

Hybrid Energy Management Systems based on Edge Processing for Electric Transportation Applications

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Abstract—In this paper, a hybrid energy management system (HEMS) based on an edge processing scheme is presented. This HEMS is considered for deployment in the electric transportation industry which is a major sector for energy management applications. This approach paves the way for the emerging convergence of energy management systems (EMS) and intelligent applications. In this proposed scheme, the HEMS is integrated with edge processing to realize its intelligent and sustainable deployment. The HEMS is tested on a designed simulation platform and is re-deployed on an edge device for model verification. The implemented HEMS utilizes a battery and ultra-capacitor pack as the source. The battery pack and the ultra-capacitor pack have a rated maximum voltage of 50.4 V each.

Index Terms—Battery, edge device, edge processing, hybrid energy management system, ultra-capacitor.

I. INTRODUCTION

Since the industrial revolution and up to the present day, the world is still heavily relying on energy produced by fossil fuels which have major implications to global climate change, air pollution that is pivotal to health issues which tally of at least 5 million premature deaths each year and natural energy resources depletion. The energy market is gearing towards renewable energy sources and storage. The energy production of the modern energy sector contributes to at most 75% of the total carbon dioxide emission (CO₂) emissions worldwide which is a major factor in global climate change and health pollution [1], [2]. In order to provide a cleaner energy supply for the demand worldwide, the energy industry is gearing towards an alternative approach of greener and sustainable energy. Rapid development and deployment of renewable energy sources are scaling towards industrial applications. This trend aims to promote the sustainable and stable deployment of renewable energy resources-based applications [3]. As of 2018, a total of 179 countries have started an initiative to invest in the application of renewable energy in their countries. As of 2020, the renewable energy sector provides 15% to 20% of the total global energy demand [4]. Renewable energy systems are composed of energy harvesters and storage which vary in terms of application and deployment. One of the most promising sectors utilizing renewable energy and storage is the transportation sector whereas electric vehicles (EVs) are mostly utilized. From 2020 to 2021, the global EV sale ramped up to an outstanding sales growth of 98%. Based on statistics

presented in [5], a total of over 4-million EVs and 2.4 plug-in hybrid vehicles were sold in the first half of 2020 to 2021. By the year-end of 2021, the total EVs globally are at least 16 million whereas two-thirds are pure EVs.

Early electric vehicles are powered by a battery. The manufacturers use a nickel-metal hydride battery or lithium-ion-based battery [6] however, due to the high-power demand of EV parts, the driving range is limited and the capacity of the batteries depletes over time since it is known to have high energy but low power density. These characteristics are affected by the peak power variations that cause rapid battery life degradation. In terms of the transportation sector, this is in line with the speed variations in motor traction demands such as for speed and braking variations. To improve the battery-based applications, the researchers integrate an ultra-capacitor to enhance the EV car energy source. The combination of battery and capacitors is gaining research interest for actual deployment since it realizes sustainable systems for a plethora of applications such as for energy storage and source. On the other hand, capacitors have low energy density and high-power density. Going further, capacitors have rapid charging and discharging capability with a known high output power density and low-power-to-weight ratio. The combination of battery and capacitors can realize an efficient system capable of high energy density for the driving range and a high-power density for acceleration. The capacitor is capable of a strong charge based on energy regeneration which is also a pivotal factor. This demands a hybrid management system that can handle the dynamics difference between batteries and capacitors.

Hybrid energy management system (HEMS) applications and deployment are rapidly increasing owing to its benefits compared with other energy systems such as battery management systems (BMSs) and capacitor management systems (CMSs). By combining batteries and capacitors, the high power and energy density enhances the overall performance of the deployed system and also maximize the life of the battery and UCs. Though conventional HEMS is in demand nowadays, the deployment of HEMS requires innovation in this intelligent systems era. The deployment of HEMS nowadays requires the state-of-the-art capability to realize intelligent applications.

In the introduction of the hybrid era for transportation applications such as EVs, the researchers are still developing

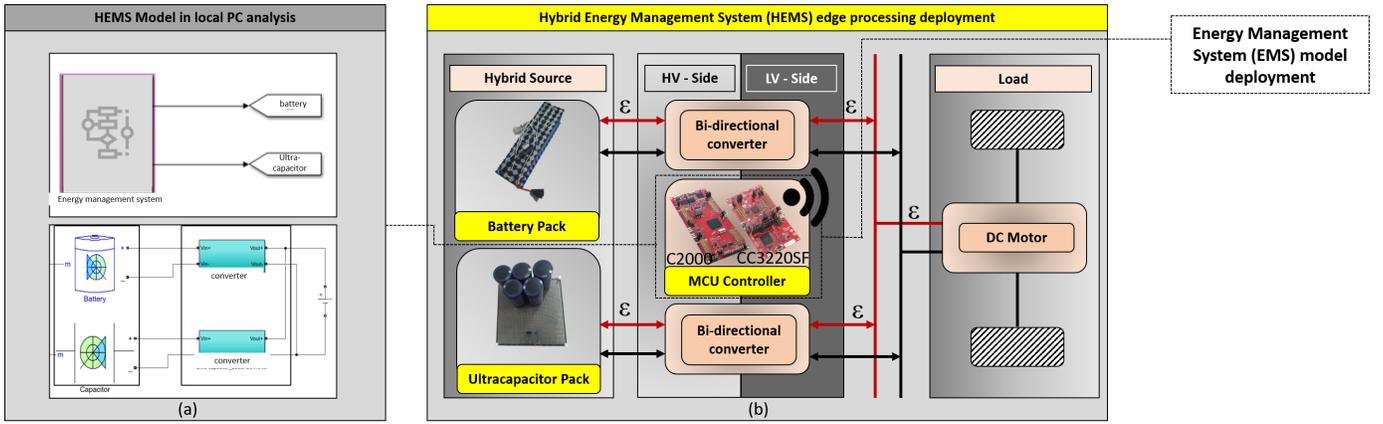


Fig. 1. Overview of the proposed HEMS based on edge processing for electric transportation application (a) HEMS modelling in local PC (b) edge based processing HEMS with the deployed HEMS model.

an optimal way to allocate the power that is coming from batteries and capacitors. This management system aims at monitoring, balancing, controlling, protecting, and enhancing the efficiency of these battery cells and capacitor cells on their deployment. This paper focuses on the analysis of HEMS for intelligent applications, particularly for electric transportation applications. We comprehensively analyze and implement a system for HEMS that enables internet-of-things-based computing paradigms such as edge processing. Edge processing is used to address the demand for intelligent applications of HEMS and the constraints of the current intelligent approach such as data processing efficiency. Edge-based application realizes the convergence of energy management and intelligent applications.

II. RELATED STUDIES

A. Energy management system

Energy management system (EMS) is a research hotspot in terms of sustainable application and deployment. EMS research aims to improve the overall safety, efficiency, reliability, stability, and deployment capability of both energy storage and sources. In summary, opportune EMS is being deployed to ensure that energy storage and sources adhere to the deployment parameter and standards [7]–[9].

B. Battery management system

One of the most commonly used EMS is for battery-based applications. This is in line with the ongoing demand for battery-based applications such as in the electric transportation industry such as EVs. Researchers focused on the improvement of BMS in terms of design and cost trade-off, fault adaptivity [10], and intelligent-based applications [11]. This is in line with the demand for intelligent energy management applications for the transportation industry such as the internet-of-vehicles (IoV) and edge processing.

C. Capacitor management system

Capacitors are often compared with the battery for their deployment characteristics. The energy management for

capacitor-based applications is known as the capacitor management system (CMS). Research and studies prove that capacitors such as ultra-capacitors and super-capacitors last longer than batteries. This is due to the fact that capacitors can handle the peak variation of a system demand such as voltage and current during the charging and discharging phase. This strengthens the physical toll tolerance of capacitors compared with batteries [12]. With the emerging demand for intelligent applications as mentioned in the BMS section, CMS and capacitor-based applications are also gearing toward intelligent applications [13].

D. Hybrid energy management system

Hybrid energy systems combine an energy source with another. This is to address the dynamics and peak variations which are the constraints of the deployed energy sources. For this case, a hybrid energy management system (HEMS) is deployed to ensure the effectiveness and co-deployment of the combined energy source. HEMS is the combination of the BMS and CMS. HEMS aims to maximize the interrelation between batteries and capacitors considering their distinct dynamic behavior [14], [15].

TABLE I
COMPARATIVE ADVANTAGE OF EXISTING HEMS APPROACH AND THE PROPOSED EDGE HEMS DEPLOYMENT

Reference	Criteria	Conventional HEMS	Proposed Model
[16]	Intelligent applications consideration	No	Yes
	Edge processing application consideration	No	Yes
[17]	Intelligent applications consideration	Yes	Yes
	Edge processing application consideration	No	Yes
[18]	Intelligent applications consideration	Yes	Yes
	Edge processing application consideration	No	Yes

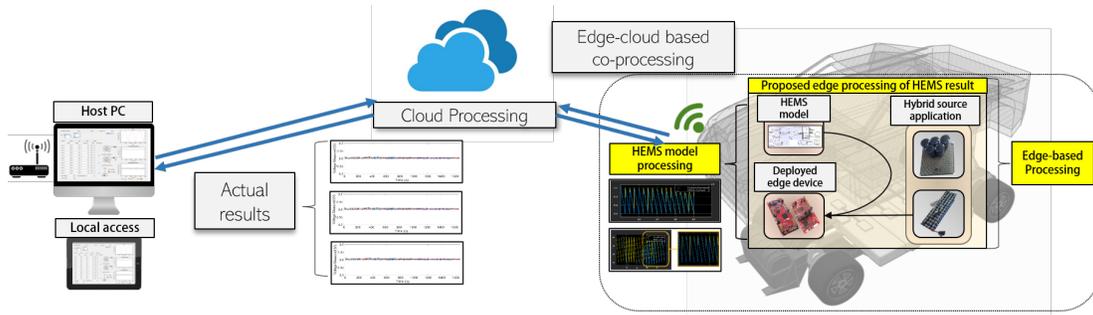


Fig. 2. The proposed HEMS actual result for edge processing.

E. HEMS convergence to the edge computing paradigm

The convergence of EMS and this intelligent era is pivotal and rapidly increasing nowadays. The emerging edge AI devices innovate the conventional deployment of EMS towards intelligent applications [19], [20]. In terms of HEMS convergence to intelligent applications, its core focus is to adapt with the overall demand and parameters of the system to ensure the maximum efficiency of both sources (battery, capacitors, etc.) when deployed using EMS models.

Table I summarizes the proposed HEMS deployment approach of this paper, which realizes its convergence to the edge-computing paradigm. Most papers and research focus on the development of EMS models and on optimizing existing HEMS. The proposed approach of this paper is the convergence of the HEMS model for edge-based processing. Edge-based processing considers intelligent applications such as the deployment of state-of-the-art HEMS models.

III. METHODOLOGY

This paper aims to presents a HEMS processing approach using edge processing to realize the convergence of EMS to intelligent applications as shown in Fig. 1. The sources used for this proposed HEMS are 1) batteries and 2) ultra-capacitors. With the edge-based processing, the load and peak requirement of the HEMS is learned and predicted by the system. This makes the HEMS adaptive to a multitude of deployment parameters and applications. Two specific conditions are managed by the HEMS through the learned parameters which are 1) utilize ultra-capacitors at peak power demand and 2) utilize batteries at stable power demand. The analysis of HEMS is performed at the edge device which for this application is the Texas Instrument TMS320F28035 C2000. The model utilizes an electric transportation platform for simulation particularly with the motor as the load. The battery pack and ultra-capacitor pack has a rated voltage of 50.4 V respectively for the HEMS implementation of this paper. The model is first deployed in a local PC for verification and analysis prior to the edge device deployment. The deployed model realizes soft and hard real-time applications whereas, in the actual deployment, a wireless communication module is integrated into the Texas Instrument TMS320F28035 C2000.

In the Fig. 1 shows the overview of the proposed HEMS based on edge processing for electric transportation applica-

tions. Fig. 1(a) shows the HEMS model which is simulated and designed in a local PC. Fig. 1(b) shows the HEMS deployed with the EMS model. The figure highlights which represents the energy of the two sources and the demand energy of the load which is a motor based on electric transportation. The C2000 is the central MCU or the edge device for this application where an EMS model is deployed. The CC3220SF is the proposed wireless communication module used to realize soft and hard real-time applications. The edge-based application depends on the model deployed whereas, for this application, the total current demand and power demand of the system are processed.

A. HEMS design considerations

The design consideration of the HEMS is the peak current demand of the system with respect to the load. The demand current of the system should equalize the total current of the HEMS. An energy management model is deployed to process the parameters of the HEMS such as the average load demand and learn this parameter. The HEMS adheres to the total load demand and equalizes the total demand and supply by managing both sources.

IV. RESULTS AND DISCUSSION

In the Fig. 2 shows the actual HEMS result for edge processing together with its processing capability. The HEMS model is deployed for electric transportation applications whereas this papers' methodology addresses the demand of HEMS application of this era, which is for intelligent transportation and smart vehicles. The deployed edge device with

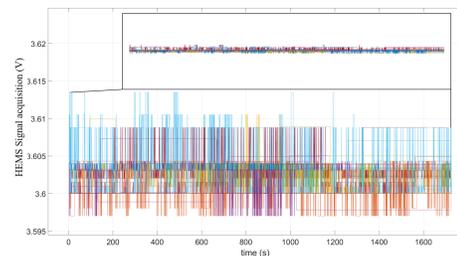


Fig. 3. The acquired HEMS parameters from local PC.

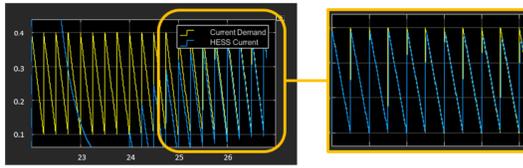


Fig. 4. The model deployment on local PC simulation.

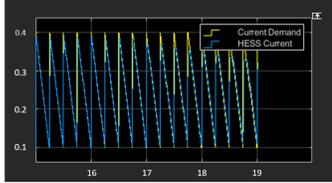


Fig. 5. The model deployment on edge device.

the HEMS model can independently process and control the HEMS. The integrated wireless communication allows the HEMS to communicate and transmit the actual result to the cloud or to local servers paving way for co-processing capability. In the Fig. 3 shows the actual monitoring result of the HEMS whereas these acquired HEMS parameter is accurate and is stable. The stability of the signal acquired proves that the deployed HEMS model on edge is effective.

In the Fig. 4 shows the actual initial results of the energy management model deployed on a local PC. It can be seen that the overall current demand and the hybrid energy storage system composed of two energy sources are equalizing. Though this is an initial result, this model proves to be promising in terms of deployment to the edge devices whereas when this model was uploaded to the C2000, the same results is yielded.

In the Fig. 5 shows the actual deployment of the HEMS model on the edge device. The current demand for the hybrid system is equalized with the current supplied by the batteries and ultra-capacitors. With this result, the peak variations in terms of the current demand of a hybrid system are analyzed. The peak variations represent the driving cycle of electric transportation. An energy management model for the hybrid of battery and ultra-capacitor is simulated and modeled in a local PC followed by the deployment on an edge device. This realizes HEMS edge processing. With the help of a wireless communication module integrated into the C2000, this HEMS model can realize soft and hard real-time applications, which is pivotal for its deployment in this intelligent system era.

V. CONCLUSION

The proposed hybrid energy management's (HEMS) main goal is to maximize the correlation of two sources ensuring that both perform at maximum efficiency. In terms of this application, two different sources were used and tested for edge-based processing namely, batteries and ultra-capacitors. The batteries provide the average current whilst the ultra-capacitors provide the transient current. The energy management system deployed equalized the HEMS current demand and the supply from batteries and ultra-capacitor.

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