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Review on Hybrid Energy Storage System for Electric Vehicle

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Abstract— *The electricity garage is the coronary heart of electrical cars, which determines efficiency, electricity, and using range, etc. The call for of present day electric vehicles requires the ESS to maintain high power density, together with the high height power. In recent times, batteries and super capacitors, that can supply energy and power capability respectively, are used because the ESS in industrial practice. Hybridization of them, the hybrid energy garage device (HESS), will take their individual blessings, for this reason providing a huge burst of present day and storing enough strength to ensure a sufficiently long riding range. This paper opinions the country of generation for batteries, super capacitors, and the HESS. Numerous structures and topologies of HESS are discussed, and manage strategies are investigated.*

Keywords: Battery, super capacitor, hybrid energy storage System, electric powered vehicle, manage.

1. Introduction

The electricity storage system (ESS) has been an emerging area for ensuring a hit software of electrical vehicles (EVs). The price and riding performance of EVs especially rely upon the functionality and efficiency of the ESS, that may maintain a big amount of electricity, at the side of the functionality of responding immediately to the weight call for. In general, the primary requirements for an ESS consist of energy density, power density, charging speed, life expectancy, cost, weight, and length [1].currently, batteries and super capacitors continue to be as the main options for ESSs. Batteries have high energy density, noticeably low cost in line with watt-hour, however low unique electricity, and short cycle lifestyles; whilst super capacitors preserve high height power, lengthy cycle lifestyles, but pretty low electricity density, and high cost per watt-hour [2]. Manifestly no unmarried energy storage tool ought to fulfill all of the requirement stated above. but, combining the two, a hybrid electricity storage system (HESS), can doubtlessly overcome the drawbacks of each single power garage tool [3]. Even though sounds promising, unique consideration need to be taken under consideration when it comes to physical device consciousness [4], [5]. Mounting studies has been devoted to research the most appropriate structure and topology for HESSs.

Solutions vary concern to the requirement on system complexity, flexibility and price [1], [6]. Generally while integrating an HESS, controllers are utilized to manage the energy flow. Efficient algorithms or control techniques are hard to gain the ultimate overall performance [7]. This paper critiques the kingdom of the artwork of battery, super capacitor, and battery-super capacitor HESS for superior electric car applications. The control methods for the HESS are mentioned.

The relaxation of the paper is prepared as follows: Sections II and III gift the existing battery and super capacitor technology for automobile packages, respectively. Sec-tion IV addresses the battery-super capacitor hybrid energy storage machine, with emphasis at the topological shape. Segment V is devoted to introducing the control strategy and set of rules for the HESS. Sooner or later, conclusions and future studies guidelines are summarized in section VI.

II. BATTERIES FOR ELECTRIC POWERED CARS

Growing excessive-performance rechargeable batteries for electric cars is tough due to the need to meet a couple of battery necessities: excessive strength density, excessive power, safety, long life expectancy, low price, low resistance, and minimal environmental effect [8].

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Lead-acid batteries have been first of all used in advance hybrid electric powered vehicles (HEVs) and EVs (e.g., GM EV1) [9], [10]. However, the driving variety become no longer quite high-quality due to the inadequate energy density, which had additionally confined its marketplace acceptability. Ever due to the fact that then, mounting research has been centered at the improvement of better precise electricity batteries. NiMH batteries quick became the technology of choice for the emerging HEV market. Main automotive businesses which include Daimler Chrysler, Ford, GM, Honda and Toyota, have developed HEVs with NiMH batteries on board [10].

Despite the fact that NiMH battery holds approximately twice the energy density because the conventional lead-acid battery, its performance, in conjunction with the fantastically excessive fee, are still some distance from sat-is faction. Inside the beyond decade, researchers have became their pursuits into Lithium-ion generation. Lithium ion batteries have higher energy density than some other kind batteries, roughly two times as a great deal strength density as NiMH batteries. It's been extensively used in cell telephones, laptops, and many different mobile gadgets. The capability of storing excessive strength and its rather low value make the improvement of industrially produced EVs possible [9]. However, to fully satisfy the wishes of heavily produced EVs, new technologies need to be evolved for Lithium-ion batteries to similarly boom the electricity storage and charging/discharging abilities. In addition, the battery cycle lifestyles ought to be lengthened without sacrificing the value [11].

III. SUPERCAPACITORS FOR ELECTRIC POWERED AUTOMOBILES

Lately, another energy garage tool, the super capacitor, that is quite specific from batteries in phrases of electrical traits, demonstrates its advantage in electric vehicle packages further, special hobbies have to be centered on greater correct prediction of destiny electricity demand via combining actual-time data (e.g., site visitors, terrain) and historic driving facts, in order that higher electricity control could be achieved to improve the overall performance of HESSs.

Fig. 1. LS Mtron's cylindrical and prismatic super capacitors [13]

often does no longer allow sufficient energy densities to fulfill the call for of big electricity pulses at a rather low financial, volumetric and weight value [15]. They do now not deliver as immediate fee/discharge competencies as super capacitors. The rather lengthy charging time has a tendency to be a vital issue. Further, the existence expectancy of batteries is shorter, specifically while they are cycled at tremendously high price/discharge fee. Such immoderate usage of batteries can also probably motive protection problems due to overheat. Therefore, battery packs in commercialized electric powered motors are generally outsized to accommodate the large strength call for and hired with advanced cooling structures to make sure battery existence. Super capacitor, also called the ultra capacitor, is a form of electrochemical capacitors (proven in discern 1). It differs from traditional capacitors in each the electrolyte and electrode design. In a super capacitor, there's no conventional stable dielectric. on the contrary, electric powered electricity storage is performed by the electrostatic double-layer capacitance or electrochemical pseudo capacitance. The previous is a result of separation of double layer fee on the interface between a conductive electrode and an electrolyte when the voltage is carried out, while the running mechanisms of pseudo capacitors are redox reactions, inter-

collation and electro sorption [14]. Super capacitors are plenty quicker to price than batteries. They outperform batteries also due to their strong electric properties, broader temperature range and longer lifetime.

Super capacitors were first of all added inside the early Seventies to provide backup energy for pc memory. After years of evolution, it's far then extended to various programs, e.g., locomotives, defibrillators, buses, Wi-Fi operations, etc. However, due to its low electricity density, the main objective of utilizing super capacitors nevertheless remains as buffering energy to and from rechargeable batteries, mitigating the consequences of top electricity and brief interruptions because of their high unique power and fast charging/discharging price. Such characteristics could also basically make sure a a success utility of super capacitors in electric vehicles, wherein rechargeable batteries are the primary strength storage device.

IV. BATTERY-SUPERCAPACITOR HYBRID POWER STORAGE GADGET

The energy supply is the heart of an electric powered vehicle. Batteries nonetheless continue to be the number one electricity sources for electric cars, since they have a fantastically excessive power density, as shown in desk I. however, the advanced battery generation instantaneous charge/discharge capabilities as super capacitors. The tremendously long charging time tends to be a critical issue. In addition, the life expectancy of batteries is shorter, especially when they are cycled at relatively high charge/discharge rate. Such excessive utilization of batteries could also potentially cause safety issues due to overheat. Therefore, battery packs in commercialized electric vehicles are typically oversized to accommodate the large power demand and employed with advanced cooling systems to ensure battery life.

TABLE I
PERFORMANCE COMPARISON BETWEEN BATTERIES AND SUPERCAPACITORS [16]

Property	Supercapacitors	Batteries
Charge/Discharge Time	Milliseconds to Seconds	1 to 10 hrs
Energy Density	1 to 5Wh/kg	8 to 600Wh/kg
Pulse Load	up to 100A	up to 5A
Life Expectancy	10 years	3 years

Super capacitors, characterized by way of large electricity density (approximately 5-10kw/kg [17]), may want to offer high peak cutting-edge (as much as 100A) almost right away with high efficiency, which activates acceleration and regenerative braking and decrease charging time considerably [18]. This appears to be an answer to triumph over the electricity deficiency and charging inefficiency of batteries. But, the super capacitors cannot store lots electricity. Conversely, the battery can shop mass quantity of electricity. However, without immoderate utilization or over sizing of components, a battery pack cannot supply as plenty immediately strength as super capacitors. Consequently, a promising solution seems to integrate batteries with super capacitors forming an HESS, which can deliver a huge burst of contemporary and additionally save sufficient electricity to make sure a sufficiently long riding range.

Because of the excessive unique power of super capacitors, hybridizing super capacitors with batteries will reduce the pressure on the battery pack and probably enhance acceleration and hill mountain climbing performance. Super capacitors also can assist the battery in taking pictures power from regenerative braking with their fast charging functionality. Further to power performance and vehicular overall performance, length and fee of electricity storage devices are predominant issues currently in enterprise packages. Take a natural electric powered car as an example. Tesla Roadster weighs 2690 kilos whilst more than 900 pounds weight comes from the battery pack [19]. adding a splendid-capacitor financial institution can compensate such an difficulty and offer extra flexibility in distributing size and weight for each electricity storage device in the design section, in order that the favored storing and peak contemporary traits may be achieved. With this being stated, it has been observed that the HESS constructed from two 18650- cell lithium-ion batteries and two a hundred-F ultra capacitors achieves a height electricity of 132W, that's a seven instances improvement as as compared to the lithium-ion cells alone [20].

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There has been mounting studies on investigating the foremost topology or structure of the HESS (see certain evaluations in papers [1], [4], [5], [6], [7]). To be had answers range in terms of flexibility, complexity and fee. In standard, the shape of the existing HESS may be categorized into sorts: the passive HESS and the lively HESS, every of which has several sorts of topologies.

A. Passive HESS

The consultant feature of a passive HESS is the direct aggregate of the battery and the super capacitor in parallel. As shown in figure 2, the battery is first off linked to the super capacitor, and then connected to a DC/AC inverter to deliver power to the traction motor. Because of the direct connection, the terminal voltage of the battery and the super capacitor will maintain exceedingly regular, as a result imposing high risk of destructive battery if a right away electricity is required from the traction motor. To resolve this issue, a DC/DC converter is inserted between the energy garage bank and the DC/AC inverter, shown in figure 3 to make certain both the battery and the super capacitor function in the secure variety [21].

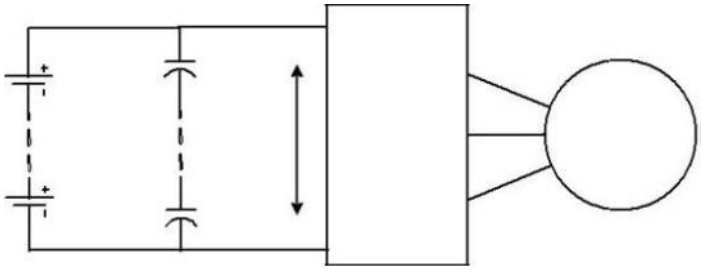

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Fig. 2. Simple passive configuration

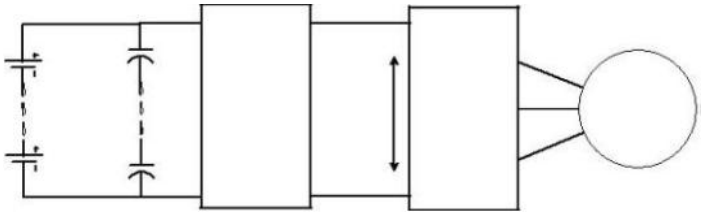

Fig. 3. Passive configuration with DC-DC converter

The advantages of the mentioned passive topologies include ease of implementation in the HESS and no hard control devices needed. The major restriction of the passive structure exhibits in managing the power flow. Due to fact that the battery and the super capacitor have the same power, the power distribution ratio between the super capacitor and battery only depends on their internal resistances [7]. Hence, the advantages of the super capacitor and battery are not effectively utilized. Therefore, passive structures are not applicable when flexible and efficient power management is needed.

B. ACTIVE HESS

Compared with the passive HESS, an energetic HESS requires more sophisticated strength digital converters and controllers for batteries and super capacitors. The controller may be programmed in step with certain techniques or algorithms, permitting the HESS to function with greater flexibility. Fig. 4 indicates the topological diagram of the super capacitor/battery configuration. Unlike the direct connection of the battery and the super capacitor within the passive HESS, a DC/DC converter is inserted in among as an interface, permitting the super capacitor to characteristic in a extensive range of voltage [18]. But, the voltage of the battery nevertheless remains steady due to the direct hyperlink with the DC/AC inverter. Glaringly, there is a comparable problem for the battery as within the passive HESS, since it is not covered correctly with the aid of any DC/DC converters. A change topology, with the super capacitor and the battery swapped, should probably clear up the issue. As shown in fig. 5, the strength waft of the battery could be maintained in the safe range by using the DC/DC converter and the super capacitor acting as an power buffer [20]. Though, the operating variety of the super capacitor is limited because of the direct hyperlink with the DC/AC inverter.

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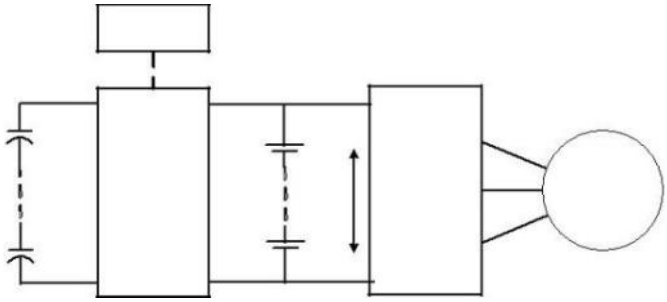

Fig.4. Super capacitor battery configuration

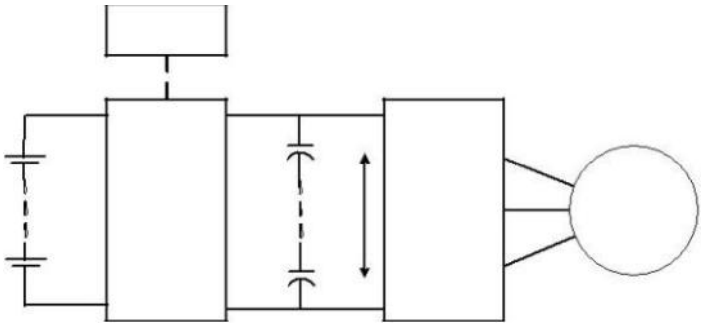

Fig. 5. Battery super capacitor configuration

To completely make use of each the super capacitor and the battery, DC/DC converters are hired to shape a cascaded topology as defined in fig 6. The DC/DC converter between the super capacitor and the DC/AC inverter can growth the super capacitor's buffering capability. rather than cascaded connection, the battery and the super capacitor might be connected to the DC/AC inverter and completely managed with the aid of a DC/DC converter in my view [7], [23], [24]. The topology is proven in parent 7. This structure exhibits the advantage in controlling the cutting-edge glide due to the parallel connection. In addition, it increases the ability of the HESS, permitting the system functioning in various modes [25]. But, the price for realizing such topology is extraordinarily better as compared to the aforementioned topologies.

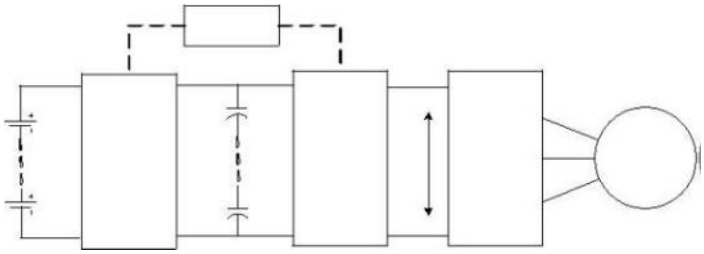

Fig.6. Cascaded configuration

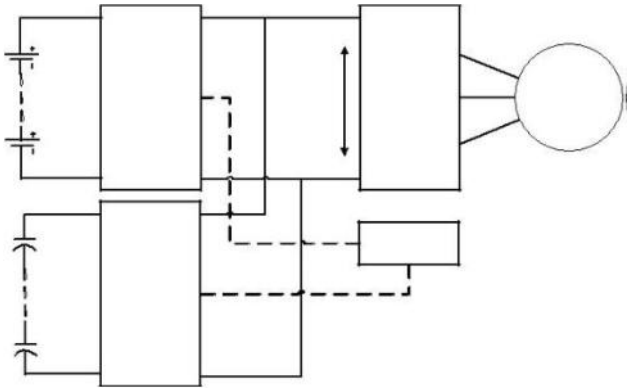

Fig.7. multiple converter configuration

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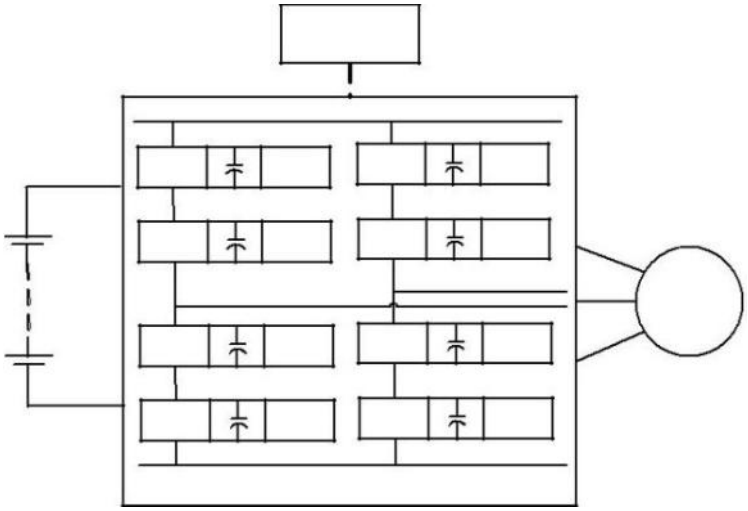

Fig. eight. Modular multilevel configuration

Lately, a new battery/ultra capacitor converter primarily based on a modular multilevel topology is introduced [26], as proven in figure eight. in preference to a regularly occurring DC/DC converter to fully control the complete super capacitor bank, DC/DC converters are modularized in distinctive tiers, associated with each character super capacitor. The Foremost benefit lies within the adaptability to one-of-a-kind voltage and power stages. In addition, this kind of attention outperforms different structures in failure management because of a couple of modules. But, the modularized multilevel structure increases the machine complexity, as a result making it hard and pricey to construct in practice.

V. MANIPULATE STRATEGY FOR HESS

All the active HESSs added above could find their applicability. To ensure a a success software of the HESS in electric cars, management of electricity drift, i.e., constructing up the controllers, is the key for a given bodily system of the HESS. premier use of the super capacitor financial institution and the battery pack calls for an green energy waft controller among the two energy garage subsystems. The efficiency of controllers is decided through each reliable bodily digital gadget and strong manipulates algorithms constructed into the controller. This phase discusses the state of-the-artwork algorithms and techniques in growing controllers.

The algorithms or strategies are used to decide the proportion of strength call for within the HESS at positive immediate. They ought to be developed with the intention of completely using each character strength storage subsystem's benefits. In widespread, the targets that an powerful manage approach or algorithm should reap include at least one of the following [24]: Maximize driving range; Minimize component stress; Maximize life expectancy of the HESS; Fulfill immediately load demand; Control power flow for destiny call for optimally.

More frequently than now not, a couple of targets are concerned in constructing the manipulate algorithm. The running principle is to keep the battery current as constant as feasible at some point of the transient demand to ease the battery pressure, accordingly extending the driving variety and improving device lifetime. Meanwhile, the super capacitor, acting as an auxiliary energy source, must help the battery through managing massive modern-day bursts and top strength demand without exceeding the maximum capability [3]. This may probably manifest throughout regenerative breaking, acceleration, and fast charging, and so forth. Despite the fact that the standards seem sincere, issue arises in lots of approaches in phrases of implementation in Practice, which ends up in mounting research efforts devoted to this vicinity. up to now there may be no established approach to the manage strategy. The techniques to the hassle can be roughly divided into categories based totally on whether or not demand prediction is incorporated or no longer.

A. control without demand Prediction

Most of the prevailing algorithms belong to this category. Based at the bodily specification (e.g., state of charge, internal resistance, etc.) and records facts (e.g., speed, driving profile, and so forth.), one could develop analytical manipulate mechanisms with recognize to unique targets. In widespread, the most reliable manage on this class handiest relies upon at the country of individual electricity garage devices, and the history and current vehicle dynamics, since the destiny load call for is difficult to are expecting. The algorithms or techniques up to now include both deterministic and non-deterministic algorithms.

1) Deterministic Algorithms: Deterministic algorithms reflect the basic precept of controlling power flow within the HESS. Commonly, records about the driving pattern are needed for proper control, in conjunction with the device structure, and electrical specifications of each aspect or equivalent circuit models [27]. The manage coverage has a tendency to be intuitive and easy to put in force. For example, paper [17] provides a look-up table strategy to decide the proportion of strength drift in and out of every man or woman power garage device. Meanwhile, due to the lack of prediction, the immediately pace is a crucial reference for distributing energy float. Paper [28] develops a control policy to make sure that the super capacitors are properly charged for the viable upcoming acceleration when journeying at sluggish speed. Conversely, whilst the vehicle is going for walks at high velocity, the ultra capacitors are sufficiently discharged in preparation for a destiny regenerative braking event. The main gain of these kind algorithms is that they're easy to implement and computationally green. However, complete information of the physical gadget is typically needed, together with thoughtful anticipation of diverse eventualities in order to make certain a robust manipulate method.

2) Non-deterministic Algorithms: Non-deterministic algorithms include stochastic strategies, heuristic algorithms and optimization techniques at the intention of optimally controlling each man or woman strength supply. For instance, paper [29] adopts the idea of neural networks and develops an green energy-control system for the HESS in hybrid electric automobiles. Such analytical techniques are commonly expressed in closed mathematical paperwork. Paper [22] offers an optimization framework for computing the sub-superior contemporary glide of the HESS in electric automobiles by means of incorporating the vague load profile. Inspired via electricity structures optimization, paper [30] introduces a new predictive set of rules the usage of probability weighted Markov method to determine the energy sharing in actual time. A comparable model predictive manages system for the HESS is proposed by way of paper [2].

These algorithms normally do not want any prior records about the using profile. But, the overall performance may additionally vary depending at the precise driving pattern and records facts used for schooling. Consequently, the real optimality may not be assured to acquire.

B. control with demand Prediction

Future load profiles can be used to achieve top-quality control of the cutting-edge float in comparison with those without demand prediction. But, the accurate load profiles/demand pre-diction might not be clean to reap because they depend on many factors, e.g., the road circumstance, visitor's density, and velocity and the driving sample of a specific driving force. The state of affairs may be changed by using the use of onboard GPS and terrain information, actual-time and historic visitors and riding facts, and superior modeling strategies. In different words, if the destiny driving situations are acknowledged, one ought to attain the essential information to expect energy call for based totally on the vehicular dynamic equations.

1) Riding circumstance Prediction: visitors float models or site visitors forecasting methods may be used to anticipate riding circumstance in the future (generally within a determined range). In popular, traffic goes with the flow models are categorized into 3 stages: macroscopic level, microscopic level, and microscopic level, in keeping with the extent of info representing the visitors systems [31]. Similarly, the predictions of destiny using situations are also categorized into three tiers: macroscopic stage, microscopic stage, and microscopic stage.

Macroscopic degree visitor's models describe the average behavior of the traffic, e.g., visitor's density, visitor's extent, and traffic velocity [32]. Macroscopic degree refers to the using conditions in close to future with a horizon around 30-three hundred seconds [33], at the same time as the microscopic stage models forecast the using situations surrounding a automobile which include pace limits, stop signs, upstream site

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visitors, and preceding automobile condition with a prediction horizon round 10-30 seconds [34], [35], [36]. The microscopic visitor's model ought to seize the brief and fast dynamics, which makes it promising for electricity demand prediction.

2) DEMAND FOR PREDICTION: This component explains the way to make electricity demand prediction for an HESS given the expected riding situations. According to basic physics ideas, the asked energy Preq can be expressed as [37]

$$P_{req} = F_{res}\ v_{veh}$$

Where F_{res} is the riding resistance pressure (N), and vive is automobile pace (m=s). Here the riding resistance pressure F_{res} is the combination of aerodynamic drag pressure F_{aero}, rolling resistance pressure F_{roll}, climbing force F_{climb} and acceleration preliminary pressure F_{acc}.

The aerodynamic drag force is because of the drag upon car body when transferring through air, which is a feature of the aerodynamic drag coefficient, air density, and the frontal place. The rolling resistance force is usually generated because of the deformation at the wheel and road floor, that is closely depend upon vehicle mass and road floor situation. Further, the hiking force is depending on the car mass and the angle of incline. Sooner or later the acceleration initial force is a characteristic of the automobile mass, acceleration, and the correction coefficient of rotation mass.

By means of combining all of the above equations and considering the performance of drive train $_T$, motor $_{mc}$ and brake $_{bra}$, the load energy P_{load} ,that a car want to overcome (kW), can be basically represented as:

$$P_{l\epsilon} = \begin{cases} P_r = T_m\ ; & i\imath\ P_r > 0 \\ P_r = T_b\ ; & i\imath\ P_r < 0 \end{cases}$$

on this feel, the destiny load demand is essentially a feature of driving related parameters which include the anticipated pace and acceleration, and terrain statistics, e.g., attitude of incline, and so on. Onboard navigation and sensor structures should potentially offer correct prediction of slope records within a determined range. the rate and acceleration prediction may be acquired through visitors glide fashions said in the preceding subsection, together with the GPS, real-time traffic records, and historical riding sample.

VI. CONCLUSIONS

Hybrid power garage machine has been proved to be a promising solution for the strength concern of electrical vehicles with single electricity garage device. at the same time as batteries and super capacitors in my view can't meet all of the necessities for electric powered automobiles, the HESS may want to supplement their drawbacks. special HESS systems and manipulate techniques had been addressed in the paper. To make the HESS more aggressive, future studies efforts need to be committed to decreasing the price and increasing the capability and efficiency of batteries and super capacitors, along with their HESS, by using introducing evolutional substances and transformational power electronics. further, special pastimes should be targeted on extra correct prediction of future power call for through combining real-time records (e.g., traffic, terrain) and historical using facts, in order that higher electricity manipulate might be accomplished to enhance the performance of HESSs.

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