A Review on Optimization and control algorithm of storage array used for E Vehicle

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Abstract - In recent years, the oil consumption for transportation has grown at a higher rate. Statistical analysis has shown that, discovery of new oil reserves and the current consumption rate, research says the world oil reserve will be depleted by 2049 [1]. The massive utilization of Internal Combustion Engine (ICE) vehicles has contributed dramatically to the pollution of the medium and large cities [2].The environmental problems of the greenhouse effect and global warming are directly related to vehicle emissions, government agencies and organizations have developed stringent standards for fuel consumption and emissions [3]. In this scenario, battery powered Electric Vehicles (EVs) seem like an ideal solution to deal with the energy crisis and global warming since they have zero oil consumption and zero emissions on the road. The zero local emissions and the silent driving of the electric vehicles are few attributes that can help to restore the quality of life in cities [2]. Given the short range trips and frequent stop and go driving characteristics of city driving, electric vehicles can deliver performance similar to an ICE vehicle at reduced costs compared to conventional gasoline engine vehicles under city driving [2,4]. This paper is focused on reviewing all the useful data available on EV configurations, battery energy sources optimization techniques, impacts, trends, and possible directions of future developments. Its objective is to provide an overall picture of the current BEV technology and ways of future development to assist in future researches in this sector.

Key Words: Electric vehicle, Batteries, optimization techniques, Trends and future developments, control algorithms

1. INTRODUCTION *(Size 11, Times New roman)*

Lot of barriers to EV adoption although electric vehicles offer a lot of promises, they are still not widely adopted, and the reasons behind that are quite serious as well.

Technological Problems

The main obstacles that have frustrated EVs' domination are the drawbacks of the related technology. Batteries are the main area of concern as their contribution to the weight of the car is significant. Range and charging period also depend on the battery. These factors, along with a few others, are demonstrated below:

1. Limited Range

EVs are held back by the capacity of their batteries [5]. They have a certain amount of energy stored there, and can travel a distance that the stored energy allows. The range also depends on the speed of the vehicle, driving style, cargo the vehicle is carrying, the terrain it is being driven on, and the energy consuming services running in the car, for example air conditioning. This causes 'range anxiety' among the users [10], which indicates the concern about finding a charging station before the battery drains out. People are found to be willing to spend up to $75 extra for an extra range of one mile [14]. Though even the current BEVs are capable of traversing equivalent or more distance than a conventional vehicle can travel with a full tank range anxiety remains a major obstacle for EVs to overcome.

2. Long Charging Period

Another major downside of EVs is the long time they need to get charged. Depending on the type of charger and battery pack, charging can take from a few minutes to hours; this truly makes EVs incompetent against the ICE vehicles which only take a few minutes to get refueled. A way to make the charging time faster is to increase the voltage level and employment of better chargers. Some fast charging facilities are available at present, like Fuel cell vehicles (FCVs) need sufficient hydrogen refueling stations and a feasible way to produce the hydrogen in order to thrive.

3. Safety Concerns

The concerns about safety are rising mainly about the FCVs nowadays. There are speculations that, if hydrogen escapes the tanks it is kept into, can cause serious harm, as it is highly flammable. It has no color either, making a leak hard to notice. There is also the chance of the tanks to explode in case of a collision. To counter these problems, the automakers have taken measures to ensure the integrity of the tanks; they are wrapped with carbon fibers in case of the Toyota Mirai. In this car, the hydrogen handling parts are placed outside the cabin, allowing the gas to disperse easily in case of any leak, there are also arrangements to seal the tank outlet in case of high-speed collision [16].

4. Social Problems

Social Acceptance:

The acceptance of a new and immature technology, along with its consequences, takes some time in the society as it means change of certain habits [17]. Using an EV instead of a conventional vehicle means change of driving patters, refueling habits, preparedness to use an alternative transport in case of low battery, and these are not easy to adopt.

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Insufficient Charging Stations

Though public charging stations have increased a lot in number, still they are not enough. Coupled with the lengthy charging time, this acts as a major deterrent against EV penetration. Not all the public charging stations are compatible with every car as well; therefore it also becomes a challenge to find a proper charging point when it is required to replete the battery. Tesla and Nissan have been expanding their own charging networks, as it, in turn means they can sell more of their EVs. Hydrogen refueling stations are not abundant yet as well. It is necessary as well to increase the adoption of FCVs. In [18], a placement strategy for hydrogen refueling stations in California is discussed.

5. *Economic Problem*

The price of the EVs is quite high compared to their ICE counterparts. This is because of the high cost of batteries [10] and fuel cells. Mass production and technological advancements will lead to a decrease in the prices of batteries as well as fuel cells. Figure 1 shows the limitations of EVs in the three sectors. Table 1 demonstrates the drawbacks in key factors, while Table 2 suggests some solutions for the existing limitations.

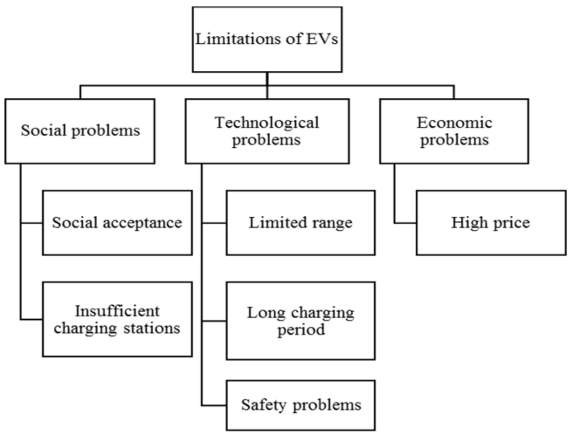

Figure 1. Social, technological, and economic problems faced by EVs.

Table 1. Hurdles in key EV factors. Adapted from [20].

Factor	Hurdles
Recharging time	Weight of charger, durability, cost, recycling, size, charging
Hybrid EV	Battery, durability, weight, cost
Hydrogen fuel cell	Cost, hydrogen production, infrastructure, storage, durability, reliability
Auxiliary power unit	Size, cost, weight, durability, safety, reliability, cooling, efficiency

6. *Optimization Techniques*

To make the best out of the available energy, EVs apply various aerodynamics and mass reduction techniques, lightweight materials are used to decrease the body weight as well. Regenerative braking is used to restore energy lost in braking. The restored energy can be stored in different ways. It can be stored directly in the ESS, or it can be stored by compressing air by means of hydraulic motor, springs can also be employed to store this energy in form of gravitational energy [19].

The energy consuming accessories on a car include power steering, air conditioning, lights, infotainment systems etc. Operating these in an energy efficient way or turning some of these can increase the range of a vehicle. LEDs can be used for lighting because of their high efficiency [19].

Table 2. Tentative solutions of current limitations of EVs

Limitation	Probable Solution
Limited range	Better energy source and energy management technology
Long charging period	Better charging technology
Safety problems	Advanced manufacturing scheme and build quality
Insufficient charging stations	Placement of sufficient stations capable of providing services to all kinds of vehicles
High price	Mass production, advanced technology, government incentives

Aerodynamic techniques are used in vehicles to reduce the drag coefficient, which reduces the required power. Toyota Prius claims a drag coefficient of 0.24 for the 2017

II. *Control Algorithms*

Control systems are crucial for proper functioning of EVs and associated systems. Sophisticated control mechanisms are required for providing a smooth and satisfactory ride quality, for providing the enough power when required, estimating the energy available from the on-board sources and using them properly to cover the maximum distance, charging in a satisfactory time without causing burden on the grid, and associated tasks. Different algorithms are used in these areas, and as the EV culture is becoming more mainstream, need for better algorithms are on the rise.

Driving control systems are required to assist the driver especially at high speeds and in adverse conditions such as slippery surfaces caused by rain or snow. Driving control systems such as traction control, cruise control, and different driving modes have been being applied in conventional vehicles for a long time. Application of such systems appeared more efficient in EVs as the driving forces of EVs can be controlled with more ease, with less conversion required in-between the mechanical and the electrical domains. In any condition, forces act on a vehicle at different directions; for a driving control system, if is essential to perfectly perceive these forces, along with other sensory inputs, and provide torques to the wheels to maintain desired stability. In Figure 2, the forces in different direction acting on each wheel of a car is shown in a horizontal plane. In [24], The algorithm had three parts: a supervisory level for determine the desirable dynamics and control mode, an upper level computing the yaw moment and traction force inputs, and a lower level determining the motor and braking commands. This system proved useful for enhancing lateral stability, maneuverability, and reducing rollover. Figure 3 shows the acting components of this system on a vehicle model while Figure 4 shows a detailed diagram of the system with the inputs, controller levels, and actuators. Tahami et al., introduced a stability system for driving assistance for all-wheel drive EVs in [8]. A proportional integral (PI) closed loop control system was used here to monitor the reference steering position. It was achieved by distributing torque at the front wheels. Direct yaw moment control and traction control were also employed to make the differential drive system better.

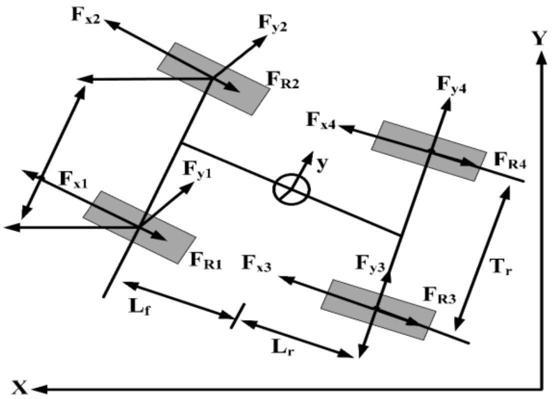

Figure 2. Forces acting on the wheels of a car. Each of the wheels experience forces in all three directions, marked with the ‘F’ vectors. L_f and L_r show the distances of front and rear axles from the center of the vehicle, while T_r shows the distance between the wheels of an axle. Adapted from [8].

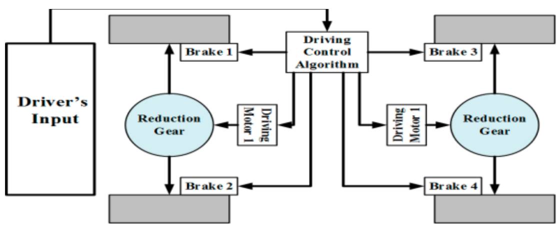

Figure 3. Main working components of the driving control system for four-wheel-drive EVs proposed by Juyong Kang et al. The driving control algorithm takes the driver’s inputs, and then determines the actions of the brakes and the motors according to the control mode [25].

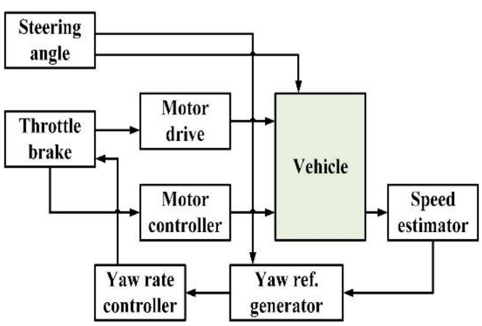

Figure 4. Working principle of vehicle stability system proposed by Tahami et al. A neural network was used in the yaw reference generator [8].

III. *Energy management is a big issue for EVs.*

For vehicles with multiple energy sources (e.g., HEVs), efficient energy management algorithms are required to make proper use of the energy on-board. Zhou et al., proposed a battery state-of-charge (SOC) measuring algorithm for lithium polymer batteries which made use of a combination of particle filter and multi-model data fusion technique to produce results real time and is not affected by measurement noise [27]. They used different battery models and presented the tuning strategies for each model as well. Their multi- model approach proved to be more effective than single model methods for providing real time results. Working principle of this system is shown in Figure 5.

Yuan et al., compared Dynamic Programming and Pontryagin’s Minimum Principle (PMP) for energy management in parallel HEVs using Automatic Manual Transmission. The PMP method proved better as it was more efficient to implement, required considerably less computational time, and both of the systems provided almost similar results [31]. In [32], Bernard et al., proposed a real time control system to reduce hydrogen consumption in FCEVs by efficiently sharing power between the fuel cell arrangement and the energy buffer (ultracapacitor or battery). This control system was created from an optimal control theory based non-causal optimization algorithm. It was eventually implemented in a hardware arrangement built around a 600 W fuel cell arrangement. Geng et al., used an equivalent consumption minimization strategy (ECMS) in [22] to estimate the optimum driving cost. Their system used the battery SOC and the vehicle telemetry to produce the results, which were available in real time and provided driving cost reductions of up to 21.6%.

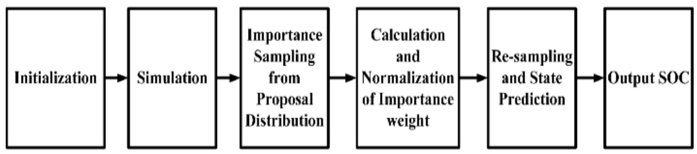

Figure 5. Working principle of the SOC measuring algorithm proposed by Zhou et al. [180].

As pointed out in Section 8, the grid is facing some serious problems with the current rise in EV penetration. Reducing the charging time of the vehicles while creating minimal pressure on the grid has become difficult goal to achieve. However, ample research has already been done on this matter and a number of charging system algorithms have been proposed to attain satisfactory charging performance

The load management system proposed by Deilami et al., in [12] considered market energy prices that vary with time, time zones preferred by EV owners by priority selection, and random plugging-in of EVs—for providing coordinated charging in a smart grid system. It then used the maximum sensitivities selection (MSS) optimization technique to enable

EVs charge as soon as possible depending on the priority time zones while maintaining the operation criteria of the grid such as voltage profile, limits of generation, and losses. This system was simulated using an IEEE 23 kV distribution system modified for this purpose. Mohamed et al., designed an energy management algorithm to be applied in EV charging parks incorporating renewable generation such as PV systems [34]. The system they developed used a fuzzy controller to manage the charging/discharging times of the connected EVs, power sharing among them, and V2G services. The goal of this system was to minimize the charging cost while reducing the impact on the grid as well as contributing to peak shaving. The flowchart associated to this system is shown in Figure 5.

To alleviate the problems at the distribution stage of the grid—which is highly affected by EV penetration—Geng et al., proposed a charging strategy comprising of two stages aimed at providing satisfactory charging for all connected EVs while shifting the loads on the transformers [120]. The first stage utilized Pontryagin's minimum principle and was based on the concept of dynamic aggregator; it derived the optimal charging power for all the EVs in the system. The second stage used fuzzy logic to distribute the power calculated in the first stage among the EVs. According to the authors, the system was feasible to be implemented practically [120]. In [11], Richardson et al., employed a linear programming based technique to calculate the optimal rate of charging for each EV connected in a distribution network to enable maximized power delivery to the vehicles while maintaining the network limits. This approach can provide high EV penetration possible in existing residential power systems with no or a little upgrade. Sortomme et al., developed an algorithm to maximize profit from EV charging in a unidirectional V2G system where an aggregator is present to manage the charging [13].

IV Trends and Future Developments

The adoption of EVs has opened doors for new possibilities and ways to improve both the vehicles and the systems associated with it, the power system, for example. EVs are being considered as the future of vehicles, the existing charging technologies have to improve a lot to make EVs widely accepted. The charging time has to be decreased extensively for making EVs more flexible. At the same time, chargers and EVSEs have to able to communicate with the grid for facilitating V2G, smart metering, and if needed, bidirectional charging [23]. Better batteries are a must to take the EV technology further. There is a need for batteries that use non-toxic materials and have higher power density, less cost and weight, more capacity, and needs less time to recharge. Though technologies better than Li- ion have been discovered already, they are not being pursued industrially because of the huge costs associated with creating a working version. Besides, Li-ion technology has the potential to be improved a lot more. Li-air batteries could be a good option to increase the range of EVs [7]. EVs are likely to move away from using permanent magnet motors which use rare-earth materials. The motors of choice can be induction motor, synchronous reluctance motor, and switched reluctance motor [7]. Tesla is using an induction motor in its models at present. Motors with internal permanent magnet may stay in use [7]. Wireless power transfer systems are likely to replace the current cabled charging system. Concepts revealed by major automakers adopted this feature to highlight their usefulness and convenience. The Rolls-Royce 103EX and the Vision Mercedes-Maybach 6 can be taken as example for that. Electric roads for wireless charging of vehicles may appear as well. New ways of recovering energy from the vehicle may appear. Goodyear has demonstrated a tire that can harvest energy from the heat generated there using thermo-piezoelectric material. There are also chances of solar-powered vehicles. Until now, these have not appeared useful as installed solar cells only manage to convert up to 20% of the input power [9]. Much research is going on to make the electronics and sensors in EVs more compact, rugged and cheaper—which in many cases are leading to advanced solid state devices that can achieve these goals with promises of cheaper products if they can be mass-produced. Some examples can be the works on gas sensors [35], smart LED drivers [36], smart drivers for automotive alternators [37], advanced gearboxes [38], and compact and smart power switches to weather harsh conditions [39]. The findings of [40–46] may prove helpful for studies regarding fail-proof on-board power supplies for EVs. The future research topics will of course, revolve around making the EV technology more efficient, affordable, and convenient. A great deal of research has already been conducted on making EVs more affordable and capable of covering more distance: energy management, materials used for construction, different energy sources etc. More of such researches are likely to go on emphasizing on better battery technologies, ultracapacitors, fuel cells, flywheels, turbines, and other individual and hybrid configurations. FCVs may get significant attention in military and utility-based studies, whereas the in-wheel drive configuration for BEVs may be appealing to researchers focusing on better urban transport systems. Better charging technologies will remain a crucial research topic in near future.

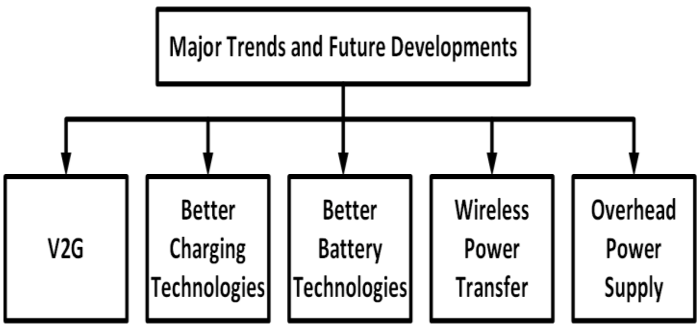

Figure 6. Major trends and sectors for future developments for EV.

1.1 Outcomes

The goal of this paper is to focus on the key components of EV. Major technologies in different sections are reviewed and the future trends of these sectors are speculated. The key findings of this paper can be summarized as follows:

- There are also strong chances for BEVs to be the market dominators with ample advancement in key technologies; energy storage and charging systems being two main factors.
- Currently EVs use batteries as the main energy source. Battery technology has gone through significant changes, the lead-acid technology is long gone, as is the NiMH type. Li-ion batteries are currently in use, but even they are not capable enough to provide the amount of energy required to

appease the consumers suffering from 'range anxiety' in most cases. Therefore the main focus of research in this area has to be creating batteries with more capacity, and also with better power densities. Metal-air batteries can be the direction where the EV makers will head towards. Lithium-sulfur battery and advanced rechargeable zinc batteries also have potential provide better EVs. Nevertheless, low cost energy sources will be sought after always as ESS cost is one of the major contributors to high EV cost.

- Ultracapacitors are considered as auxiliary power sources because of their high power densities. If coupled with batteries, ultracapacitors produce a hybrid ESS that can satisfy some requirements demanded from an ideal source. Flywheels are also being used, especially because of their compact build and capability to store and discharge power on demand. Fuel cells can also be used more in the future if FCVs gain popularity.
- EV impacts the environment, power system, and economy alongside the transportation sector. It shows promises to reduce the GHG emissions as well as efficient and economical transport solutions. At the same time, it can cause serious problems in the power system including voltage instability, harmonics, and voltage sag, but these shortcomings may be short-lived if smart grid technologies are employed. There are prospects of research in the areas of V2G, smart metering, integration of RES, and system stability associated with EV penetration.

CONCLUSIONS

EVs have great potential of becoming the future of transport while saving this planet from imminent calamities caused by global warming. They are a viable alternative to conventional vehicles that depend directly on the diminishing fossil fuel reserves. Batteries for EV have been discussed in detail in this paper. The key technologies of each section have been reviewed and their characteristics have been presented. The impacts EVs cause in different sectors have been discussed as well, along with the huge possibilities they hold to promote a better and greener energy system by collaborating with smart grid and facilitating the integration of renewable sources. Limitations of current EVs have been listed along with probable solutions to overcome these shortcomings. The current optimization techniques and control algorithms have also been included. A brief overview of the current EV market has been presented. Finally, trends and ways of future developments have been assessed followed by the outcomes of this paper to summarize the whole text, providing a clear picture of this sector and the areas in need of further research

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