Energy Management System for Battery/Ultracapacitor Electric Vehicle with Particle Swarm Optimization

[1]Selim Koroglu, [1]Akif Demircali, [1]Selami Kesler, [2]Peter Sergeant, [3]Erkan Ozturk, [1]Mustafa Tumbek

[1]Dept. of Electrical and Electronics Eng., Pamukkale University, 20070, Kinikli, Denizli, Turkey

[2]Department of Electrical Energy, Systems and Automation, Ghent University, Gent, Belgium

[3]Department of Automotive Engineering, Pamukkale University, 20070, Kinikli, Denizli, Turkey

***Abstract*—Energy usage and environment pollution in the transportation are major problems of today's world. Although electric vehicles are promising solutions to these problems, their energy management methods are complicated and need to be improved for the extensive usage. In this work, a heuristic optimization approach, Particle Swarm Optimization is used to provide an optimal energy management system for a battery/ultracapacitor powered electric vehicle without prior knowledge of the drive cycle. The proposed scheme has been simulated in Matlab and applied on the ECE driving cycle. Results show the effectiveness of the applied method for the energy management problem of the multi-source electric vehicles with the lowest possible energy usage.**

***Index Terms*— Battery, electric vehicle, energy management, particle swarm optimization, ultracapacitor.**

1. INTRODUCTION

In recent years, depletion of petroleum resources, global warming and climate change has caused an increased interest about effective usage of available energy resources. Electric vehicles (EVs) are promising solutions about transportation to those problems because of high efficiency of electric motors and almost zero emission of drivetrains. Improvements on power converters and control techniques lead to increase of usability and drivability of them. However, there are some drawbacks and unresolved problem that are research subjects of many researchers. Energy management of energy sources is one of these problems because of only one type of energy source could not provide the needs of the entire drive profile. It is a common solution to use multi energy storage devices to overcome the disadvantage of each source and taking benefit of every source in an optimal way.

Batteries, fuel cells, ultracapacitors (UC) and flywheels are the most researched storage solutions for the electric vehicle energy source [1]. Energy storage systems in electric vehicles need to have high specific energy, high specific power, long cycle life and safe operation in all road conditions [2]. Fuel cells and flywheels are not sufficient yet to supply all needs of vehicles due to limited storage capability, safety and operational constraints [1]. Batteries provide a high specific energy but their specific powers are not enough to meet the vehicle instant power need most of the time. Therefore, integration of UC with batteries is an accepted solution because of the ability of UC to provide or absorb high powers [1]-[3]. Integration and management of these two sources are studied by using several methods in literature. Fuzzy logic [2], simulated annealing [4], particle swarm optimization (PSO) [1], model predictive control [5] methods are some of them. Despite the difference between them, it is generally not possible to compare the effectiveness or usefulness of these methods because nearly all of the methods are applied to different drivetrains and topologies.

In this work, a particle swarm optimization based energy management strategy is applied to the Alatay-EV whose general connection topology is shown in Fig. 1.

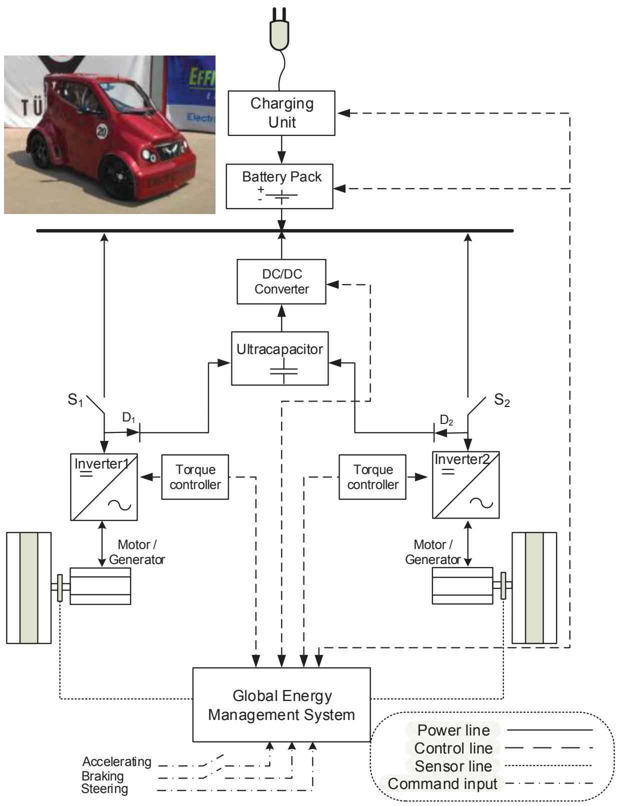


Fig. 1. General connection topology of Alatay-EV

Optimization of the energy management strategy (EMS) is achieved in two stages. The first stage is to restrict the search space of the optimization method according to conditions of storage devices and power demand of the vehicle. After determination and restriction of the search space, the power sharing optimization is implemented by using the PSO introduced by Kennedy and Eberthart [6].

This paper is structured as follows. The first section states the needs for this work and gives an introduction to the subject. The second section presents the structure of the EMS and gives detailed information about the optimization method. Section 3 represents the results of simulations studies, and discussion of the obtained results. Finally, conclusions are given in Section 4.

2. Energy Management Strategy

In this work, power losses are neglected to provide simplicity. Only power sharing is considered as illustrated in Fig. 2 [3]. Here, the battery provides the continuous power while the UC provides peak powers. For accepting high regenerative powers and sometimes to provide high power to accelerate the vehicle, there is a power exchange between battery and UC. This exchange results in a more efficient use of energy storage devices and by consequence longer the driving range. The energy exchange is implemented according to some rules. These rules are formed by considering the minimum and maximum capacities of storage devices, demanded power and maximum obtainable power of battery. These rules and relevant actions are described in details in [4]. Forming the rules is implemented according to working constraints and operational needs of the vehicle and storage devices.

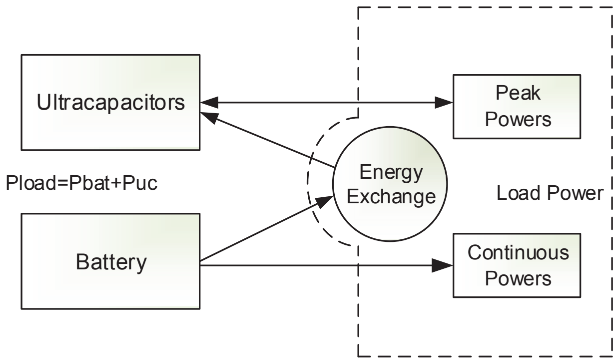


Fig. 2. General power sharing scheme [3]

In electric vehicles, demanded power and supplied powers from battery and UC must be in equilibrium in any case and in the whole time interval as described in (1).

$$P_{dem}(t) = P_{bat}(t) + P_{UC}(t) \quad \forall t \tag{1}$$

where the demanded power is calculated according to (2), and the constants and parameters used in this equation are given in Table I.

$$P_{dem} = m.a.V + \frac{1}{2}.C_d.\rho.V^3 + K_r.m.V + m.g.\sin(\theta).V \tag{2}$$

This power equilibrium is subject to certain restrictions in terms of minimum and maximum charging/discharging powers as (3).

$$\begin{aligned} P_{bat,\min} &\le P_{bat}(t) \le P_{bat,\max}, \quad \forall t \\ P_{UC,\min} &\le P_{UC}(t) \le P_{UC,\max}, \quad \forall t \end{aligned} \tag{3}$$

where minimum and maximum powers are as described in (4). Here, minimum power represents the maximum charging power, while the maximum power is the maximum discharging power from the storage units.

$$P_{i,\min} \le 0 \le P_{i,\max}, \quad i \in \{bat, UC\} \tag{4}$$

The objective function to be minimized can be expressed as in (5) as described in [3], [4].

$$J = \min \sum_{k=1}^{t=N} \{P_{dem}(t) - (w_{Bat}(t) * P_{bat,\max}(t) + w_{UC}(t) * P_{UC,\max}(t))\} \tag{5}$$

where N is the time interval of the chosen drive profile and w_{Bat} and w_{UC} is the weighting factors of battery and UC, respectively. Also the weighting factors have restrictions as in (6).

$$\begin{aligned} & w_{Bat}, w_{UC} \in [-1,1] \\ & P_{bat}(t) = w_{Bat}(t) * P_{bat,\max}(t) \\ & P_{UC}(t) = w_{UC}(t) * P_{UC,\max}(t) \end{aligned} \tag{6}$$

Here, the objective is to provide optimal sharing of power among battery and UC by determining the weighting factors of them. In this paper, for the determination and optimization of these factors, PSO is used. Details of the PSO method are given in the next subsection.

TABLE I

Assumptions and constants used in the simulation

Name	Value	Unit
Mass (*m*)	400	kg
G	9.81	m/s^2
Kr	0.012	
Θ	20	Degree
P	1.2	kg/m^3
cd	0.3	
Front Area (*A*)	1.64	m^2
Number of Battery Cell	32	
Battery Cell Nominal Voltage	3.2	V
Battery Cell Nominal Capacity	36	Ah
Battery Nominal Discharge Current	21.6	A
Number of UC Cell	30	
UC Cell Nominal Voltage	2.7	V
UC Cell Nominal Capacity	0.244	Ah

In the implementation phase some threshold values for battery and UC must be determined to avoid damage of the storage devices. For this purpose, the battery state of charge (SOC) level is restricted between 35% and 95%. In a same way, UC minimum and maximum SOC are limited between 80% and 90% to show effective operation of the algorithm. Also, the operating voltages of battery and UC cells are (2.8-3.7) and (0-2.85) respectively. Detailed specifications and some constants about vehicle, battery and UC are given in Table I.

A. Particle Swarm Optimization

PSO is a population based evolutionary computation technique, inspired from the social behavior of bird flocking and optimizes a function by utilizing a population of particles that fly through the solution hyperspace [6]. Particles are initialized randomly and seeking for optimal solution is carried out by updating its velocity and position at each iteration. Updating policy for each particle consist of best experience of its own and the entire population. Fig. 3 shows a flow chart of finding optimal weighting factors w_{Bat} and w_{UC}. The steps of the program flow are described below:

- Step 1: Parameters of PSO like swarm size, acceleration coefficients, inertia weight, maximum velocity and iteration are defined. Positions of each particle are randomly initialized within a predefined range.
- Step 2: Objective function fitness's are calculated for each particle.
- Step 3: From fitness evaluation, particle best position (*pbest*) and global best position (*gbest*) are obtained.
- Step 4: According to evaluated fitness's, velocities of particles will be calculated and positions will be updated. The velocity formula is given below:

$$\begin{aligned} v_i^d(t+1) &= wv_i^d(t) + c_1R_1(t)(pbest^d(t) \\ &\quad - p_i^d(t)) + c_2R_2(t)(gbest^d(t) - p_i^d(t)) \\ p_i^d(t+1) &= p_i^d(t) + v_i^d(t+1) \end{aligned} \tag{7}$$

where c_1 and c_2 are acceleration coefficients, w is weight factor, R_1 and R_2 are random variable, and p_i^d is position of particle.

- Step 5: If the fitness reached a specified value or maximum iteration exceeded, algorithm exits from the loop.
- Step 6: PSO algorithm is terminated and optimal parameters are obtained.

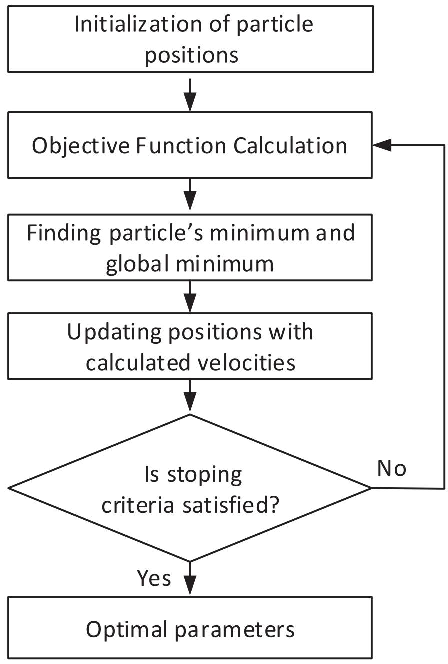


Fig. 3. Flow chart of PSO algorithm.

3. Results and Discussions

The proposed energy management strategy is applied on ECE driving cycle shown in Fig. 4 [7]. Drive cycle data gives information of the speed of the vehicle. The demanded power according to this drive profile is calculated according to (2).

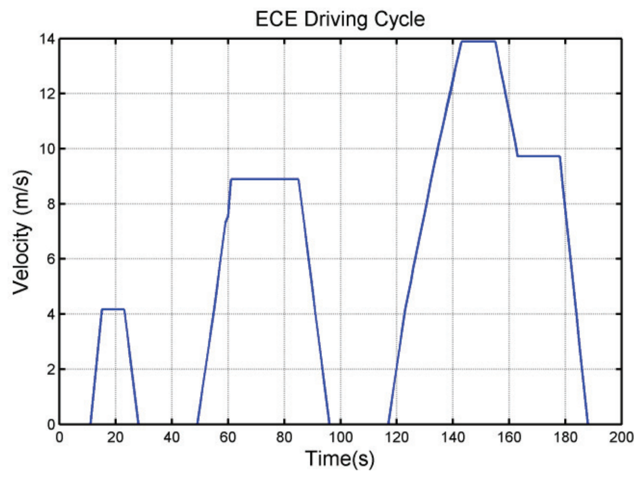
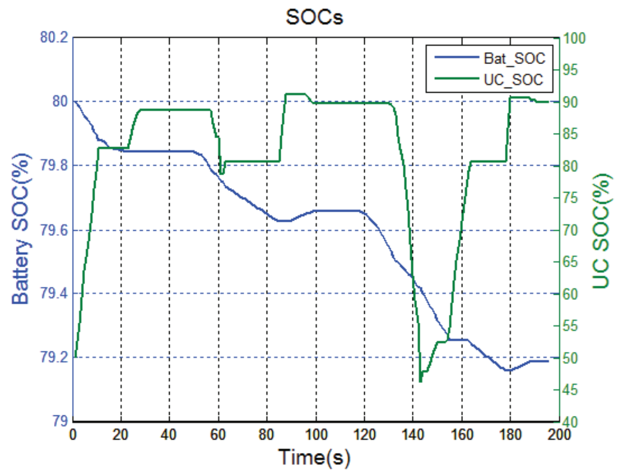
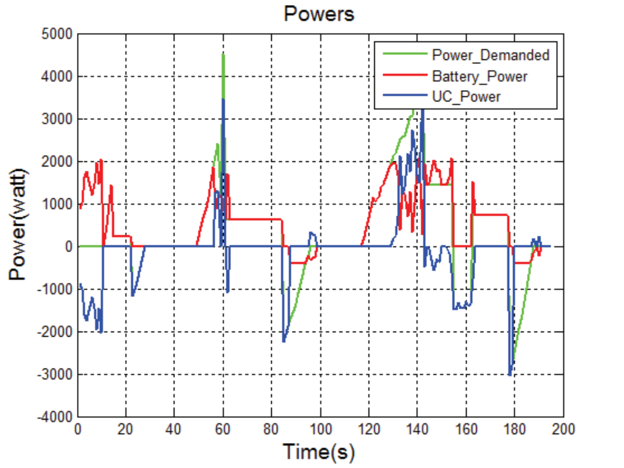


Fig. 4. ECE Driving cycle.

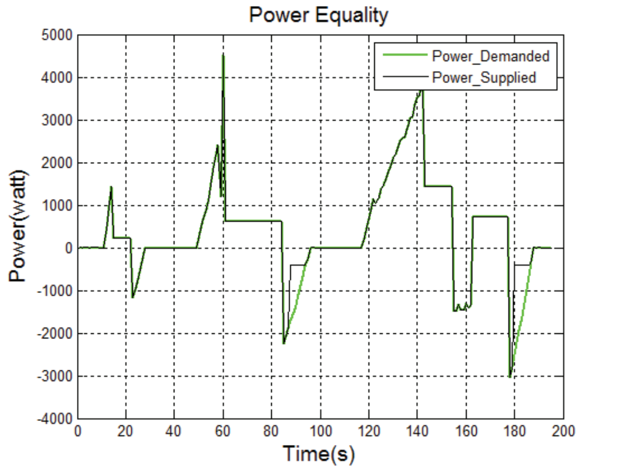
Some setup results of the management method is given in Fig. 5 and Fig. 6 to show the optimization process. In the first setup, battery and UC initial SOCs are determined as 80% and 50% respectively. From Fig. 5 a), energy exchange between battery and UC can be seen. For example, in the first 8 seconds power demand is zero and UC SOC is below the threshold value. So, battery charges the UC in this case. This increment provides to rise UC SOC for the later use to accelerate the vehicle. In Fig. 5 b), demanded power and supplied power from each source are illustrated. Power exchanges between sources can be seen clearly in this figure. As a result, power equality is given in Fig. 5 c). This figure shows good matching of demanded and supplied powers.



(a)



(b)

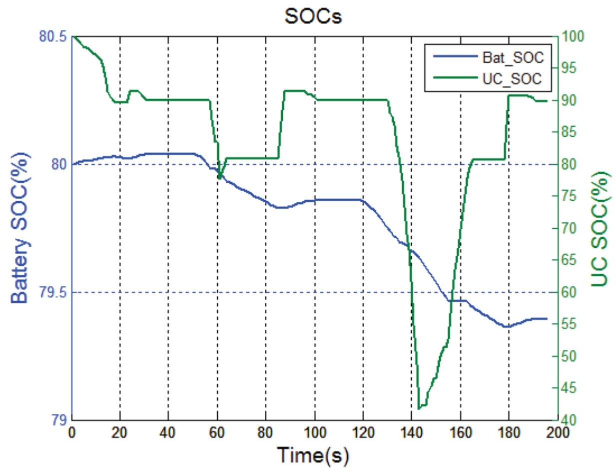


(c)

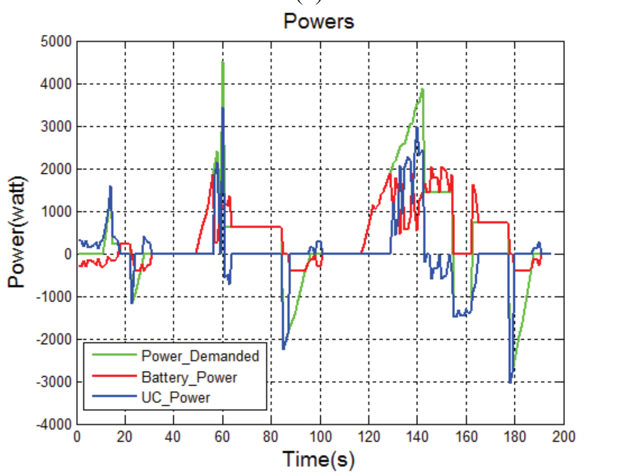
Fig. 5. Battery initial SOC: %80, UC initial SOC: %50, a) battery and UC SOC values, b) battery, UC and demanded powers, c) demanded and supplied powers.

In Alatay-EV vehicle batteries have much more power density. It results to demand power is met by battery power most of the time. Used batteries can supply approximately 2 kW (21.6 A continuous discharge current and 96 V nominal voltage). However maximum demanded power about 3 kW for the ECE driving cycle.

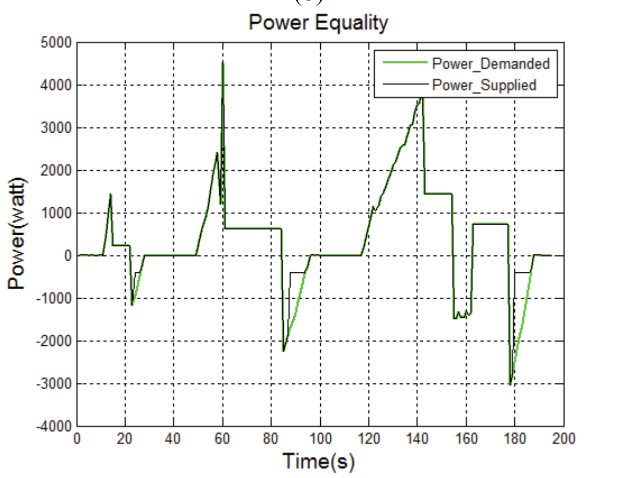
In the other simulation setup battery and UC initial SOCs are determined as 80% and 100% respectively, and the results are shown in Fig. 6.



(a)



(b)



(c)

Fig. 6. Battery initial SOC: %80, UC initial SOC: %100, a) battery and UC SOC values, b) battery, UC and demanded powers, c) demanded and supplied powers.

In this work, the power losses of gear box, motors and inverters are neglected to provide simplicity and avoid from the computational effort. Demanded power from the drive cycle is considered as demanded power from energy storage devices. Also the DC-DC converter between battery and UC must be included for realistic and correct results. Every energy exchange between these devices cannot be efficient in every time.

4. CONCLUSION

Electric vehicle technology is a growing issue with the concerns about future of the petroleum resources and climate change. One of the major components of these technology is the energy management of used storage devices in vehicle because of none of the current energy storage devices is enough the entire need of the vehicle. For this purpose, optimal power sharing and energy management of a battery/UC powered electric vehicle is studied in this work. Optimization of power sharing is achieved with an effective PSO technique. It is concluded that the PSO technique can be used effectively for the energy management problem of the multi-source electric vehicles with the less energy usage.

ACKNOWLEDGMENT

This work was supported by the Scientific and Technological Research Council of Turkey, the Fund of Scientific Research Flanders under Grant 114E023, and the special research fund of Ghent University.

REFERENCES

[1] J. P. Trovão, C. H. Antunes, "A comparative analysis of meta-heuristic methods for power management of a dual energy storage system for electric vehicles", *Energy Conversion and Management*, vol. 95, pp. 281–296, 2015.

[2] Y. Wang, W. Wang, Y. Zhao, L. Yang, W. Chen, "A fuzzy-logic power management strategy based on Markov random prediction for hybrid energy storage systems", *Energies*, vol. 9, no. 1, Article number:25 ,2016.

[3] L. C. Rosario, "Power and Energy Management of Multiple Energy Storage Systems in Electric Vehicles", PhD. dissertation, Cranfield University, United Kingdom, 2007.

[4] J. P. Trovão, P. G. Pereirinha, H. M. Jorge, C. H. Antunes, "A multi-level energy management system for multi-source electric vehicles - An integrated rule-based meta-heuristic approach", *Applied Energy*, vol. 105, pp. 304-318, 2013.

[5] R. T. Meyer, R. A. DeCarlo, S. Pekarek, " Hybrid model predictive power management of a battery-supercapacitor electric vehicle", *Asian Journal of Control*, vol. 18, no. 1, pp. 150–165, Jan. 2016.

[6] J. Kennedy, R. Eberhart, "Particle swarm optimization", *Proceedings IEEE International Conference on Neural Networks*, Perth, Australia, vol.4, Nov/Dec, 1995, pp. 1942-1948.

[7] W. Courtois, Dynamometer Drive Schedules [Online] Available: http://www.epa.gov/dynamometer.htm, Access date: 09.05.2016