Distributed Battery System with Wireless Control and Power Transfer – A Concept Introduction*

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Abstract— **The paper introduces the concept of a battery system or pack architecture that is divided into several battery modules that share the load power wirelessly and are controlled wirelessly. Each of the wireless battery modules includes its own power electronics for DC-AC power conversion for Wireless Power Transfer (WPT), regulation of voltage and State-Of-Charge (SOC), and wireless communication link with an on-board unit. The on-board unit combines the power received wirelessly from all of the battery modules (AC-DC or AC-AC conversion) and its master controller uses the voltage, current, and other information received wirelessly from the battery modules to wirelessly send back control commands in order to regulate the discharge (or charge) rate of each battery module. For example, in the Electric Vehicles (EVs) application this wirelessly controlled and distributed battery system or pack can potentially allow for exchanging or swapping the wireless battery modules in a safer, easier, and faster manner. This can potentially contribute to significantly reduced "Range Anxiety" phenomenon that is associated with EVs.**

Index Terms — Battery Management System, Control, Wireless Power, Wireless Communication, State-Of-Charge, Battery, Electric Vehicle.

I. Introduction

Longer driving range is one of the most desired characteristics in an Electric Vehicle [1-9]. This is mainly in order to reduce what is referred to by "Range Anxiety" as a result of having to continuously worry about the need to recharge, the need to find or have access to a charging station, and the need to having to wait during EV charging time.

Faster EV charging systems and stations have been developed over the years [3]. However, charging stations are not available as much as fossil-fuel gas stations are and they cannot serve as many vehicles as gas stations can. Moreover, faster charging can impact battery health, safety and life.

Wireless power transfer charging of EVs is discussed in the literature as a more convenient alternative to wired or conductive charging [4, 6, 10]. However, the main difference from the user prospective between WPT charging and conductive charging is the elimination of the need to plug a wired connector in an EV instead of parking above or near a WPT charging coil and system. The EV driving range is mainly a function of the capacity of the battery (in addition to EV weight, system's efficiency, and charging speed) and not the charging type.

Battery swapping is an old concept that has been revisited over the years for EV application. However, the large size, heavy weight, and electrical and mechanical connections of a battery pack in addition to the needed facility and trained personnel are among the main reasons that resulted in not adopting yet this concept for current EV application. If these reasons are eliminated or can be dealt with, battery swapping might become one of the most promising solutions for "Range Anxiety" issue. This is the main objective of the concept which is introduced in this paper.

This paper introduces the concept of distributed battery system architecture with wireless control and power transfer. Next Section presents the basic and general wireless battery system architecture for EV application. Section III discusses the general controller concept and Section IV presents some preliminary results. The conclusion is given in Section V.

II. Wireless Battery System Architecture For EV Application Example

Consider the case when a conventional battery pack is divided into N battery modules as illustrated in Fig. 1. Moreover, consider the case, unlike in a conventional battery pack, when each of these modules is inside an enclosure with no wired/conductive connection to the outside. This is the first step which yields to what is referred to in this paper by the Wirelessly Enabled and Distributed Battery Energy Storage (WEDES) system with several independent battery modules (WEDES-MX modules).

Each WEDES-MX module includes battery cells in addition to dedicated electronics and wirelessly exchanges power, information, and control commands with an On-Board Unit (OBU) as illustrated in Fig. 2. The OBU combines the power from multiple WEDES-MX modules and deliver a regulated voltage/current/power to the rest of the system.

Fig. 1 and Fig. 2 show an illustrations of how a WEDES-MX module conceptual design might look like. It might be a box container with a handle for carrying/handling that communicates with the OBU through an inductive wireless power transfer (or any other type of wireless power transfer) and a low-power short-range communications. The OBU

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includes host slots, which accept the insertion of WEDES-MX modules. As a result, the WEDES-MX modules are easily removable and swappable. They can potentially be replaced with charged modules within approximately the same time it takes to fill up a tank of a fossil fuel gasoline vehicle and within much shorter time that it takes to charge a conventional battery pack integrated in an EV. The uncharged WEDES-MX modules can be charged outside the EV using a charging station with host slots (or can be charged when they are inserted in the EV overnight for example).

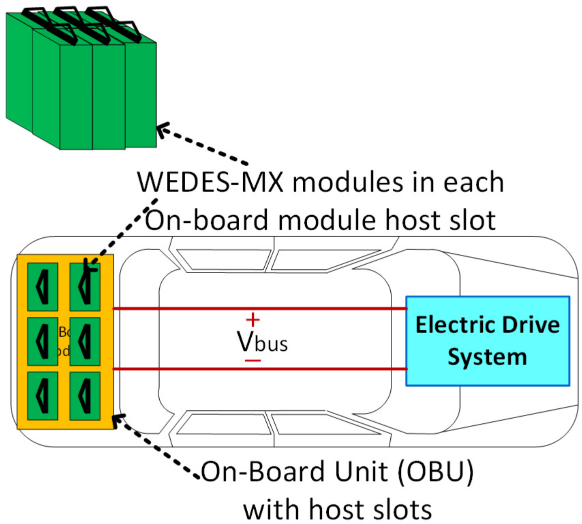


Fig. 1. Illustration diagram for the presented WEDES system concept for EV application: EV with example WEDES-MX modules and an OBU.

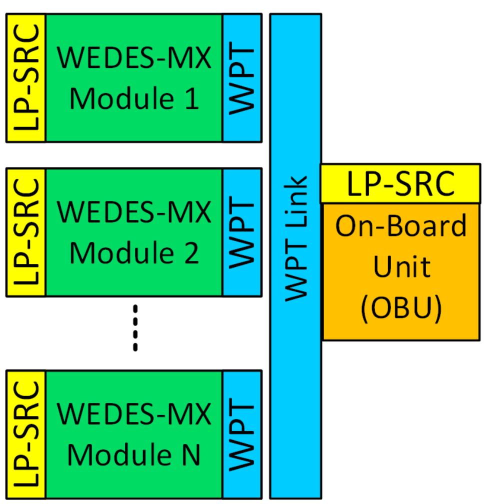


Fig. 2. Block diagram to illustrate the general WEDES system concept and architecture.

III. Controller

A general controller's block diagram for the WEDES system controller is illustrated in Fig. 3. A general flowchart for the WEDES controller is illustrated in Fig. 4. Each WEDES-MX controller sends its information, such as the current and voltage of its battery (I_r and V_r, where r = 1, 2, … N) wirelessly to the OBU controller. The OBU controller uses the information and sends each WEDES-MX controller a control commands to control how much power/energy each WEDES-MX module should supply or be discharged at ($P_{r\text{-ref}}$, where r = 1, 2, … N). This can realize State-Of-Charge (SOC) control [7] or balancing between the WEDES-MX modules while supplying power to the load that is connected to the OBU.

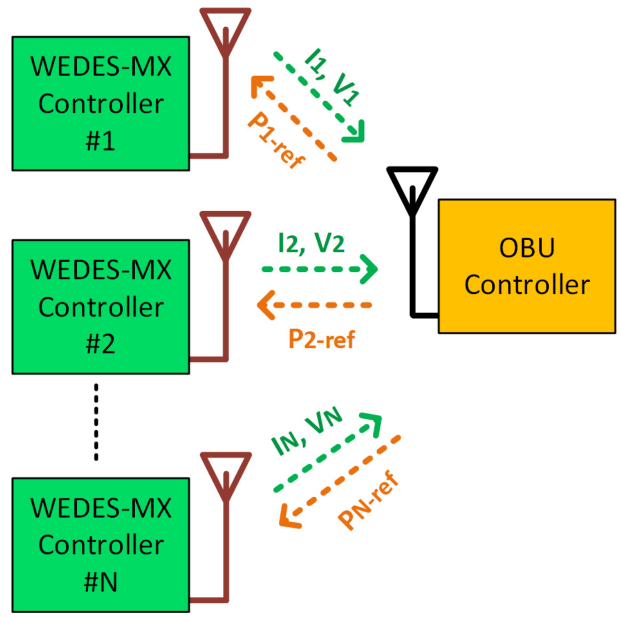


Fig. 3. Block diagram to illustrate the general concept of the WEDES wireless controller.

IV. Preliminary Results

A preliminary low-power experimental prototype with two WEDES-MX modules is built in the laboratory. Each module includes five 2.6 Ah 18650-size cylindrical lithium-ion battery cells that are connected in series, each with a nominal voltage of 3.7 V [11]. The load power is set at 40 W. Wi-Fi Local Area Network (LAN) communication link is created between the WEDES-MX modules and the OBU (with no internet connection) for wireless communications. Inductive WPT is used to exchange power between each WEDES-MX module and the OBU.

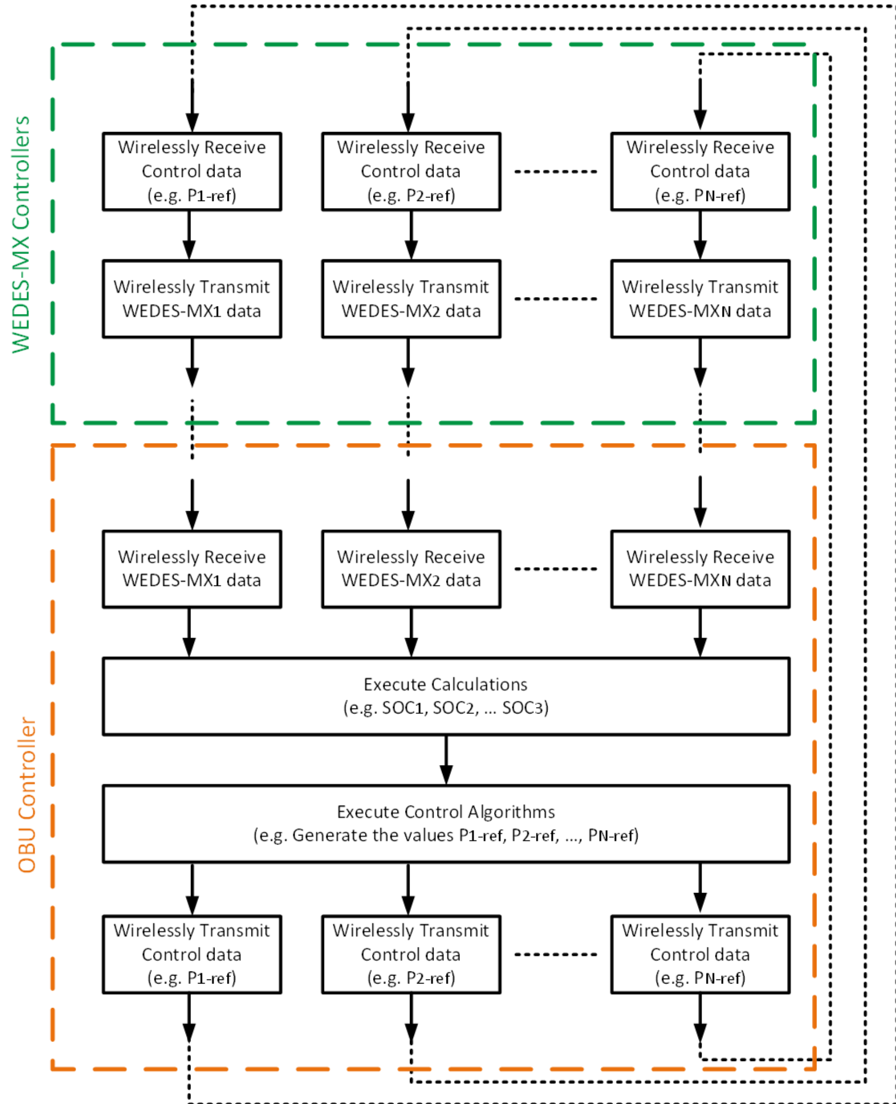
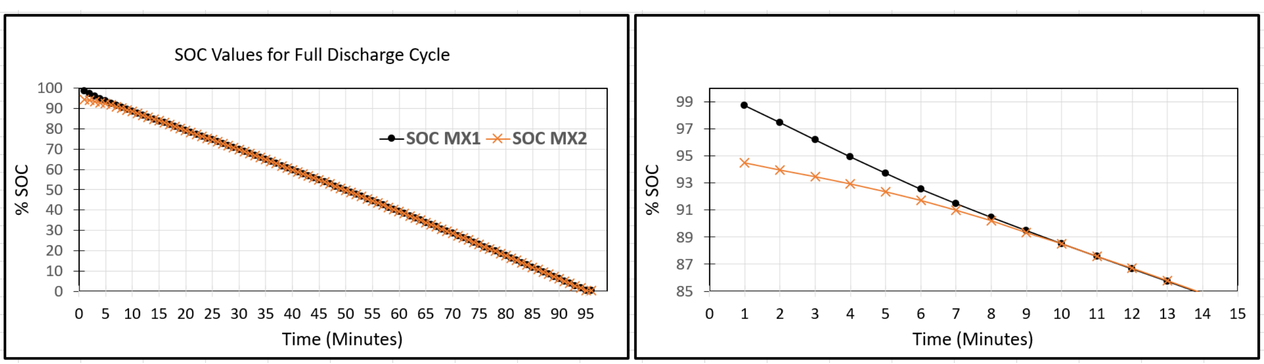


Fig. 4. A general WEDES wireless controller flowchart.



(a) (b)

Fig. 5. Preliminary proof-of-concept experimental results of SOC balancing for two WEDES-MX modules: (a) Zoom-out view and (b) Zoom-in view.

Fig. 5 shows sample proof-of-concept experimental results for SOC balancing control for two WEDES-MX modules. The operation started with about 4% SOC mismatch between the two WEDES-MX modules before the two SOC values of the two WEDES-MX modules become equal/balanced after several minutes. The load power continue to be shared by the two WEDES-MX modules during the operation of the system.

V. CONCLUSION

Wireless power transfer charging of EVs is discussed in the literature as a more convenient alternative to wired or conductive charging. However, the main difference from the user prospective between WPT charging and conductive charging is the elimination for the need to plug a wired connector in an EV instead of parking above or near a WPT charging coil and system. The EV driving range is mainly a function of the capacity of the battery (in addition to EV weight, system's efficiency, and charging speed) and not the charging type being conductive or wireless.

This paper presents a general concept that utilizes and controls wireless power transfer in a different system architecture and control. In this concept, several battery modules wirelessly transfer their power and information to an on-board unit that wirelessly controls the power/energy/discharge rate of each module and combines the received power/energy from all battery modules. This results in a wirelessly distributed battery system or pack. Each wireless battery module does not have electrical connections with the on-bard module because it sends and receives its power and information wirelessly. The on-board unit controller can perform SOC balancing control and can determine the number of modules to use.

In the EV application, this wirelessly controlled and distributed battery system or pack can potentially allow for exchanging or swapping the wireless battery modules in a safer, easier, and faster manner. This can potentially contribute to significantly reduced "Range Anxiety" associated with EVs.

Future work includes but is not limited to developing new control methods and algorithm for the presented systems and the development of a complete proof-of-concept prototype with multiple modules.

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