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A Fuzzy Logic Control Based Novel Fast Charging Scheme for Electric Vehicle with Hybrid Energy Storage System

V.Umachitra, N.Chandrasekaran

Abstract—Recently electric vehicles are gaining more attention. The major factor to be noted in the development of electric vehicle is the battery technology. Concerned with the battery, a fast charging scheme should be used. In this paper a novel fast charging scheme for the electric vehicle is proposed. Hybrid energy storage system which is a combination of battery and Super capacitor is used, and also online fuzzy logic controller is used for real time evaluation. Hybrid electric vehicles have a major focus in recent years and they have been made leaps and bounds in development. The major benefit of using Hybrid energy Storage System is that the life span of the batteries are extended also the charging time of the battery is greatly reduced. The Fuzzy Logic Controller keeps the State Of Charge within limits which also enhances the life time of the battery.

Index Terms— Electric Vehicle (EV), Fuzzy Logic Controller (FLC), Hybrid Energy Storage System (HESS), State Of Charge (SOC).

I. INTRODUCTION

During the last few decades, environmental impact of the petroleum based transportation infrastructure. Vehicles making use of engines working on the principle of combustion can usually drive their energy from a single or a few sources, usually non-renewable fossil fuels. A key advantage of EV is regeneration and suspension; their capability to recover the energy lost during braking.

In the middle of 19th century the EVs came into existence first, when electricity was among the preferred methods for motor vehicle propulsion. The EVs provides a level of comfort and ease of operation when compared to the gasoline cars of the time. When the internal combustion engine is the dominant propulsion method for motor vehicles, the electric power has remained common place in other vehicle types such as trains and smaller vehicles.

There are two preeminent bottlenecks in the spread of EVs: First is the life time of the battery [6]. EV batteries differ from starting, lighting, and ignition (SLI) batteries because they are designed to give power over sustained periods of time. Deep cycle batteries are used rather than SLI batteries for these applications [9]. A deep cycle battery is a Lead-Acid battery designed to be regularly deeply discharged using most of its capacity. A deep cycle battery is designed to discharge between 50% and 80% of its capacity, depending on the manufacturer and the construction of the battery. The batteries must be designed with a high ampere-hour capacity.

Batteries for EV are characterized by their relatively high power-to-weight ratio; energy to weight ratio and energy density; smaller; lighter batteries reduce the weight of the vehicle and improves its performance. New materials are utilized to perpetuate the battery life and also the storage density to save weight and space. Besides the new materials, there are still some researches focusing on how to form HESS to enhance the battery operating condition [2], [8].

The second factor to be considered in the development of EV is the charging time [9]. Long charging time would influence the normal driving significantly. Some fast charging schemes and related devices are developed to abridge the charging time [12],[13]. Most of the researches need additional device to apprehend the fast charging scheme. The main short coming is that the supplementary devices increase the overall cost and weight of vehicles.

In this paper, a fast charging system which utilizes the HESS within the vehicles is proposed [1]-[4], [7],[20]. The system can realize the fast charging control of battery without additional devices [10]. Online FLC is used for real time evaluation. FLC is used to keep the battery SOC within suitable range and increases the life time of the battery [16]. The FLC eliminates non linearity, uncertainty and optimizes the power output.

II. HYBRID ENERGY STORAGE SYSTEM

Hybrid energy storage systems have been investigated with the objective of improving the storage of electrical energy [1] - [4], [20]. In these systems, two (or more) energy sources work together to create a superior device in comparison with a single source. Fig.1 shows the Ragone chart which depicts the characteristics of different storage elements.

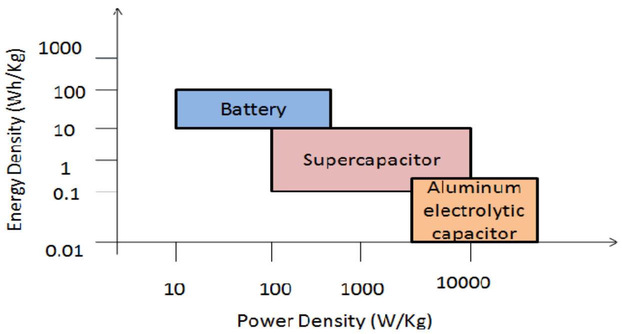

Fig. 1 Ragone chart

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Specifically batteries and Super capacitors have complementary characteristics that make them attractive for a hybrid energy system [13] - [14], [20]. When traditional batteries are paired with Super capacitors optimized for high voltage levels, Super capacitors are more attractive then batteries. Price of these components has fallen 99% in the past decade, while battery costs have fallen 30-40% in the same time period. In most applications, a primary energy source handles a continuous energy demands, engineers can size batteries to handle peak demands or use Super capacitors to compensate the demand [4],[15],[17].Using Super capacitors also allows downsizing of the primary energy source [5]. High power Super capacitors provide burst power required by high current demands associated with acceleration, starting, steering and regeneration. Pairing a Super capacitor with a battery improves the power density of the hybrid supply, which has the added advantage of allowing the battery to operate without seeing the large current spikes that would be present in the absence of Super capacitor. The Super capacitor acts as a load leveling device with a goal of improving battery life. Also it has high specific power, long life cycle and excellent low temperature behavior. By combining battery and Super capacitor, battery takes over the steady load.

Hybrid systems can significantly reduce the overall energy use and environmental impacts, increase the efficiency and reliability of energy production and reduce the cost providing for the end uses. Hybrid systems can create markets for renewable energy sources that might not otherwise exist.

III. REASONS FOR BATTERY-SUPER CAPACITOR HYBRIDIZATION

A. Power vs. Energy

The EV has variable power demand. At the time of acceleration and braking, peak power occurs. The ratio of peak power to average power can be over 10:1. For applications with high peak-to-average power, batteries and Super capacitors can be combined. This acts as a virtual source with high specific power.

B. Higher energy efficiency

Delivering high power for short period of time is tedious for batteries, but it is the Super capacitor strongest suit. The Super capacitor is able to deliver or receive energy in peak power situation and it can act as a load leveling device for the battery. This results the battery demand to become closer to the average power demand, thus reducing its RMS and peak currents.

C. Regenerative braking

The energy involved in the acceleration and deceleration transients is roughly two thirds of the total amount of energy over the entire mission in urban driving. Therefore, increasing the energy recovered by regenerative braking has a great potential to extend the range of an EV. Charge current in batteries are limited to a smaller value compared to discharge current. This characteristic limits the energy that can be recovered by regenerative braking. Super capacitors may have an important role in braking situation, because they can be charged very fast and their life is to a much higher degree in comparison with batteries.

D. Temperature range

Super capacitors can operate under a wider temperature range than batteries. Combining both attenuates the reduction in power available from batteries in extreme temperature conditions.

IV. FAST CHARGING SCHEME WITH REFLEX CHARGING

In today's daily life, the driving route is random. So fast charging technology is needed to meet the user's needs. The pulse charging method gradually replaces the traditional constant current charging to eliminate concentration polarization and increase the randomness of crystal formation. When pulse charging method is concerned, a proper ion and crystal diffusion time is provided between pulses. This eliminates the potential of polarization and improves the charging efficiency. The pulse interval is set not more than one-tenth of the second, or else the charging time will be prolonged and thus the fast charging process cannot be reached. The reduction of concentration polarization takes more than few seconds. So, a further correction is made on the basis of pulse charging.

Some of the fast charging schemes that are presently available incorporate negative pulse fast charging algorithms that claim to have great benefits to batteries. This result in reduced recharge time, low temperature rise, full recharge capabilities, as well as shorten equalization times.

A short term negative pulse is added to the diffusion interval to accelerate the ion diffusion and increase the randomness of the crystallization. This method is also known as Reflex charging (or) Burp charging [8]-[13]. Fig. 2 shows the reflex current wave form.

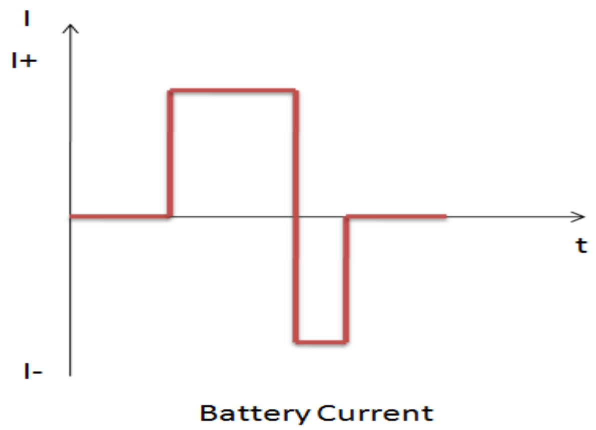

Fig. 2 Reflex wave form

Negative pulse charging scheme generally consist of one (or) more of the following charging sequences:

- A positive sequence
- A rest period (no charging)
- A discharge pulse (burp)

The sequencing, duration and the repletion rate of each of the above sequences can vary. This is shown in Fig. 3.

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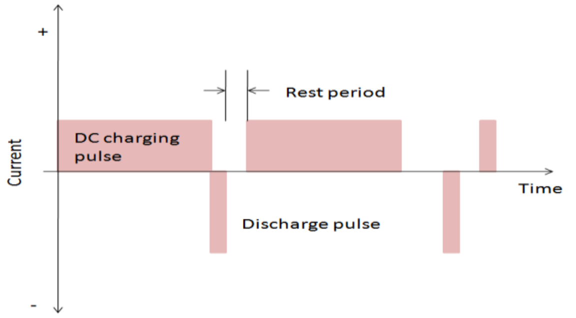

Fig. 3 Generic Negative Pulse Charging Scheme

One approach to establish the benefit of any negative pulse charging scheme is to run a controlled experiment where all parameters are controlled except for test parameters. If one wants to establish the true benefit of negative pulse charging on the battery, one need to do the following:

- Start with the batteries of the same age, model, capacity and voltage.
- Establish the same operating conditions for the batteries (same loading, temperature, watering)
- Charge the batteries through significant portion of their life cycles. The test should run through the battery life cycle to establish distinct performance.
- Establish test criteria, such as capacity tests every 50 or 100 cycles, to access any performance improvement with one charge cycle vs. other.

V. FUZZY LOGIC CONTROL STRATEGY

Intelligent control such as FLC has become more and more popular as the modern computer capabilities have considerably increased. Fuzzy logic was chosen because it can handle both non linear data and linguistic knowledge. Researches in this field have clearly shown that fuzzy logic could be successfully applied to the design of Hybrid Electric Vehicle (HEV) control strategies [16].It has been successfully applied in HEV areas of energy management strategy. Also FLC was applied in regenerative braking distribution types of HEVs. The main idea of these control strategies is based on load-leveling strategy, which attempts to operate the ICE in its efficiency peak point or its best fuel use at all times and uses the electric motor as a load leveling device according to the SOC of the energy storage system. The structure and parameters of all these fuzzy control strategies are designed based on the designer acquaintance of the problem. Because FLC is used for the entire range of operation, the strategies can be very complex with possibly hundreds influences. The system cost could also increase as a number of influences requires high performance controller with fast peripherals which makes acquisition, conditioning of output, fast and easy to handle. In this paper a simplified fuzzy logic scheme combined with rule based control strategy is proposed.

VI. MAIN CIRCUIT AND CONTROL CONFIGURATION

The study object of this paper is electrical vehicle with hybrid energy storage device. To prevent harmonic pollution, the fast charging equipment is connected to centralized storage in station to lessen the influence the main grid. DC/DC topology is adopted as fast charger for the billing convenience. Buck converter is used in this paper to simplify the control mode to meet the charging requirement of different types of vehicles. The control object of buck converter is the DC bus voltage. The reference value is sent through communication line from chip on-vehicle to charging station. The control mode of battery converter is changed according to the state of battery. Reflex charging scheme is adopted for fast charging. Super capacitor used has the main aim of maintaining the DC bus voltage. The voltage of the Super capacitor is controlled to meet the requirement of vehicle accelerate or brake. The block diagram is shown in Fig. 4. The power flow direction that is analyzed in control design is shown in Fig. 5.

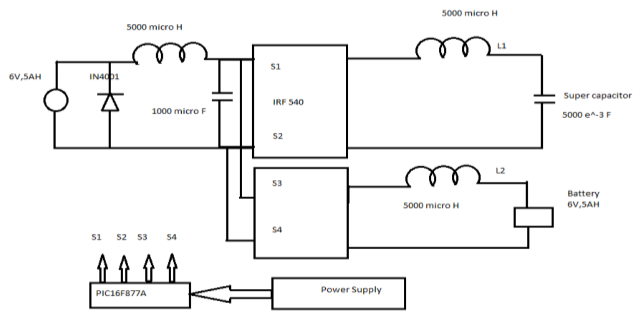

Fig. 4 Proposed Block Diagram

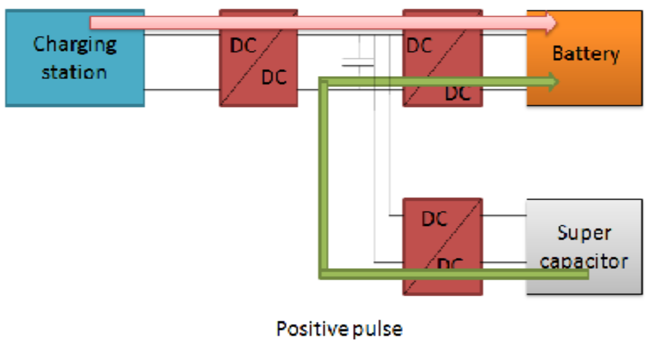

Fig. 5 (a) Reflex Charging Power Flow for Positive pulse

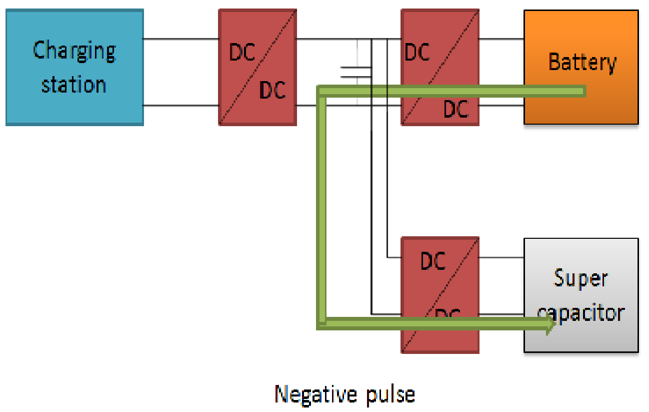

Fig. 5 (b) Reflex Charging Power Flow for Negative pulse

Fig. 5 Reflex Charging Power Flow

When positive current pulse is provided, station and Super capacitor are supplying power to battery. When negative current pulse is controlled, Supper Capacitor is controlled to maintain the DC bus voltage.

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Buck converter in station cannot receive the feedback energy because the unidirectional design. A logic comparison block is added to Super capacitor converter control. When input current from charging station is lower than a threshold value, Super capacitor converter is controlled to maintain DC bus voltage. When input current from charging station is higher than a threshold value, station charger can maintain DC voltage around reference value.

VII. SIMULATION RESULTS

A simulation model is established in MATLAB/SIMULINK to testify the validity. Fig. 6 shows the simulation model with battery, buck converter, super capacitor. The FLC control strategy is used.

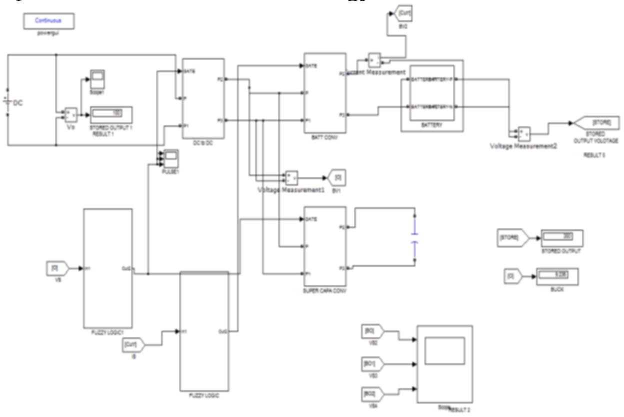

Fig .6 Simulation model

The simulations results are shown in Fig. 7. The input to the system DC voltage of 100V. The input to the system is shown in Fig. 7 (a). On simulating the input the 100V input is stepped down 9.236V by the buck converter. This is shown in Fig. 7(b). The battery converter output is obtained as 6.593. The battery converter output voltage is shown in Fig. 7(c).The Super capacitor output voltage is limited to 1.486V. This is shown in Fig. 7(d).

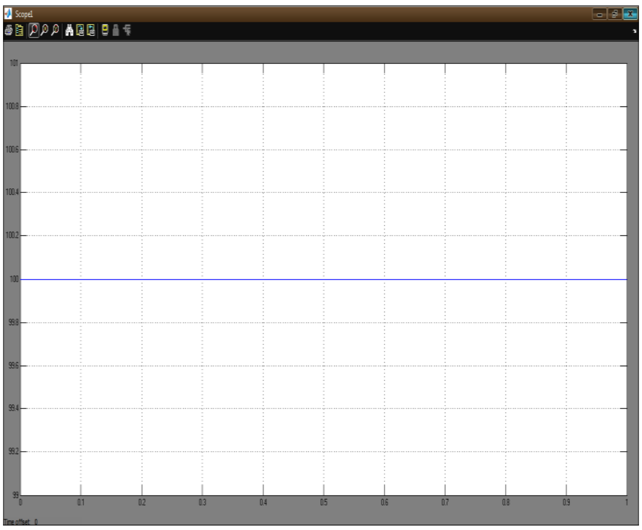

Fig. 7(a) DC input to the system

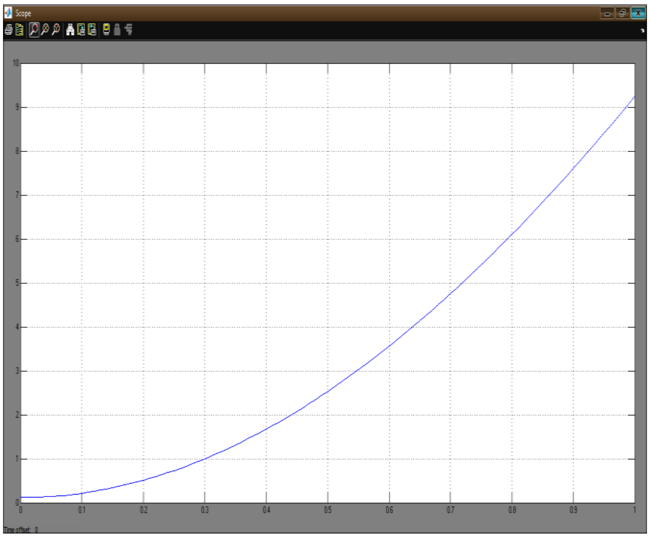

Fig. 7 (b) Output of the Buck converter

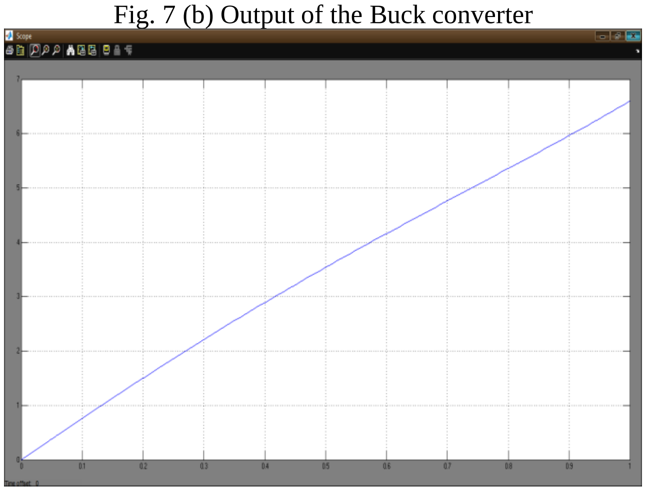

Fig. 7(c) Output of the Battery converter

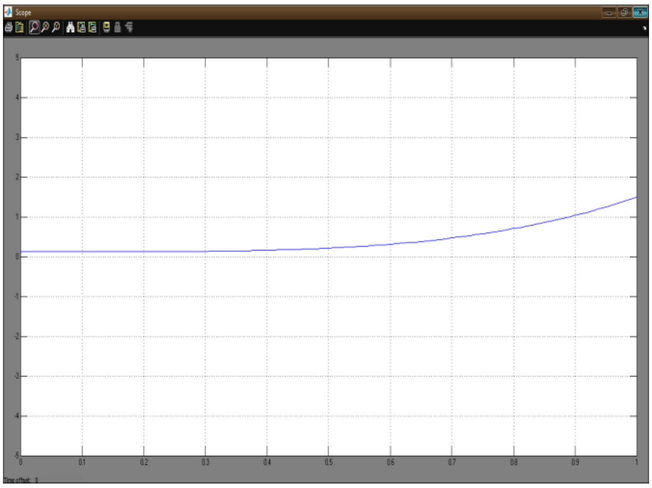

Fig. 7 (d) Super capacitor voltage

Fig. 7 Simulation Results

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VIII. CONCLUSION

A novel fast charging scheme for electrical vehicle is proposed in this paper to meet three goals: reflex charging of the battery, DC bus voltage stabilization, limiting Super capacitor voltage. It uses HESS which is a combination of battery and Super capacitor. It also uses online FLC for real time evaluation. The HESS can increase the life span of the batteries by improving their working condition and also shortens the charging time thereby increasing the efficiencies of the batteries. Hybrid energy storage also enhances the stability of the system. Online FLC is used to keep the battery SOC within suitable range and increase life time of the battery.

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