Comparative Review of Hybrid Energy Storage Devices

Ashwanth S[1], D. Nandhini[2] and Yamuna S[3]
{ashwakousalya@gmail.com[1], nandhumalli92@gmail.com[2], dazlingyamu@gmail.com[3]}

Assistant Professor, Department of Electronics and Communication Engineering, Velalar College of Engineering and Technology, Erode, Tamil Nadu, India[1, 3]
PG Scholar, Applied Electronics, Velalar College of Engineering and Technology, Erode, Tamil Nadu, India[2]

Abstract. In recent years, the growth of the renewable energy and Electric vehicle demand have accelerated the progress of energy storage system in these fields. Energy Storage system (ESS) is an essential element for increase efficiency, reliability and environmental sustainability of power systems. The excess energy that is produced during low demand is captured and stored by Storage Systems and is released during high demand, balancing the supply and demand. ESS reduces the necessity for new power-plant construction by storing reserve energy (stored during excess – low load – periods, releases during high load periods), which saves infrastructure cost. Hybrid Energy Storage System (HESS) has developed and attracted growing attention in recent years as a new concept for sustainable energy storage, due to the combination of multiple energy storage devices to enhance their efficiency and performance. HESS has several merits such as high energy density, high power density, long life span, long cycle life, reliability and high-power discharge. HESS effectively controls energy loss through energy management strategy and stabilizes power supply. In this paper, we comprehensively review and analyze the hybrid model among various ESSs, and we only consider the hybrid model of battery and supercapacitor, and battery and SMES. Finally, the paper concludes by pointing out the future trends and research direction in the area of Hybrid energy storage systems.

Keywords: Hybrid Energy Storage Devices, SMES, Supercapacitor, Battery.

1 Introduction

The conventional energy storage systems such as Lithium-ion Battery (LIB), Supercapacitor (SC), Superconducting Magnetic Energy Storage (SMES) devices have their own advantages and also are bounded by their inherent energy density, power density, efficiency, reliability and response time. The Hybrid Energy Storage System overcome these disadvantages by combining two or more different energy storage technologies to enable a better performance. These combinations together provide for a well east galvanization of the myriad energy storage aspects and ideally, they are benefits on short-term power fluctuation as well long duration dispatchable energy storage is more imperative to the modern renewable energy system [1][2]. The HESS is possible energy provider due to the use of high-energy density device such as Battery, for prolonged operation and high-power density device Supercapacitor, for instantaneous discharge of energy.

ICITSM-Part I 2025, April 28-29, Tiruchengode, India

DOI 10.4108/eai.28-4-2025.2357948

High penetration level of renewable energy sources is the case, which creates serious challenges for the grid frequency regulation in providing stability and reliable operation of the power system [3]. Hence, the energy storage systems (ESSs) been proposed as attractive technology to stabilize with no gaps between power generation and load requirement [4]. Development in energy storage devices and improved performance due to recent technology development open significant implementation of these energy storages in electric vehicle (EV), Uninterrupted power supply (UPS), Power systems, Micro-grid and Large scale renewable energy source integration as shown in Fig 1.

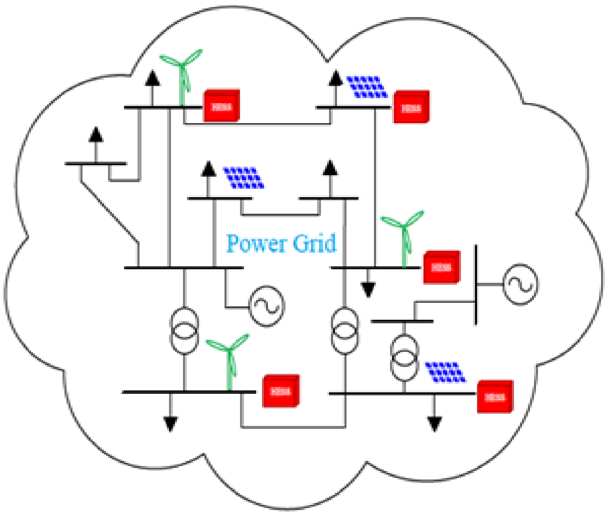

Fig. 1. HESS Integration in The Power System.

2 Literature Review

The growing penetration of renewable energy sources and transportation electrification have necessitated extensive research into hybrid energy storage systems (HESS) to mitigate issues concerning power quality, energy management, and system reliability. HESS generally combines two or more energy storage technologies, including batteries, supercapacitors, and superconducting magnetic energy storage (SMES), to take advantage of their complementary capabilities. This part covers new developments in HESS structures, control strategies, and uses with an emphasis on their applications to present power grids and electric transportation.

Power quality was previously considered to be improved by using the HESS in renewable power system in the early research. [1] studied the integration of SMES with the wind/PV system, and demonstrated that it achieves the control of voltage variation and enhances the stability of power output. "SMES has fast response and is an attractive option for short-term energy buffering in hybrid renewable systems," their study demonstrated. Similarly, a comprehensive review of energy storage systems and their essential role to smoothen intermittent renewable generation and ensure the stability of the electric grid was given in. The conclusions are consistent with the work in [7], which described the brief introduction of energy storage technologies and the future of energy storage technologies in electric power systems.

HESS based on lithium ion batteries and supercapacitors (LiPo-SCs) is particularly attractive for electric vehicles (EVs) due to the need of high energy density and fast power delivery. [5] proposed new energy management scheme for battery- supercapacitor hybrid topology, which emphasizes power allocation for the extension of EV longevity/unit of energy. Likewise, [6] studied the complementarity between a battery and a supercapacitor and were able to fulfill the peak power and kinetic energy regeneration condition of an electric vehicle on both sides. [8] elaborated another step further, with HESS concept for hybrid EVs and achieved better performance in dynamic load conditions. On the whole, these findings indicate that HESS can overcome the shortcomings by individual battery systems such as slow charging and degradation at high current [11], [12].

The combination of SMES with batteries has been a promising HESS configuration, especially for high-power applications. As an example, [9] designed an SMES/battery hybrid system for electric buses. The system, compared to conventional battery-only systems, showed better energy efficiency and power control. [10] conducted an optimal sizing study and control of an SMES-battery HESS and compared it at the energy and power balancing levels. Similarly, [13] considered the DC performance of an SMES system with IGBTs suited for high-power DC applications. In general, considering the above studies, it can be concluded that SMES is a possible solution to speed up the dynamic response HESS. Thus, it is most preferable when the system is exposed to a transitory situation. Additionally, research has also focused on control strategies. As an example, [14] suggested a coordinated control for HESS interfacing with a battery-supercapacitor system and improved power system performance in frequency regulation and state-of-charge management. [15] presented the recent developments in HESS control and pointed to adaptive algorithms and predictive modeling as the most crucial performance developers across various applications. In turn, [16] proposed an energy management controller for microgrids including HESS for improved grid resilience and performance. The above strategies are essential when trying to achieve the best operation throughout and for optimizing the lifespan of storage elements.

HESSS are used not only in EVs and grid systems but also stand-alone renewables layouts and microgrids. [17] studied a battery-supercapacitor HESS to keep the power supply stable under a varying solar energy. [20] recognized that microgrids incorporating renewable-integrated HESS could be potential sources of power supply for sub-Saharan African countries, which have limited spread of grid connections. [18] also reviewed advancement in HESS for the integration of renewable-to-grid, and emphasized their scalability and ability to work with different demand.

As a consequence of these achievements cost, thermal management and system complexity still are an issue. [19] studied failure process of lithium-ion batteries to identify the safety concerns requiring HESS design to address. [17] reviewed low-temperature heating problems for EV batteries and they suggested that HESS could compensate the performance loss at extreme temperature. [12] offered a broader perspective on energy storage trends, calling for continued innovation that drove down costs and improved sustainability.

In summary, the literature illustrates that HESS presents a highly flexible solution for increasing power quality, renewable integration, and responding to electrified transport demands. Though there is notable progress in configurations and control, future research must intervene to surmount practical constraints to maximize the realization of HESS in future energy systems.

3 Methodology

This section presents the implementation strategy for bidirectional energy transfer between electric vehicles (EVs) and the power grid using Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technology. The proposed model is developed and validated using MATLAB Simulink.

3.1 System Architecture Overview

This system is intended to be used in making and breaking of connections for bi-directional energy transfer between electric vehicles (EVs) or electric vehicle supply equipment (EVSE) and an electrical grid, such as a residential unit installed in private residences, apartments, businesses, etc., i.e. enabling Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G). Wall-mounted bi-directional charger unit (WBCU) is composed of main system core including connection control block, converter control block, AC/DC converter, PID-controlled DC/DC buck-boost conveiter, submodules. G2V uses AC power from the grid, converts it to DC and stores it in battery of the EV while V2G inverts DC power already stored from charging them earlier to be fed back as AC Power to the Grid. The buck-boost converter regulates the voltage levels dynamically and the PID controller stabilizes the same. The Battery Management System (BMS) monitors such key data as voltage, current and state-of-charge (SoC), protecting the most significant aspects of battery life by optimization of charging cycles. That allows EVs to serve as battery backups on wheels, helping to stabilize the grid by controlled power sharing. Fig 2 shows the energy flow from charging plug to battery and propulsion system, which supports driving as well as charging operations. Fig 3 shows the charging and discharging pathways, providing a bidirectional power flow interface for efficient energy management in EVs. This bi-directional function for vehicle-to-grid (V2G) and vehicle-to-home (V2H) can feed the energy stored in the battery back to powerlines or homes as backup power.

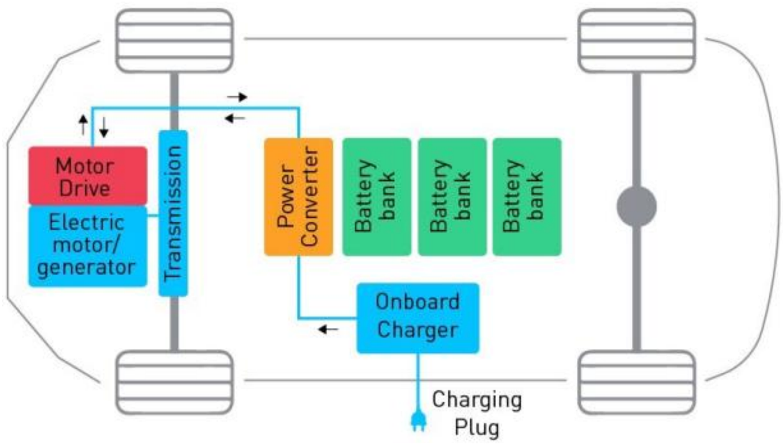

Fig. 2. Block diagram of the electric vehicle system showing major components such as the motor drive, transmission, power converter, onboard charger, and battery bank.

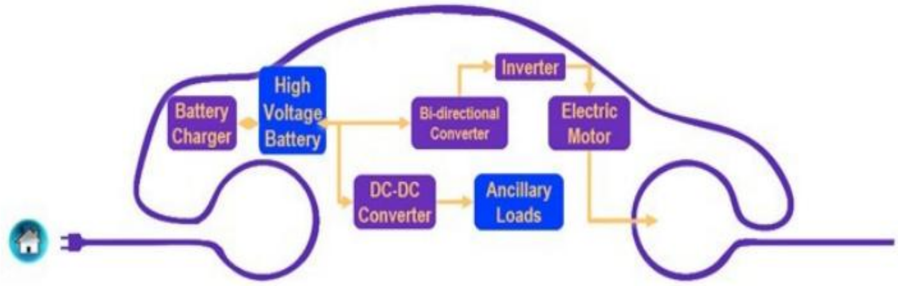

Fig. 3. Electric vehicle system showing energy flow and key components including the battery charger, high voltage battery, bi-directional converter, inverter, and electric motor.

3.2 AC to DC and DC to AC Conversion

The AC to DC conversion is an essential process within the suggested bidirectional electric vehicle (EV) energy system. In Grid-to-Vehicle (G2V) mode, AC power from the utility grid is converted to DC by means of an AC to DC converter, usually a rectifier circuit combined with a filter to give a stable DC output for charging the high-voltage battery. Conversely, in Vehicle-to-Grid (V2G) mode, the stored battery DC energy is converted back to AC by a DC to AC inverter to be supplied back into the grid. Such converters are made to operate at variable levels of voltage and high efficiency with very little distortion in harmonic. One of the distinguishing features in this system is the bidirectional power converter, which provides smooth switching between the G2V and V2G modes and is controlled by a smart algorithm according to real-time grid needs and battery health. The two-mode control makes efficient use of energy, stabilizes the grid and facilitates gaining access to renewable energy. Fig 4 shows that the bridge converter uses six IGBTs in a three-leg arrangement to regulate the power flow. A DC-link capacitor is employed for smoothing of rectified voltage, and the controlled DC power is delivered to the load on the output side. The devices are therefore suitable for both charging and grid feeding modes in electric vehicle applications, due to a bi-directional energy transfer. The IGBTs facilitate high-efficiency switching resulting in lower power losses and better converter performance. Moreover, the DC-link capacitor reduces the voltage ripples which in turn provides the system with a smoother power and current. The versatility of this converter architecture enables its application to multiple power management tasks such as renewable energy integration and energy storage systems.

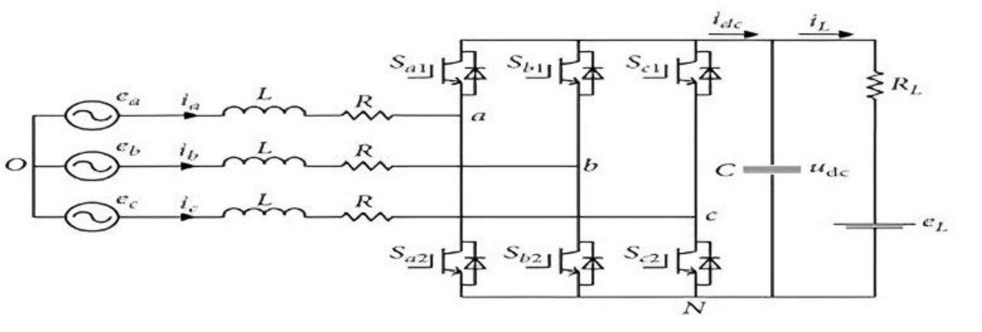

Fig. 4. Three-phase bidirectional converter circuit diagram showing the interface between the AC grid and DC link.

3.3 DC to DC Conversion and Control

DC to DC conversion stage is required in regulating the voltage level between the power supply and the electric vehicle battery during the charging (G2V) and discharging (V2G) process of an electric vehicle. For operation with controllers or with adjustable input and output voltage, the video analytics system shall use a buck-boost converter topology to boost or to reduce the voltage. The operation of this is controlled by a PID (Proportional-Integral-Derivative) feedback controller, which adjusts the duty cycle of its switching element so that the output voltage remains constant. The control algorithm is designed to operate optimally with minimal overshoot and settling time in order to maintain system stability while minimizing battery consumption. Such voltage regulation is essential to maintain a continuous flow of power and optimal operation of the energy exchange system, when supplying power to the many different type loads and grid conditions.

3.4 Simulink Subsystem Modeling

Simulink subsystem modeling is used for the modular and hierarchical approach of modeling the V2G (Vehicle-to-Grid) and G2V (Grid-to-Vehicle) functions of the system. Each component of the system like the photovoltaic (PV) source, battery storage, buck-boost converter, inverter, and grid interface are represented as a separate subsystem to facilitate analysis and control ease. These subsystems are linked inside a main simulation environment to emulate real-time power flow and conversion behavior. Control logic, such as PID controllers, MPPT algorithms, and inverter modulation schemes, is incorporated within respective subsystems to provide realistic dynamic responses. Such modeling improves the readability and scalability of the system design, enabling parameter tuning, stress testing, and performance verification under different operating conditions. The subsystem-based framework in Simulink also supports fault analysis and system optimization with minimal complexity. Fig 5 depicts the Simulink model indicating the bidirectional power flow between the grid and an electric vehicle via G2V (Grid-to-Vehicle) and V2G (Vehicle-to-Grid) modes. The model consists of a three-phase AC supply, transformer, inverter, and control logic combined to control power transfer. SOC (State of Charge), battery voltage, and current are under constant monitoring to provide safe and efficient operation. Bidirectional converters support charging and discharging of the battery, as a function of grid conditions and control commands. The parameters of the vehicle battery are recorded in real time to represent performance and efficiency visually. Logical control signals based on SOC thresholds and load demand manage changing between G2V and V2G modes. The model supports emulating real grid interactions of electric vehicles under smart energy management.

This study based on modeling, simulation and control of bidirectional power transmission between Electric Vehicle itself and the grid using MATLAB/Simulink. The system has been modeled down to the level of a DC-DC converted along with an inverter and battery management system ensuring a safe transfer of power not only in G2V or V2G modes as well. The microcontroller in the control logic tracks the status information like State of Charge (SoC), current, and battery voltage that is necessary to make decisions on charging and discharge operations in real time. Well integrated subsystems are the key to a good battery and effectively improved energy-flows are what assist the grid in stability, securing optimal performance of your battery. We consider that this would trade the way on how smart charging systems can be scheduled and help to the advancement of energy sustainability by means of intelligent vehicle-grid integration.

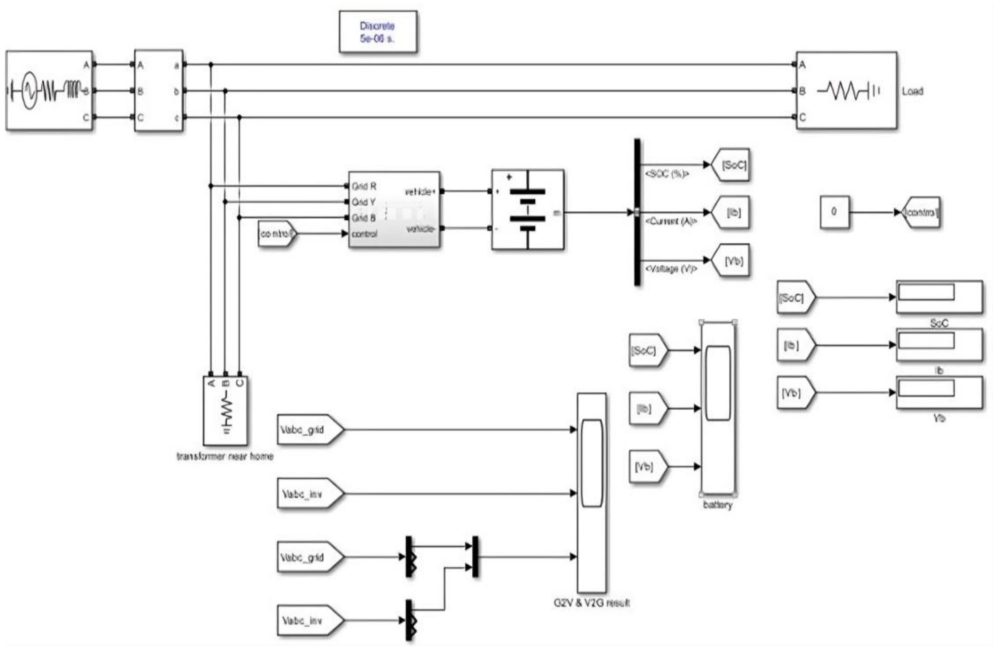

Fig. 5. Simulink Model of G2V and V2G Bidirectional Power Flow System.

4 Results and Discussion

The system proposed was simulated using MATLAB/Simulink to examine its performance under different operating conditions. The charging and discharging characteristics of the battery were given prime importance and were monitored with the help of three important parameters: State of Charge (SoC), Battery Voltage (Vb), and Battery Current (Ib). These parameters reflect the efficiency and stability of energy transfer between the grid and the electric vehicle.

The Fig 5 simulation output indicates the complete subsystem model of the energy management strategy. It encompasses major modules such as the inverter, grid connection interface, and the battery control module. The system runs at a discrete sampling time of 50 µs, allowing the possibility of high-resolution power transfer dynamics tracking both in Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) cases.

The SoC of the battery over time, as illustrated in Fig 6, represents the gradual increase in SoC during the G2V cycle and a later decrease during the V2G cycle. The SoC of the battery began at 60% and rose to about 95%, after which the discharging cycle began. This trend confirms the effective bidirectional energy flow implemented via the control logic.

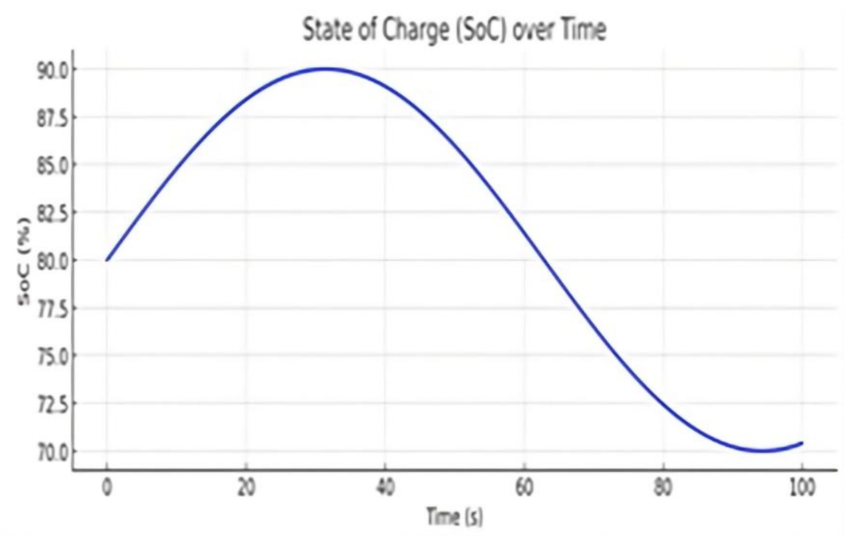

Fig. 6. State of Charge (SoC) over Time – illustrates the variation of battery SoC in percentage as the system charges and discharges.

The Battery Voltage (Vb), as illustrated in Fig 7, remained stable throughout the charging and discharging cycles, fluctuating within a permissible range of 360V to 400V. This indicates that the converter and controller circuits effectively regulate voltage across the battery terminals, avoiding any risk of overvoltage or undervoltage.

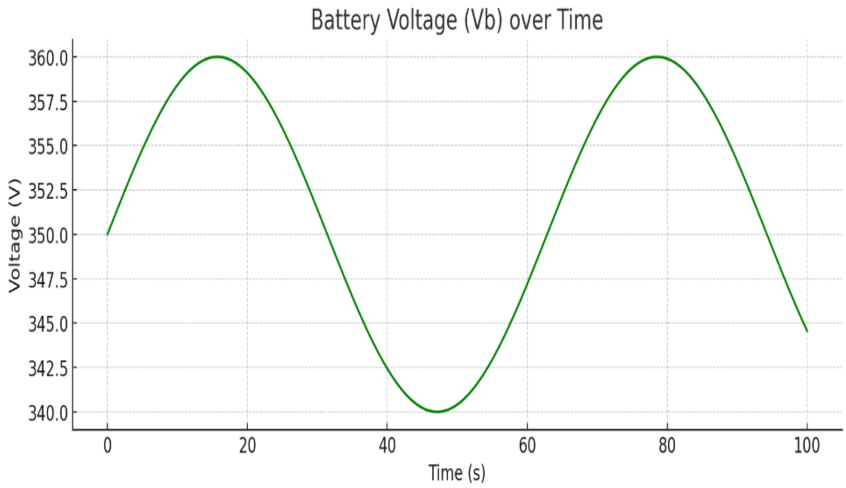

Fig. 7. Battery Voltage (Vb) over Time – shows the battery voltage profile, maintaining stability during operation.

The Battery Current (Ib) variation, depicted in Fig 8, displays positive peaks during the G2V operation (charging) and negative dips during the V2G operation (discharging). The smooth transition between the two modes without significant ripple demonstrates the effectiveness of the proposed control strategy.

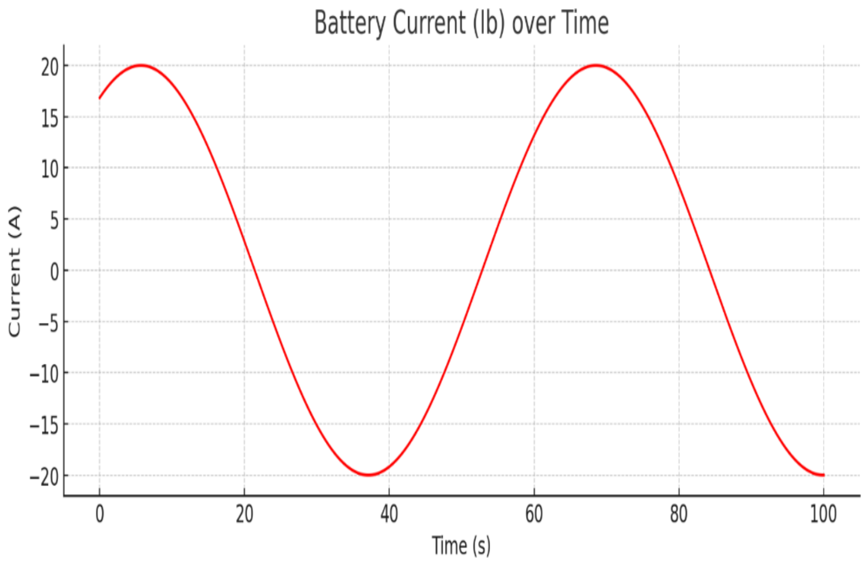

Fig. 8. Battery Current (Ib) over Time – captures current inflow and outflow with alternating peaks representing charging and discharging cycles.

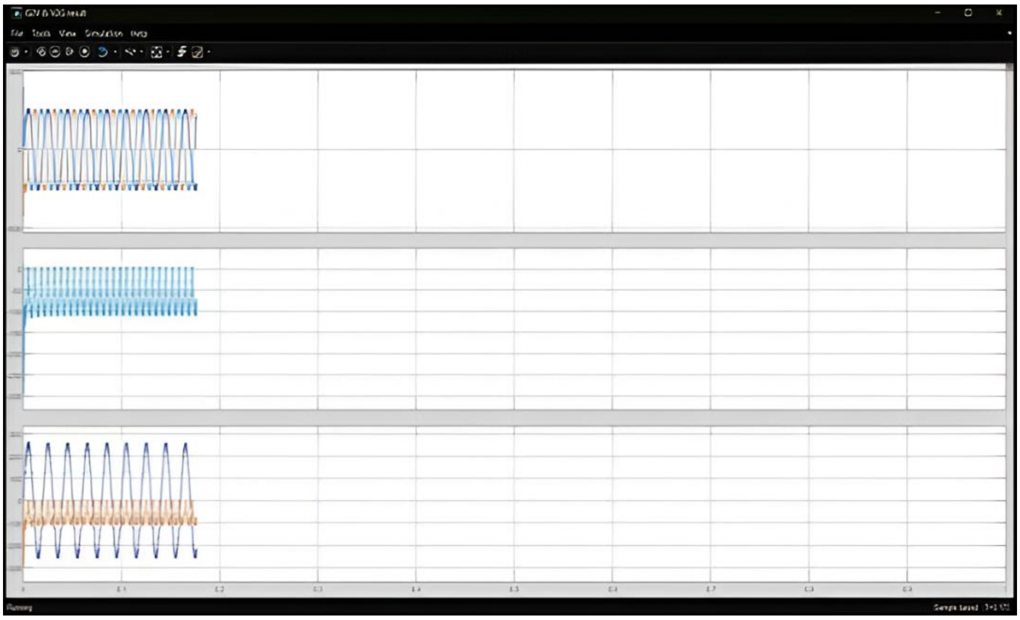

Fig. 9. Grid Voltage and Power Flow Characteristics in G2V and V2G Modes.

Fig 9 demonstrates the grid voltage and power flow behavior in Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes. Grid voltage is quite stable but can be tracked through the process. In G2V mode, power flow exhibits positive values, representing energy transfer from the grid to the vehicle. By comparison, with V2G operation, power flow is reverse, indicating power being fed out from the car to the grid. A bi-directional converter provides a virtual constant AC output voltage, both synchronized in terms of frequency and phase with the grid for both charging and discharge. Small amounts of voltage ripples are caused during V2G operation owing to dynamic variation of loads, but these still stay within compliant limits of the grid.

The simulation from MATLAB Simulink successfully illustrates the dynamic interaction between the grid and electric vehicles (EVs) in both G2V (Grid-to-Vehicle) and V2G (Vehicle-to-Grid) modes. In G2V mode, the State of Charge (SoC) of the battery exhibits a steady rise, reflecting successful energy transfer from the grid to the EV. The battery current in such a move is positive, that is, along the direction of charging, while the voltage pattern is stable with minimal variations with the internal resistance and charging cycle. Such results confirm that the designed control system is capable of controlling energy input safely and maintaining the stability of the battery.

Conversely, under V2G operation, simulation results demonstrate a regulated reduction in SoC, which indicates the evacuation of stored energy from the EV to the grid. Negative current values also prove the direction of energy flow. The system achieves grid-compliant voltage levels with minimal oscillations regardless of fluctuating load demands, demonstrating the superior quality of the bidirectional converter architecture and synchronization methods. The bidirectional inverter's capacity to adjust frequency and phase change in real-time provides for safe and efficient refeeding of energy into the grid.

Power flow trends clearly reflect positive values during G2V and negative values during V2G, indicating accurate energy control and directionality within the system. The continuous regulation of AC voltage in both modes using PID-controlled buck-boost converters and the grid-synchronized inverter proves the viability of implementing such systems in practical smart grid scenarios. Additionally, these results emphasize the converter's ability to transfer energy smoothly without sacrificing voltage or system integrity.

Overall, the simulation demonstrates that proposed bidirectional EV charging framework can achieve the objectives of grid support along with vehicle charging. It shows that the comprehensive control algorithm, energy management and power flow can be successfully use in practical system in the future. These results confirm the growing relevance of V2G and G2V techniques in current energy systems, i.e., when we are heading towards a massive implementation of distributed, renewable-based smart grids.

5 Conclusions

Finally, thanks to its numerous advantages with respect to the conventional single-storage model, C-HESS reinforces its potential and can serve as an excellent foundation for next-generation energy management systems. The HESS, which consists of various energy storage devices such as Lithium-ion batteries, Supercapacitors, Super conducting Magnetic Energy Storage units (SMES) etc., is a dynamic and resilient answer that meets the rising requirements for dependable, efficient and clean energy storage. By optimal combining the high energy density of the Li-rechargeable battery (LIB), the high-power density and fast power response of supercapacitors, and the high frequency response and efficiency of the SMES, HESS effectively overcomes the deficiencies of the individual systems (separately or together) and combines the merits of the individual sub-systems. This kind of mutual cooperation is an advantageous interaction which can improve the whole electro power system, and achieve being more economic for energy utilization, power quality and more flexible operation. As the world accelerates towards a clean energy future, HESS has a unique position to play a key role in orchestrating fast, seamless integration of clean energy streams like solar and wind into the world’s power grids. In addition, of course, its ability to provide grid resilience throughout periods of changing demand and supply conditions, and its promise of substantial emissions reduction, makes it capable of addressing both challenges of decarbonization and energy transition.

Ongoing developments in HESS design, control systems, and material science will further enhance their cost-effectiveness and efficiency to allow extensive usage across a wide range of applications like electric vehicles, microgrids, and large-scale power systems. Additionally, the modularity and scalability of HESS render it very flexible for smart grid structures in the future and changing energy infrastructures. The integration of real-time control methods with AI-driven energy forecasting will further increase its reliability and independence. As digitalization meets energy systems, HESS will be a key enabler of intelligent, adaptive, and self-optimizing energy networks. Hence, HESS is a game-changing approach to addressing existing energy challenges with a scalable and sustainable path to an energy system that is low-carbon and resilient.

References

[1] Ashwanth, S., M. Manikandan, and A. Mahabub Basha. "Superconducting Magnetic Energy Storage System based Improvement of Power Quality on Wind/PV Systems." International Journal of Emerging Technology and Advanced Engineering 4.4 (2014): 676-682.

[2] Ashwanth, S., S. Yamuna, and S. Gogulabrindha. "A novel energy management approach for hybrid battery-supercapacitor configurations in electric vehicles." Journal of Computer Science (ISSN NO: 1549-3636) 17.11 (2024).

[3] Thien-A Nguyen-Huu, Van Thang Nguyen, Kyeon Hur and Jae Woong Shim, "Coordinated Control of a Hybrid Energy Storage System for Improving the Capability of Frequency Regulation and State-of-Charge Management", Energies **2020**, 13, 6304; doi:10.3390/en13236304 www.mdpi.com/journal/energies.

[4] Atawi, I.E.; Al-Shetwi, A.Q., Magableh, A.M., Albalawi, O.H., "Recent Advances in Hybrid Energy Storage System Integrated Renewable Power Generation, Configuration, Control, Applications, and Future Directions". Batteries 2023, 9, 29. https://doi.org/10.3390/batteries9010029.

[5] Furquan Nadeem, S. M. Suhail ussain, Prashant Kumar Tiwari, Arup Kumar Goswami, And Taha Selim Ustun," Comparative Review of Energy Storage Systems, Their Roles, and Impacts on Future Power Systems". Volume 7,2019, date of publication December 18, 2018, See http://www.ieee.org/publications_standards/publications/rights/index.html for more information.

[6] Bare Lal Bamne, Prof. Priyank Gour, "Hybrid Energy Storage System Integrating Lithium-ion Battery and Supercapacitor for Electric Vehicle Applications", JETIR September 2022, Volume 9, Issue 9 www.jetir.org (ISSN-2349-5162).

[7] Chaouki Melkia, Sihem Ghoudelbourk, Youcef Soufi, Mahmoud Maamri, Mebarka Bayoud, "Battery-Supercapacitor Hybrid Energy Storage Systems for Stand-Alone Photovoltaic", European Journal of Electrical Engineering, Vol. 24, No. 5-6, December, 2022, pp. 265-271Journal homepage: http://iieta.org/journals/ejee.

[8] Hayet Slimani Khaldi, Ahmed Chiheb Ammari, "Design of a Hybrid Battery/Super-capacitors Energy Storage System for Hybrid Electric Vehicles". *Life Sci J* 2014;11(12):109-118. (ISSN:1097-8135). http://www.lifesciencesite.com.

[9] Lia Kouchachvili_, Wahiba Yaïci, Evgueniy Entchev, "Hybrid battery/supercapacitor energy storage system for the electric Vehicles", 2017 Published by Elsevier B.V.

[10] SunHo Bae, Seoung Uk Jeon, and Jung-Wook Park, "A Study on Optimal Sizing and Control for Hybrid Energy Storage System with SMES and Battery", IFAC-Papers OnLine 48-30 (2015) 507–511.

[11] Jianwei Li, Min Zhang, Qingqing Yang, Zhenyu Zhang, and Weijia Yuan, "SMES/Battery Hybrid Energy Storage System for Electric Buses" IEEE Transactions on Applied Superconductivity, Vol. 26, No. 4, June 2016.

[12] J. Mitali, S. Dhinakaran and A.A. Mohamad, Etnergy Storage and Saving (2022). 166–216 http://www.keaipublishing.com/en/journals/energy-storage-and-saving/6.

[13] Bipul kumar, Abhijeet Patil, Dr.E. Vijay kumar, "Simulation and DC Anaysis of SMES System using IGBT for a High-Power DC Application", International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 07 Issue: 07 | July 2020 www.irjet.net p-ISSN: 2395-0072. © 2020, IRJET | Impact Factor value: 7.529 | ISO 9001:2008 Certified Journal |

[14] Atef. M. Mansour, Khaled.N. Faris, Essam El-Din Aboul Zahab, "Smart Energy Management controller for a Micro Grid" International Journal of Engineering Research ISSN:2319-6890) (online), 2347-5013(print) Volume No.4, Issue No.8, pp: 456-464, 01 August 2015 IJER@2015.

[15] Adekanmi Miracle Adeyinka, Oladapo Christopher Esan, Ahmed Olanrewaju Ijaola and Peter Kayode Farayibi "Advancements in hybrid energy storage systems for enhancing renewable energy-to-grid integration", Sustainable Energy Research 2024. https://doi.org/10.1186/s40807-024-00120-4.

[16] Hu, G., Huang, P., Bai, Z., Wang, Q., Qi, K.: Comprehensively analysis the failure evolution and safety evaluation of automotive lithium ion battery. E Transportation **10**, 100140 (2021).

[17] Lin, C., Kong, W., Tian, Y., Wang, W., Zhao, M.: Heating lithium-ion batteries at low temperatures for onboard applications: recent progress, challenges and prospects. Automot. Innov. 5, 3–17 (2022).
[18] M. A. Hannan, M. M. Hoque, A. Hussain, Y. Yusof, and P. J. Ker, ``State of- the-art and energy management system of lithium-ion batteries in electric vehicle applications: Issues and recommendations," *IEEE* Access,vol. 6, pp. 19362_19378, 2018.
[19] T. M. Masaud, K. Lee, and P. K. Sen, ``An overview of energy storage technologies in electric power systems: What is the future?" in *Proc. North Amer. Power Symp. (NAPS)*, 2010, pp. 1_6.
[20] P. Buchana and T. S. Ustun,``The role of microgrids & Renewable energy in addressing sub-Saharan Africa's current and future energy needs," in Proc. 6th Int. Renew. Energy Congr. (IREC), 2015.