, in order to form an axial-flux motor. The magnetic flux flows through the air gaps between the rotor and the stator in the axial direction. Table II contains the technical data and parameters of the proposed motor [12].

The output torque ripple is 2.7% in four-phase motor, which is much smaller than three phase motor. Moreover, better driving performance for the four-phase motor can be expected. For optimal current excitations, the four-phase motor presents better efficiency (91% at maximum power) and becomes a promising solution for the electric motorcycle of required specifications such as improvement electric range.

TABLE II. ELECTRIC MOTOR TECHNICAL DATA

Geometric dimensions	*4-phase*
Max. power	3 kW
Rate speed	430 rpm
Max. current per phase	54.3 A
Rated voltage	15.2 V
Avg. torque	5.9 kg-m
Max. speed	1000 rpm
Torque peak	6.05 kg-m
Number of stator poles	24
Number of Magnets	18
Magnets	BdFeB30SH
Max. flux density	1.8 T
Outer diameter	89 mm
Inner diameter	56.5 mm
Motor weight	10 kg

IV. ENERGY SOURCES

The commercially traction batteries detailed specifications are listed in Table III. As shown, lithium-ion batteries have higher energy and power density than the lead–acid and Ni-MH batteries, sufficient acceleration and high calendar life, which makes the lithium-ion appropriate for rising the travelled range of an electric vehicle. Although, Ni-MH batteries at this time is employed in hybrid electric vehicle (HEV), Li-ion battery has twice the energy density of Ni-MH battery and if the thermal safety issue is successfully addressed, Li-ion batteries have the potential to replace the Ni-MH battery for HEV applications[13].

TABLE III. TECHNICAL DATA OF TRACTION BATTERIES

Type of Battery	*Lead-acid*	*Ni-MH*	*Li-ion*
Energy density (Wh/kg)	30-50	60-120	110-160
Cycle life	200-300	300-500	500-1000
Power density(W/kg)	200-400	150-400	700-950
Fast charge time	8-16 h	2-4 h	2-4 h
Self-discharge /month	5%	30%	10%
Cell voltage	2 V	1.25 V	3.6 V
Operating temperature	-20 to 60°C	-20 to 60°C	-20 to 60°C
Maintenance requirement	3-6 month	60-90 days	Not required

The variation travel range and mass of the batteries has an important function in electric range. Lead–acid batteries have lower energy density and are heavier compared with the other traction batteries. For 2400 kWh energy storage batteries, lead-acid batteries weight is about 60 kg , Ni-MH is 27 kg and Li-ion is 17.7 kg.

By increasing the weight of vehicle, the electricity consumption would also be increased linearly. For 50 km electric driving range, the Li-ion battery can last up to 5 km longer than the Ni-MH and 20 km than the lead-acid battery.

A. Li-ion Battery modelin and simulation

In this study, the model of the battery used in [14] has been simulated in order to show the performance of the Li-ion battery (Sony 18650-1.8 Ah at C/1). The model outputs the Li-ion battery voltage profile and discharging time based on the required power of electric motor. Figure 6, shows the open circuit voltage profile versus depth of discharge (DOD) that is generated by the simulation and Figure 7 shows Li-ion battery resistance as a function of DOD.

B. Determining of Li-ion battery cpacity

Required power of the electric scooter as a function of weight of scooter, rider weight (75 kg), passenger (75 kg), acceleration, road inclination, etc is modeled for ECE-47 cycle as shown in Figure 8.

In this simulation work, the Li-ion battery with a capacity of 32 Ah, 47 V was able to sustain for close to 5350 seconds (Figure 9.) before the battery is not able to provide further current, which that this point depth of discharge is about 72% and electric range is about 43 km in two-seater condition. Figure 10, shows output voltage of battery pack in various DODs and indicate cut off voltage about 30 V.

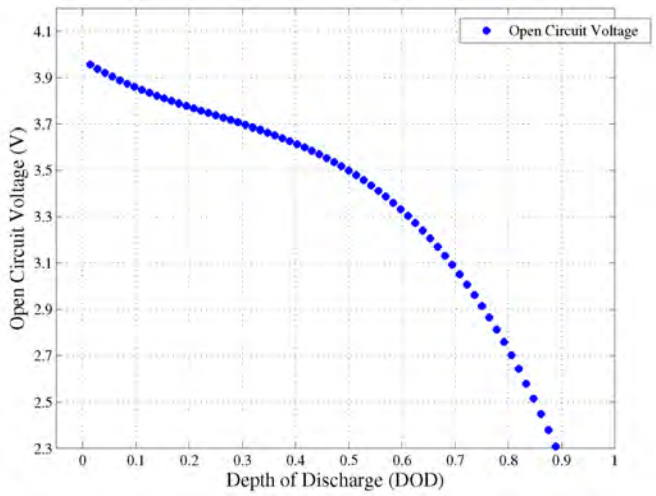

Figure 6. Simulated open circuit voltage profile vs. DOD for Sony 18650 Li-ion cell.

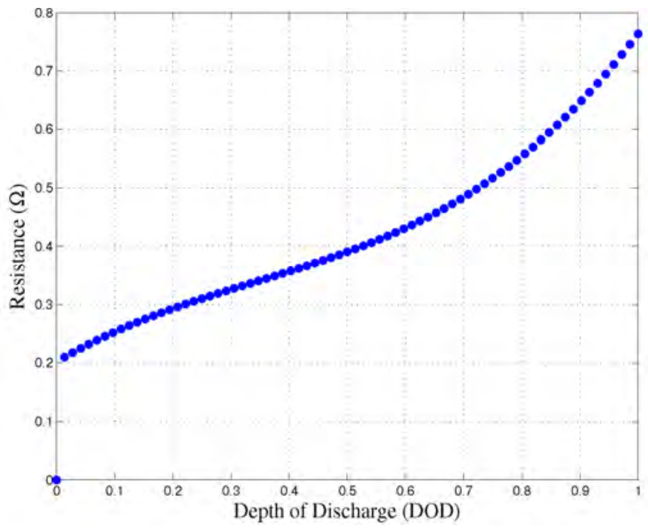

Figure 7. Discharge resistance vs. (DOD) for Sony 18650 Li-ion cell.

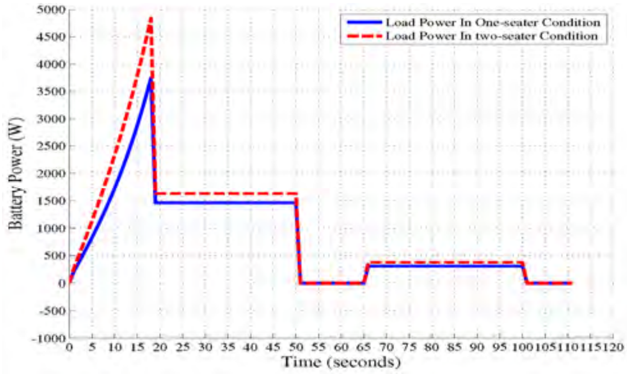

Figure 8. Battery power demand at ECE-47 cycle.

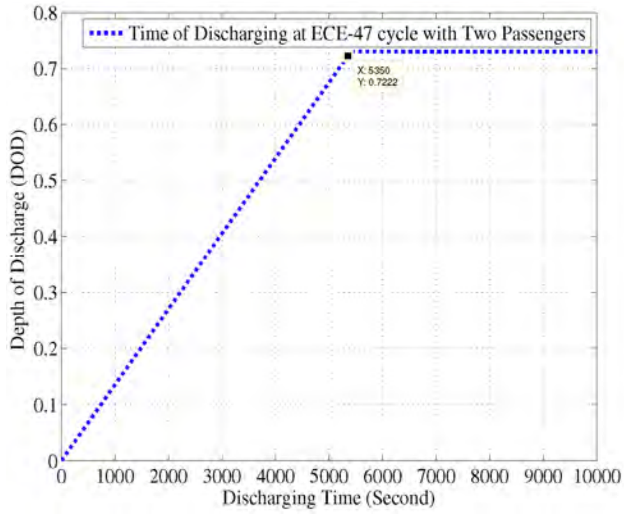

Figure 9. Discharging time of battery at ECE-47 cycle in two-seater condition.

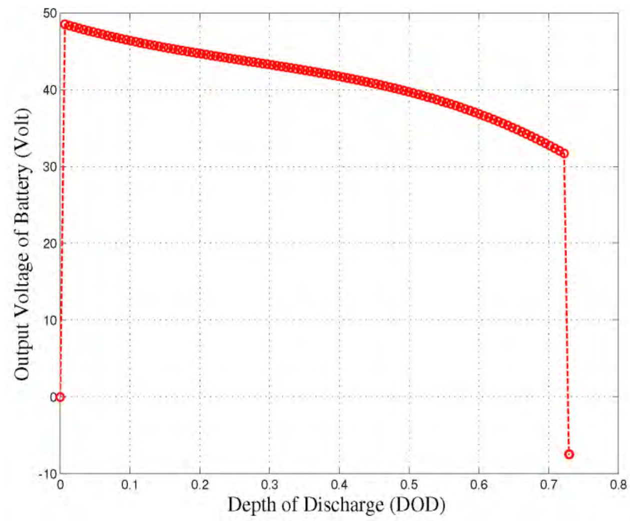

Figure 10. Output voltage of battery vs. DOD in two-seater condition.

C. Supercapacitor selecting

Ultra-capacitors are relatively new type of capacitors distinguished by phenomenon of electrochemical double-layer, diffusion and large effective area, which leads to extremely large capacitance per unit of geometrical area (in order of multiple times compared to conventional capacitors). They are taking place in the area in-between lead batteries and conventional capacitors (Figure 11) [15].

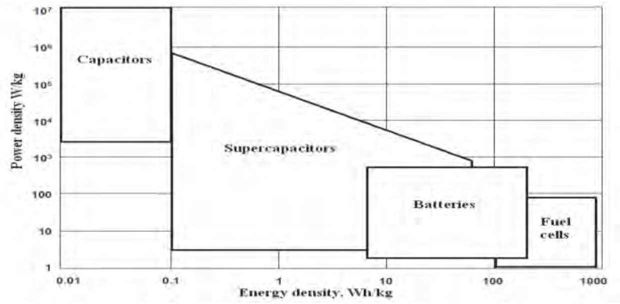

Figure 11. Area diagram for various energy storage systems.

The possibility of fast charge and discharge without lost of efficiency for thousands of cycles is the principal characteristic of an ultra-capacitor that makes it appropriate for using in energy storage systems (ESS).

Table IV contains detailed specifications of an ultra-capacitor unit [17].

TABLE IV. SPECIFICATIONS OF ULTRA-CAPACITOR UNIT.

Type	*HE1700P-0027A*
Rated voltage	2.7 V
Peak operation voltage	2.85 V
Rated current	360 A
Capacitance	1700 F
Specific power	6.85 kW/kg
Life cycle	500000 cycles

With the serial connection of the ultra-capacitor in 6 units, the powerful energy can be used to operate the scooter at the initial start and low-speed range; such units provide enough capacity to restore regenerative energy as well.

A full-wave rectifier applied direct current to ultra-capacitors in order to have regenerative braking (Figure 12). So as a replacement for the chemical reaction in a conventional battery, the ultra-capacitor charges and discharges electric power in a physical process, thus professionally absorbing and releasing impulsive and high power within an infinitesimal period of time [16].

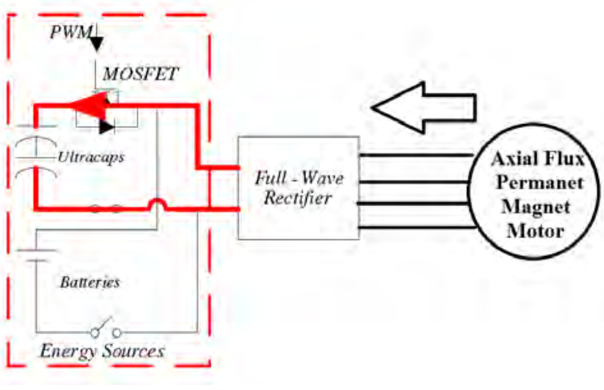

Figure 12. Shematic configuration of regenerative braking.

V. MODELING AND SIMULATION USING WITH ULTRACAPACITOR

Maximum energy storage of 16.2 V–283.3 F ultra-capacitor bank must be 37.179 kJ according to the manufacturer's detailed specifications. Each charge over an ECE47 cycle from regenerative energy fills the ultra-capacitor bank with about 6.36kJ (one-seated) and 10.628 kJ (two-seated), which is 17% and 34% of ultra-capacitor maximum energy storage. This energy is able to use for short time acceleration. Power requirements of the electric scooter are shown in Figure 13.

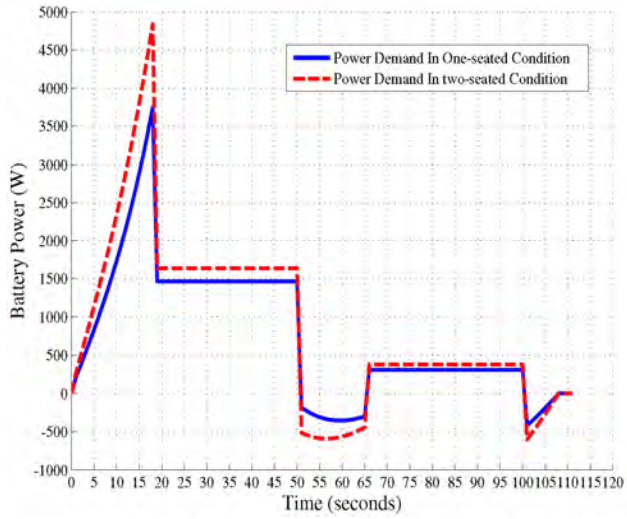

Figure 13. Power of battery with regenerative braking at ECE-47 cycle.

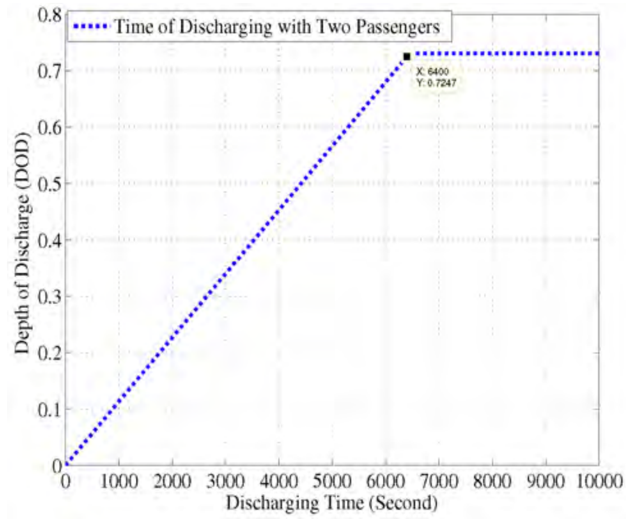

Figure 14. Discharging time at ECE-47 cycle in to-seated condition with ultracapacitor.

In this simulation, the Li-ion battery bank (32 Ah, 47 V) with an ultra-capacitor bank (27 V, 170 F) was able to prolong for 6400 seconds (Figure 14.) in two-seated condition and 8150 seconds in one-seated condition before the battery is not able to provide further current. So the electric driving range must be 66 km in one-seated condition and 51.7 km in two-seated condition. For better comparison, the overall driving range of the vehicle without regenerative charging was 58 km in one-seated and 43 km in two-seated conditions. On the other hand, ultra-capacitor with regenerative braking improved electric range electric scooter about 8 km to 8.7 km in various conditions.

VI. CONCLUSIONS

In recent years, integration of different energy sources, auxiliary energy storage elements, electric motors, and power electronic devices as the energy management strategies will operate the electric two-wheeler within the wide driving range and effective speed. As a secondary source of saving energy, the use of ultra-capacitors have become more and more attractive and viable for the next generation of electric scooters, which features quick recharge capability, high energy/power density, high efficiency, and long life cycle**.**

In this study, the proposed energy source system with a regenerative braking ability has been successfully simulated on an electric scooter.

From the results it is concluded that using the Li-ion battery reduced the charging time about 50% and the weight of scooter in compare with using lead-acid or Ni-MH batteries. At the same time it increases driving range on single battery charging up to 10%.

The results of simulations show that integration of regenerative braking with ultra-capacitor is able to provide excess acceleration, cruising, and capture regenerative energy of the scooter and finally improve the electric driving range (about 8.7 km per day). By increasing this amount of range, the proposed electric scooter will be able to satisfy 93% of consumers in two-seated conditions (heavy load).

The electric driving range and battery life in the proposed scooter with ultra-capacitor and regenerative braking system ability is 20% higher than traditional one. Generally speaking, integration of a conventional batteries, four-phase wheel motor, and ultra-capacitors is a promising goal for an electric scooter that is applicable to many models of electric vehicles.

REFERENCES

[1] Mierlo JV, Maggeto G, Lataire P. "Which energy source for road transport in the future? A comparison of battery, hybrid and fuel cell vehicles." Energy Convers Manage 2006;47(17):2748–60.

[2] M.A. Hannan, F.A. Azidin, A. Mohamed. "Multi-sources model and control algorithm of an energy management system for light electric vehicles." Energy Conversion and Management 2012; 62 : 123–130.

[3] Jonathan X. Weinert , Andrew F. Burke, Xuezhe Wei. "Lead-acid and lithium-ion batteries for the Chinese electric bike market and implications on future technology advancement." Journal of Power Sources 2007; 172: 938–945

[4] Colella WG. "Market prospects, design features, and performance of a fuel cell-powered scooter." Journal of Power Sources 2000;86: 255–260.

[5] Basavaraj S. Anami, Veerappa B. Pagi, Sangamesh M. Magi. "Wavelet-based acoustic analysis for determining health condition of motorized two-wheelers." Applied Acoustics 2011; 72: 464–469.

[6] Ying-Wei Wang. "Simulation of service capacity an electric scooter refueling system."Transportation Research Part D 2008; 13: 126–132.

[7] Antonio Affanni, Alberto Bellini, Giovanni Franceschini, Paolo Guglielmi, Carla Tassoni. "Battery Choice and Management for New-Generation Electric Vehicles" IEEE Trans. Industrial Electronics, Vol. 52, No. 5, pp: 1343–1349, OCTOBER 2005.

[8] Shaik Amjad, R. Rudramoorthy, S. Neelakrishnan, K.Sri Raja Varman, T.V. Arjunan. "Evaluation of energy requirements for all-electric range of plug-in hybrid electric two-wheeler." Journal of Energy 2011;36: 1623–1629.

[9] Bruce Lin. "Conceptual design and modeling of a fuel cell scooter for urban Asia." Journal of Power Sources 2000;86: 202–2013.

[10] Sopian K, Othman MY, Yatim B, Daud WRW. "Future directions in malaysian environment friendly renewable energy technologies R&D." ISESCO Sci Technol Vision, (Spec Ed Renew Energy) 2005;5(1):30–6.

[11] Shaik Amjada, R. Rudramoorthyb, S. Neelakrishnana, K. Sri Raja Varmana, T.V. Arjunan. "Impact of real world drive pattern and all-electric range on battery sizing and cost of plug-in hybrid electric two-wheeler" Journal of Power Sources 2011; 196: 3371–3377.

[12] Y.P. Yang, C.H. Cheung, S.W. Wu, J.P Wang. "Optimal design and control of axial-flux brushless dc wheel motor for electrical vehicles." Proceedings of the 10th Mediterranean Conference on Control and Automation - MED2002,Lisbon, Portugal, July 9-12, 2002.

[13] Siddique A. Khateeb, Mohammed M. Farid, J. Robert Selman, Said Al-Hallaj."Design and simulation of a lithium-ion battery with a phase change material thermal management system for electric scooter." Journal of Power Sources,2004;128: 292–307.

[14] Siddique A. Khateeb, Mohammed M. Farid, J. Robert Selman, Said Al-Hallaj."Mechanical-electromechanical modeling of Li-ion battery designed for an electric scooter." Journal of Power Sources,2006;158: 673-678.

[15] Seref Soylu. "Electric vehicles– the benefits and barriers." In Tech,2011, pp. 100–107.

[16] Yee-Peon Yang, Jeing-Jang Liu, Tsung-Hsien Hu."An energy management system for a direct-driven electric scoter." Journal of energy Conversion and Management,2011;52: 621–629.

[17] Byung M. Han, B. Bae. "Unified power quality conditioner with super-capacitor for energy storage." Euro. Trans. Electr. Power 2008; 18:327–343.