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A Novelty of Several Optimization Criteria Hybrid Energy Storage System and Power Management in EV Applications

S.Sankarananth[1*], *G.Santhosh Kumar*[2], and *G.Kavitha*[3]

[1]Department of EEE, Excel College of Engineering and Technology, Namakkal, Tamilnadu, India
[2,3] Department of EEE, Excel Engineering College, Namakkal, Tamilnadu, India

Abstract. The power management capabilities of hybrid energy storage systems offer several advantages for EVs, including improved performance, longer battery life, and reduced cost. HES technologies which combine Li-ion cells with ultra-capacitors (UC), are developing as just a possible alternative to the constraints of conventional ESS for conserving electricity. Lithium-ion batteries have a limited cycle life, meaning that they gradually degrade with each charge-discharge cycle. This can reduce the overall lifetime of the ESS and require more frequent replacements, adding to the cost and environmental impact of EVs. To circumvent those constraints, mixed battery packs combining battery technology as well as superconductors are being developed. To improve the design and control of hybrid energy storage systems for electric vehicles (EVs), a bi-level multi-objective framework has been proposed. A Bi-level multi-objective design and control framework, incorporating NSGA-II and fuzzy logic control, to obtain an optimal sized hybrid energy storage system and corresponding power management strategy. This dynamic and multi-objective architecture may achieve optimum solution hybrids battery bank as well as a matching significant power scheme one at a moment through integrating non-dominated sorting genetic and fuzzy logic control methods. To evaluate the effectiveness of the proposed bi-level multi-objective framework, Pareto optimal solutions of different hybrid energy storage systems are obtained. This approach can lead to significant improvements in the performance and efficiency of hybrid energy storage systems, making them more suitable for EVs and other applications that require high-performance energy storage solutions.

Index Terms—Batteries, ultra capacitors, recursive imprecise input, non - linear and non optimisation, and e – mobility

1 Introduction

The utilization of lithium-ion batteries as the primary energy storage component in electric vehicles (EVs) has become prevalent. Lithium-ion batteries are highly desirable due to their

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* Corresponding author: sankarananth.ecet@excelcolleges.com

exceptional energy density, making them well-suited for EV applications. However, it is worth noting that these batteries are comparatively costly. To address this, a hybrid approach involving the integration of both lithium-ion batteries and supercapacitors within a Hybrid Energy Storage System (HESS) has emerged. Numerous studies have focused on hybrid energy storage systems, aiming to optimize their design and power management for electric vehicles. Various optimization algorithms, such as genetic algorithms, particle swarm optimization, and fuzzy logic control, have been employed to find the optimal sizing of hybrid energy storage systems but optimization performance is low. The limited driving range of EVs equipped with HESSs. Hybrid car are gaining popularity owing to its ability to minimise carbon pollution as well as depletion of fossil fuels. These are some of the greatest obstacles in the configuration of Hybrid vehicles is indeed the choice and supervision of storage technologies. Blended energy storage devices are an appealing alternative for Electrical vehicles because they integrate the benefits of various methods of storing electricity, including such high-density battery systems as well as high-density ultra-capacitors. The strategy considers the degradation characteristics of the energy storage system and optimizes the power distribution to prolong the lifespan of the battery and ultra-capacitor [1]. State-of-charge (SOC) and state-of-health (SOH) estimation techniques for lithium-ion batteries reviewed. The advantages and limitations of different estimation methods, including the coulomb counting method, model-based methods, and data-driven methods [2]. The importance of battery cycle-life in HEVs, as it directly affects the performance and cost-effectiveness of the vehicle. The existing cycle-life models for lithium-ion batteries and highlight their limitations, such as their complexity and lack of accuracy. They argue that a control-oriented model is necessary to optimize battery usage and extend its cycle-life [3][4]. The potential applications of ultra-capacitors, which range from automotive and transportation systems to renewable energy storage and portable electronics [5], [6]. A novel approach for improving the performance of multi-port bidirectional DC-DC converters using a resilient back-propagation neural network method highlight the potential of this method for enhancing the efficiency and response time of these converters, with potential implications for a wide range of applications in renewable energy systems and electric vehicles [7],[8]. Blended battery packs provide a potential approach to the issues of power storage for energy, hybrids, and squeeze hybrid automobiles. The hybrid system combines the benefits of batteries and ultra-capacitors, resulting in improved system performance, efficiency, and lifetime [9]. The hybrid system combines the benefits of batteries and super capacitors, resulting in improved system performance, efficiency, and reliability. The battery bank provides energy storage for long-term use, while the super capacitor bank provides additional power during high-power demand events and can improve the overall system performance [10],[11]. A novel approach to energy management for fast-charging electric buses that could contribute to the development of sustainable transportation systems in urban areas. The power management approach may properly handle transfer of energy as well as decrease energy usage even while maintaining the mixed-energy storage system's steady functioning [12]. A mathematical model that captures the dynamic behavior of the HESS and uses it to optimize the sizing of the battery and ultra-capacitor components. The optimization problem is formulated as a mixed integer nonlinear program (MINLP) that minimizes the cost of the HESS while satisfying the power and energy requirements of the EV [13]. High gain converters for PV systems and presents two techniques - CI and SCC - for achieving high voltage gain [14]. The multi-objective optimization approach using GA and FDM techniques provides an efficient and cost-effective solution for the B/SC ESS, making it a valuable contribution to the field of EVs and renewable energy [15]. The convex programming optimization approach provides an efficient and effective solution for power management and dimensioning, making it a valuable contribution to the field of sustainable transportation [16]. To use a bandwidth-based technique, the Combination outside of energy storage capacity and sequential Plug - in hybrid fuel efficiency is demonstrated. The importance of energy storage systems in HEVs and the need for an efficient control strategy that can improve the fuel economy and extend the driving range of HEVs [17]. A multi-objective optimization approach to determine the optimal sizing of the HESS, which includes both batteries and ultra-capacitors. The non-dominated sorting genetic algorithm II (NSGA-II) to solve the optimization problem and obtain a set of Pareto-optimal solutions [18]. The different EMS used in EVs, which are responsible for managing the energy flow between the energy sources and the EVs. The different control strategies used in EMS, such as rule-based control and optimization-based control [19]. A utility function-based real-time control strategy for a battery ultra-capacitor hybrid energy system to improve the performance and efficiency of the HES by dynamically adjusting the power flow between the battery and the ultra-capacitor based on the energy demands of the system [20]. A supervisory power splitting approach for a new ultra-capacitor battery vehicle that deploys two propulsion machines to improve the energy efficiency and performance of the vehicle by dynamically splitting the power between the ultra-capacitor and the battery based on the driving conditions [21]. This study focuses on investigating the sizing and control of a hybrid energy storage system (HESS) for an electric race car. The analysis's research goal is to reduce the running costs of a cycling team all while lowering the harm wrought by discarded batteries. The HESS combines the advantages of both battery and ultra-capacitor technologies to provide high energy density and high-power density, respectively.

2 A Structure for Energy Monitoring Using Dual Level Optimised Solution

Figure 1 illustrates the suggested Bi-level optimum development and management structure in developing and controlling a mixed battery system with evs (1). This structure in order to enhance the strength and monitoring of both the HESS via lowering a race car team's running costs and decreasing the harmful ecological effect that waste produces batteries. The interventions to address are divided into two levels, with the main layer in charge of something like the HESS's optimisation and the decreased level in charge of such HESS's true power operations. The proposed energy management system (EMS) utilizes a fuzzy logic controller (FLC) to determine the power distribution between the battery and super capacitor in an electric vehicle. The FLC takes into account the power demand of the driving profile P_{Dem}, as well as the battery state of charge x_{SOC^*} and super capacitor state of energy x_{SOE^*}, as its inputs. Based on these inputs, the FLC calculates the requested power from the super capacitor P_{reqsc^*}, which is used to supply power to the vehicle during periods of high-power demand. The requested power from the battery is then calculated by subtracting P_{reqsc^*} from P_{Dem}, resulting in $P_{reqbat^*} = P_{Dem} - P_{reqsc^*}$. This approach allows for optimal power distribution between the battery and super capacitor, taking into account the strengths and weaknesses of each energy storage device. By utilizing the super capacitor to supply high power demand, the battery's lifespan is extended, and its capacity is preserved for lower power demand periods. The FLC-based EMS thus offers an efficient and reliable method for managing power distribution in electric vehicles, ensuring optimal energy utilization while maintaining the health and longevity of the energy storage systems. Its Bi-level optimum solution modelling and development approach entails a 2 different process flow aimed at optimising its power distribution system of such an electric car's hybrid battery pack (HESS). Its first process employs a non - linear and non-algorithm that produces a power control system larger size variable framework but also associated fixed optimization parametric matrix. Its FLC-based Management system then employs the newly developed fuzzification to regulate the produced HESS as well as perform the required battery energy and capacitors. To find the optimum power supplies between both the 2 devices that store energy, its FLC considers input data like the driving site's power requirements and the condition of the lithium-ion battery and capacitors. Its Bi-level optimum solution design and oversight method could indeed accomplish a best solution among power effectiveness and expense while making sure consistent and dependable procedure of such HESS through optimizing both measurement variables and the adjustable variables of the system for energy management. This method provides a convenient and effective way to handle battery bank in evs, enabling enhanced operation as well as energy efficiency. Its primary goal of this study is to find the best sizing variable, N_{sc*} and parametric variable, x_{mf*} for such nonlinear functions, which are significant features for such HESS configuration and genuine Cell cycle EMS. These variables are critical for the combination battery system as well as the true Cell cycle energy monitoring system to function properly (EMS). By optimizing the EMS, it will be possible to generate a series of control commands, u(t) = [$P_{reqbat*}$, P_{reqsc*}], which will be used to maximize the number of laps, J_{laps*} and battery cycle life $J_{lifebat*}$. Also, the initiative will look into several strategies for enhancing the overall quality of such actual FLC-based management systems and such mixed battery system. These methods will also include examining the control techniques, power converters elements, as well as the controller's smart energy technique. The investigators want to determine the most efficient ways to raise the efficiency of the actual cell - cycle EMS as well as the mixed battery system via doing an extensive investigation of these variables. The required system is based for the batteries, written as $P_{reqbat*}$, as well as the required performance and focuses for the capacitors, indicated as P_{reqsc*}, are the components of both the control command sequence, indicated as u(t), which is provided by the optimised EMS. This response instruction set aims to improve the number of circuits that may be performed on a specific racetrack (J_{laps*}), and also to prolong the current battery total cycle life ($J_{lifebat*}$). In certain words, system EMS's job is to determine the best way to distribute power between both batteries to ensure that the electric car may go as many laps as it can while still protecting the batteries. This functional form, designated as J, considers the system's present state x(t), its control command sequence u(t), or any pertinent variables (p). The EMS may assure that the hybrid cars function at maximum efficiency, producing the maximum performance with preserving the battery's condition, by optimising J.

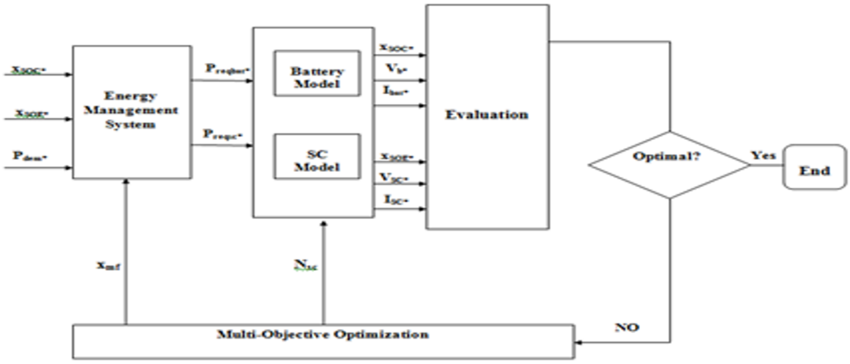

Fig. 1. Bi-Level optimum design as well as control structure.

During time t, its first dynamics conditions explain the connection between both the platform's state vector, represented as x(t), and the console's inputs, written as u(t), as well as any important factors, denoted as p. These restrictions can be written mathematically as x(t) = f[x(t); u(t); t; p], that illustrates how the console's state variables develop as a consequence of such inflows with external influences. In some other terms, the equation demonstrates how the console's current state is impacted by its former condition, this same input sequence signal, as well as other key aspects, such as ambient circumstances or system features. Researchers and technologists can construct computational equations that properly represent the characteristics of the phenomenon and can be utilised to design successful control schemes by knowing first ever dynamics requirements. Algebraic approach requirements (g[x(t); u(t); t; p]) are mathematics expressions that describe the permitted possible values for just a collection of controller parameters. These restrictions can be represented as g_{min} g[x(t); u(t); t; p] g_{max}, wherein g_{min} as well as g_{max} reflect the system parameters' lowest and highest permissible values, accordingly. Design parameters are algebraic formulas that indicate the set of permitted solutions of system characteristics at certain time intervals denoted by t_0 as well as t_f. These constraints are frequently stated as b_{min} b[x(t0); t0; x(t_f); t_f; p] b_{max}, with b_{min} as well as b_{max} indicate the system parameters' lowest and highest permissible values, accordingly.

3 Essential Structure of a Hybrid Power System

Its HESS arrangement is a strong and efficient power management technology that allows battery operated cars to attain excellent result while conserving energy. This arrangement offers the vitality and power required for rapid racing while increasing battery capacity and lowering energy usage by utilising both batteries and capacitors. As seen in figure 2, the capacitor is a critical element of HESS utilised in modern vehicles (2). It presents a powerful, increased storage alternative that really can swiftly and accurately generate and receive enormous quantities of electricity. The capacitors achieve great efficiency as well as performance by managing the bilateral DC/DC conversion and leveraging its capacity for operation over a wide bandwidth.

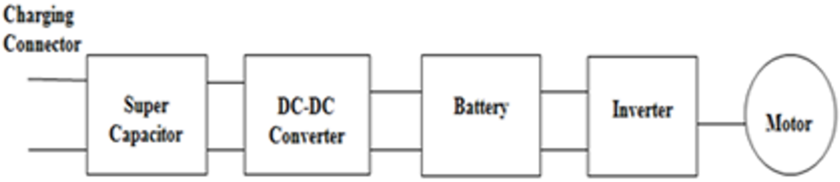

Fig. 2. An electric race vehicle with HESS configuration.

3.1 Enhanced Lithium ion Design

Although the efficient and effective resistant (R_{int}) model is commonly used in batteries modelling, it has difficulties in adequately explaining batteries behaviour under various operating situations. Developing a more dynamical prototype implementation that takes in to account many aspects, like C rate and State of charge, is required to acquire appropriate sizing specifications and power action plans again for HESS with real world applications. A revised shepherd concept was used to clearly define the variables of batteries even during charge / discharge process. This model represents the battery's behaviour more comprehensively by accounting for elements such as resistor, charge / discharge rates, including temperature fluctuations. Several indicators must be considered while rating the efficacy of a matched dynamical proposed converter. Among such measurements are voltage magnitude, steady state inversion, reactance, as well as voltage stable. The discharge and charge of the battery is represented in équations (1) and (2) respectively.

$$V_{bat} = E_0 - K\frac{Q_{max}}{Q_{max}-it}it\,K\frac{Q_{max}}{Q_{max}-it}i - R_{bati} + Ae^{(-B.it)} \tag{1}$$

$$V_{bat} = E_0 - K\frac{Q_{max}}{Q_{max}-it}it - K\frac{Q_{max}}{it-0.1Q_{max}}i - R_{bati} + A \tag{2}$$

These variables are often derived using Relationship (1) and (2) and utilized to evaluate simulation results as shown in figure 3. The technique for establishing a prototype implementation entail determining the values for these variables using observational evidence. This is often accomplished through an investigation process during which the simulation is tweaked until it precisely reproduces the behaviour of the battery under real-world situations. After calibration, a designer's correctness can be determined by comparing it to real-world data. It is frequently accomplished by showing the forecasting accuracy with the real statistics and analysing the way the two correspond. RMSE, MAE, R-squared, as well as other statistics may be employed to quantify overall level of concordance here between system as well as the inputs. In order to precisely simulate the behaviour of the batteries, both charge level (SOC) and its fluctuation rate must be measured accurately. This is commonly accomplished by employing a collection of formulas that establish the connection between the capacitor's voltages, current, and its state of charge (SOC). Expressions (3) as well as (4) provide a complete model for defining a battery's behaviour in terms of voltages, current, state of charge (SOC), and the variation of SOC. By employing thèse calculations,

$$x_{soc} = 100(1 - \frac{1}{3600Q_{max}} \int_0^{t_f} id(t)) \tag{3}$$

$$\dot{x} = -\frac{1}{3600Q_{max}} I \tag{4}$$

It is feasible to precisely simulate a battery's behaviour under various settings and forecast how it's going to behave through modifications to its surroundings or operational parameters.

3.2 Enhanced Lithium-ion Design

In recent history, accurate determination of battery deterioration has become a prominent topic of research, including major efforts being made from both academics and industry experts to build models that really can effectively forecast the behaviour of such cells over time. It's partly due to that one fact that lithium-ion battery packs are utilized in a diverse range of domains such as electric cars, energy storage, as well as electronic items, and their own long-term efficacy and dependability are crucial to their profitability. Multiple factors, such as insect reaction, stable electrolyte cross - functional and cross (SEI) creation, but also resistance increase, can all add value to battery pack degeneration. As a consequence, a number of mathematical equations have been created to accept responsibility for such variables and deduce the throughput fade of such battery systems over a period. While considerable research has been conducted to realize that it can actually determine the depletion of battery packs, experiments are still required for trying to study such devises' aging and validating storage fading frameworks. Investigators can improve their knowledge of the way these mechanisms affect and distinguish the variables that lead to their progression by collecting data on device behavioural patterns. The power loss of such a charger is determined by the combination of discharge present level (C_{rate}), temperature (T), as well as maximum current efficiency in this prototype (Ah). Expressions (5) to (8), in particular, explain how the storage loss of both the power supply can be determined using these variables. Investigators can obtain a greater awareness of the variables that make a contribution to capabilities fade in battery packs and create more reliable forecasts of their behaviour over time via this amended quasi model. As a result, the design and achievement of these battery cells can be improved, making each other more dependable as well as efficient for a wide variety of uses.

$$Q_{loss} = A_{cl} exp(\frac{-E_a}{R_{cl}})(A_h)^z \tag{5}$$

$$lnA_{cl} = a.exp\ exp\ (-b. C_{rate})\ + c \tag{6}$$

$$E_a = d + e.C_{rate} \tag{7}$$

$$A_h = \int_0^{t_f} \frac{i}{3600} dt \tag{8}$$

Investigators have developed a quantitative approach for estimating the impact of differing present rate on battery cycle existence in furthermore to employ the estimated average percentage to analyse power loss throughout battery packs. This is considérable since this present rate inside a charger can differ drastically, particularly in uses like electric cars or power system storage solutions, where the charger is exposed to differing loads as well as usage. Evaluating the allocation of present rate inside the charger over a moment is the numerical technique employed to calculate the impact that differing today's costs on average battery life. This lets investigators detect sequences of events inside the capacitors usage and create more précise models to forecast its behaviour over time.

3.3 A Capacitive Framework

The topic of this research revolved around the capacity of battery packs rather than energy storage devices. Since it was expected that now the controller's capacitors would have a substantially longer life time than just the batteries, power fading wasn't really taken into considération. A basic model thereby présuppose the energy storage might be expressed as a connected in series of a resistor as well as a capacitive banks was employed to simulâtes the behaviour of the capacitors. Furthermore, it was présumâtes that its DC/DC converters effectivités between both the capacitors as well as the DC source was a specific number of 0.95.

$$x_o = [x_{o,min}:(x_{o,max}-x_{o,min})/(N_{dis}-1) : x_{o,max}] \tag{9}$$

$$P_{dem} = (\frac{1}{2} \rho C_d A v^2 + f.m_v g + m_v.a).v \tag{10}$$

A numerical method that depicts a super capacitor behaviour is the recurrent capacitive framework. The sum of both the voltage that opens the circuit with one capacitors (V_{c*}) and the entire amount of banks (N_{sc*}) yields the overall expansive value of the capacitive pack, represented by V_{ct*}.This effect of the product is an approximation of the overall output waveform of the capacitive pack under the assumption that almost all banks behave uniformly. The series resistance of one capacitors (R_{sc*}) multiplied by the entire quantity of banks (N_{sc*}) yields R_{sct*}, which stands for the given total resistor of the capacitive pack and represents the period at stage k+1. An approximation of the capacitive pack's overall resistance is given by this solution. Preqsc* stands for the motivated individual from the capacitors, while dc represents the performance of the DC/DC converters. The ability of the entire capacitive pack, denoted by the symbol C_{sct*}, is determined by dividing the capacity of each individual account, C_{bank*}, through the sum of all the banking systems, N_{sc*}. An estimation of the capacitive pack's overall ability to store energy is given by this equation. The aim of this process potential of a capacitive pack was marked by V_{ct*}max, as well as the capacitive pack's level of charge is shown by x_{SOE*}. These variables play a crucial role in deciding how well the capacitive pack performs and behaves in terms of storing and delivering energy. A technique is used to calculate the capacitive pack's overall energy output.

$$P_{sc} = V_{ct}.\frac{V_{ct} \pm \sqrt{V_{ct}^2 - 4R_{sct} P_{reqsc/\eta AD\eta_{dc}}}}{2R_{sct}} \tag{11}$$

4 Integrated FIE Based On FLC

A suggested fuzzy system controller (FLC) with if-then rules, unsupervised learning, fuzzy reasoning engine, and fuzzified modules, among other important parts. Its FLC has been built on a foundation of if-then rules, which are intended to plot input data to output results using a list of rules that are fuzzy. The fuzzified function transforms the source parameters into a consist of representation that illustrates the potential for every input factor to be a part of the connected fuzzy set. A fuzzy result is generated whenever the fuzzy inference framework processes the terms and if constraints. Its fuzzy inference framework's components then alter the fuzzy result to generate crisp values. The fuzzy logic controller, also known as a "recursive the "fuzzy inference system" uses a set of guidelines for making a judgment depending on input parameters as shown in figure 3. It makes optimal utilisation variable length processing to handle several input parameters at once, enabling the implementation of intricate choice procedures. Fuzzy logic, as a conceptual structure that works with imperfect and ambiguous input, is used by the method and also is ideal for quasi systems having complicated behaviour. The floating - point technique enables parallel processing, which makes it especially beneficial in implementations where rapidity and precision are crucial.

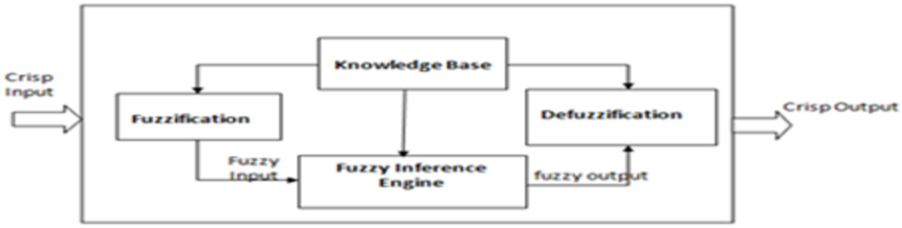

Fig. 3. Uncertainty inference system.

4.1 Fuzzy Rules

An important element of systems that utilize fuzzy logic is fuzzy régulations, which are if-then expressions that detail the connection between both relevant variables. Those rules specify the extent to which an input variable belongs to a particular crisp system in order to reflect the ambiguous or ambiguous character of actual situations. Using expertise or statistics strategies like learning algorithms, the norms can be created. The implementation being represented, as well as the information or data at hand, influence the quantity and design of the rules. The implementation being represented, as well as the information or data at hand, influence the quantity and design of the constraints. A controller that employs fuzzy logic (FLC) uses linguistic if-then expressions to convey the conditional interactions inside the controller, and fuzzy sets are such a crucial component of an FLC. If the needed power (P_{req*}) is positively high, its state of vitality is positively high, as well as the charge condition is high, therefore the capacitive power (P_{sc*}) is positively huge. It makes sense to apply the same conditional statement rules for combination energy storage devices (HESSs) of various sizes because their controls are frequently the same. In this scenario, labels just like N, P, S, M, and B, which stand for positive, optimistic, short, moderate, and huge, consecutively, are used to illustrate the created fuzzy sets. The fuzzy proposal's main goal is to increase the quantity of energy recovery power consumed while minimising the negative effects of high maximum output here on batteries by using the energy storage system as a buffer. The Controller can properly handle the flow of energy as in HESS and meet the necessary control goals in practical uses by integrating these fuzzy sets.

4.2 Membership Roles

A fuzzified function corresponds to a numerical methods characteristic that assigns a membership level to a given value in such a fuzzy system. A fuzzy set role is a type of numerical method expression. In systems that use based classification logic, fuzzy rules are employed to represent uncertainty or ambivalent ideas, and linear models play an important role in establishing the limits of these pairs. Thus every input variable is mapped to an attribute value, which reflects the degree whereby the input signal belongs towards the fuzzy system. The similarity measure can have a variety of shapes, including triangle shaped, trapezoidal, Generalized linear, and unimodal. The algorithm used is influenced by the application as well as the condition of such variables being modelled. Its trapezoidal membership operation is defined by four variables: its left as well as right shoulders, its left but also right bases. Because it can prototype both asymmetrical and symmetrical subsets, the trapezoidal predicate is a great option for just a variety of uses. Furthermore, the trapezoidal membership operation could be easily changed and changed to meet the specific needs of a given system. The fuzzification engine could indeed fully capture the uncertainty and ambiguous condition of practical cases by utilising the trapezoidal equation, leading to enhanced control efficiency and improved ruling processes. Several restrictions are built into the FLC-based EMS utilized in this structure in order to regulate the behaviour of the super - capacitors as well as battery pack. For example, the super capacitor’s status of energy (SOE) as well as current is limited to values within 0.1 and 0.99, as well as -2000A but also 2000A, respectively. Likewise, the lithium-ion device's status of charge (SOC) is limited within 0.2 but 0.9, as well as the current is managed by regulating the needed power from the battery. If indeed the lithium-ion battery runs out during simulations, the iteration is ended and the optimization techniques are evaluated. These limits contribute to the hybrid power storage devices proper functioning and security. The inter optimisation problem in eV race car designs is a difficult one to solve, although it is doable with modern techniques like NSGA-II.

5 Results

The study presents a detailed analysis of the results obtained from the multi-objective optimal sizing and control of a Hybrid Energy Storage System (HESS). Figure 4 illustrates the outcomes achieved when the total mass of the HESS is limited to 320 kg and the capacity loss is evaluated using the average current. The optimization process involved a total of 1839 iterations, which corresponds to approximately 0.92 million evaluated solutions. Each solution presented in Figure 4 is associated with specific design and control parameters. From a sizing perspective, the number of supercapacitors employed in the HESS influences the trade-off between high power density and high energy density. As shown in Figure 4, incorporating more supercapacitors reduces the average current flowing through the lithium-ion battery, which contributes to an extended cycle life but results in decreased energy density and, consequently, shorter driving mileage. Conversely, using fewer supercapacitors yields contrasting outcomes. Additionally, Figure 4 reveals that HESS configurations with the same design solutions (marked with the same color) may attain different values for both objective functions. This observation indicates that achieving Pareto optimal solutions for the same HESS, governed by uniform fuzzy rules, relies on appropriately determining the membership function parameters.

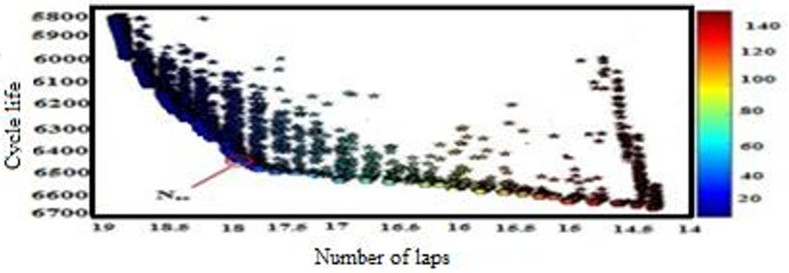

Fig. 4. If mHESS = 320 kg, inter sizing as well as control solutions are required.

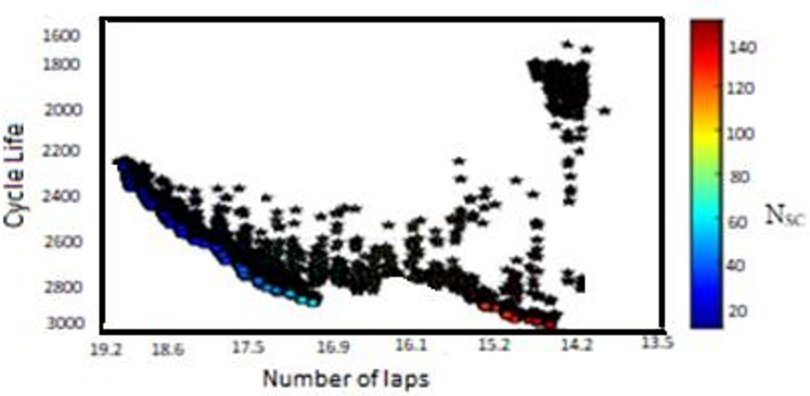

Fig. 5. The mass of the HESS is 320 kg, non-uniform C rate can be used to find Pareto solutions

In the proposed bi-level optimal sizing and control framework, the sizing parameter Nsc for each HESS and the membership function parameters xmf for the associated Energy Management System (EMS) are coupled and obtained concurrently for all solutions, including those on the Pareto front. Figure 5 displays the application of a statistical method to estimate the impact of non-uniform current rates on battery cycle life. The estimated battery cycle life ranges from 1717 to 2984. Notably, the utilization of 50 supercapacitors in the HESS leads to a 27.5% enhancement in battery cycle life. Figure 6 provides a comprehensive demonstration of the improvements in available battery cycle life achieved through the optimization of the membership functions of the Fuzzy Logic Controller (FLC)-based EMS, illustrating the benefits in detail in figure 6. The present study focuses on the analysis of optimal sizing and control outcomes for Hybrid Energy Storage Systems (HESSs) with varying total mass. By examining Figure 7, several key observations can be made : 1) HESSs with lower total mass exhibit reduced coverage of available laps, but offer extended battery cycle life due to their shorter operating mileage ; 2) It is feasible to attain a favorable compromise solution by utilizing approximately 40 supercapacitor banks along with optimized membership functions, thereby improving both objective functions effectively.

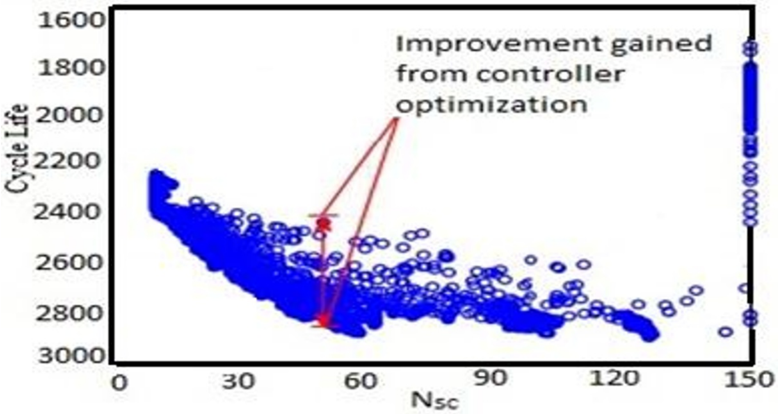

Fig. 6. The enhancement of battery cycle life is achieved through the optimization of the Fuzzy Logic Controller (FLC) based Energy Management System (EMS).

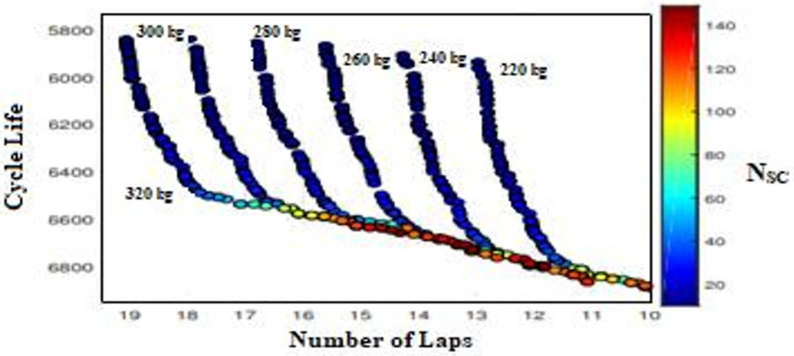

Fig. 7. Pareto optimal solutions for Hybrid Energy Storage Systems (HESS) considering varying mass values (mHESS).

6 Conclusion

Raising the amount of super capacitors could not always result in improved performance, especially if the amount of something like the mixed energy storage system has been limited mostly by the super capacitor's low energy density. Despite its great energy output, capacitors can quickly run out of charge. The proposed optimisation framework, we were able to obtain this well performance with fewer capacitors as well as an efficient power management platform. The Bi-level optimal scaling and management approach used in this investigation allows the optimisation algorithm to explore for both planning and controlling parameters at the same time, making it easier to find globally optimum solutions. The suggested optimization framework's Pareto approach allows users to choose their favourite size solution by striking equilibrium between the two outcomes. Mostly on Pareto front, the resulting optimal solutions sizing variables and genuine controller variables can be immediately utilised in real-world applications. Furthermore, the vector representation fuzzy intelligence system created in this paper can be used to a variety of actual feedback control issues, improving computing efficiency and enabling the optimisation for fuzzy logic system settings. This means that the approach is applicable not just to HESS however to other fields.

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