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OPTIMIZED CONTROLLER FOR CHARGING OF EV BATTERIES IN RENEWABLE ENERGIES

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Abstract- Using renewable types of energy and Electric Cars (EVs) can reduce energy prices and minimize radiation to a substantial extent. The intermittent nature of renewable energy sources and their sporadic use, integrating renewable energy sources into the electric grid is a challenging process. If the supply of renewable energy is not adequate to fulfill the requirement, it is expensive to pull more energy from the power grid. This may also reduce the energy efficiency of the charging process. The focus of this study is to present methods for optimizing a controller for the charging of electric vehicle batteries using renewable energy sources for energy management. The output of the Dynamic Programming optimization and a variety of other approaches used in energy optimizing software are compared to determine which one would accurately minimize the cost of energy required for charging and yet fulfill the aggregate battery charge maintaining criteria. Based on this study it is evident that the Dynamic Programming based optimization strategy provides the highest level of accuracy while maintaining a consistently high level of fuel savings in EVs.

***Index Terms* - Electric Cars, Battery, Electric Vehicles, Dynamic Programming, Renewable Energy Sources**.

I. INTRODUCTION

At the economic, environmental, industrial, and social levels, the lack of petroleum storage and the rise in gas emissions (CO_2, SO_2, and NOx) have become global issues. Utilizing renewable energy sources to generate electricity has the potential to greatly decrease gas emissions and save the environment from future catastrophe [1]. Another viable alternative to save environment damage is to switch to EVs from conventional Internal Combustion Engine (ICE) vehicles. To avoid issues like high peaks and power losses for the grid and to reduce EV owners' charging expenses, coordinated charging is very important [2]. As renewable energy sources become more prevalent, traditional fossil fuel-based power-producing facilities are being phased out as the global energy landscape transforms [3]. Plug-in hybrid electric cars (PHEV) and Battery Electric Vehicles (BEV), which are becoming more prevalent, both contain sizable, supplied battery storage capacity that could be linked to the grid while parked for extended periods, creating new possibilities for the integration of Renewable energy sources (RES) [4]. Energy system optimizations are thought to have a significant influence on the numerous techno-economic studies about electric vehicle-to-grid integration since they disclose the ideal structure, characteristics, and management of an assessed, integrated energy system [5]. EVs may provide several advantages over conventional cars, like cheaper operating costs, reduced gas emissions, etc. EVs, on the other hand, provide a special energy storage capacity to support the production of renewable energy and the electrical grid [6]. EVs could be operated in a way that supports a rooftop Photovoltaic (PV) system, which can provide for the household's electrical needs while lowering costs [7]. Additionally, using renewable energy to charge EVs would gain popularity as a green and effective energy-use strategy [8]. According to a study, charging 50,000 electric vehicles with renewable energy may cut annual gas emissions by $4x10^5$ tons [9].

However, providing EV charging with renewable energy has its own set of issues. The intermittent nature of renewable energy generation, which is greatly impacted by weather, makes it difficult to plan and schedule the operation of power systems [10]. To lower the cost of obtaining additional energy and to improve power proficiency, it is crucial to carefully investigate the stochastic features and the dynamic support between renewable energy production and capacity requirement [11]. This study examines the most effective charging techniques based on dynamic programming to lower the overall cost of charging EVs. Figure 1 shows the schematic diagram of Electric Vehicle [12].

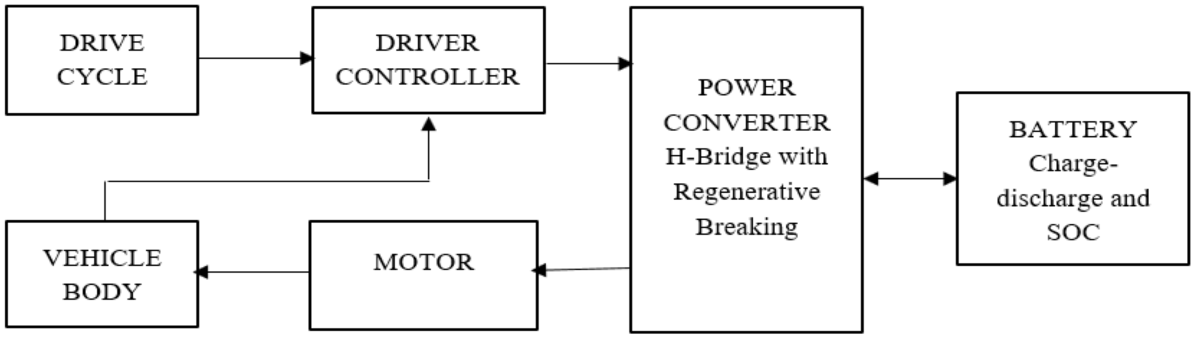

Figure 1: Block diagram of electric vehicle modelling

1.1. Electric Vehicle

An electric vehicle is a car, truck, or another motor vehicle that is propelled solely or mostly by one or more Electric Vehicles (EVs) [13]. It might be powered by a battery, a collecting system, or energy from extravehicular sources [14]. However, these methods cannot be utilized simultaneously. An EV is propelled by an electric motor as opposed to an internal combustion engine, which generates power by burning a combination of fuel and gases [15]. A few examples of electric vehicles are electric watercraft for both the surface and the depths of the sea, electric airplanes, and electric spaceships EVs [16]. Three primary categories of electric vehicles are plug-in hybrid electric vehicles (PHEV), hybrid electric vehicles (HEV), and Battery Electronic Vehicle (BEV) [17].

1.1.1. HEV (Hybrid Electric Vehicles)

Hybrid Electric Vehicles (HEV) combines an Internal Combustion Engine (ICE) with a battery pack and electric motor to reduce fuel consumption [18]. HEVs do this by applying an electric motor to propel the vehicle when ICE would be particularly wasteful, such as while accelerating from a standstill [19]. Hybrids could prefer the internal combustion engine (ICE) even if it would be more efficient for them not to do so in certain situations, such as while driving at highway speeds [20].

1.1.2. PHEV (Plug-in Hybrid Electric Vehicles)

Plug-in Hybrid Electric Vehicles (PHEV) are a dual-fuel technology that aims to replace non-renewable, high-carbon fuels in the transportation energy infrastructure with more environmentally friendly options [21]. Electricity is one of the fuels used in PHEVs. PHEVs can give execution on par with that of today's cutting-edge automobiles [22]. Benefits are the consequence of switching from traditional transportation fuels to electricity, which is more significant, as well as an efficient fuel-energy distribution from the tank to the wheels [23].

1.1.3. BEV (Battery Electric Vehicles)

Battery Electric Vehicles are known as pure electric vehicle, only electric vehicle, or fully electric vehicle refers to an EV that solely relies on chemical force accumulated in rechargeable battery sets and does not use any additional sources of power [24]. An "all-electric" or "full-electric" automobile is referred to as a BEV [25]. BEVs only use electricity, with onboard battery packs serving as a source of current for the electric motors in each vehicle [26]. BEVs lack all ICE components. Due to their exclusive dependence on electricity, BEVs often have batteries with much higher capacities and kilowatt-hour (kWh) outputs than equivalent hybrid and plug-in electric automobiles [27]. Because BEVs utilize more advanced batteries than other EV types, they are often more expensive [28]. One may get many of the benefits of a BEV while avoiding a number of its drawbacks by combining elements of BEVs with standard HEVs [29]. The PHEV has a lower cost penalty than a BEV with similar performance since it uses fewer batteries than a complete BEV [30]. Figure 2 shows the schematic diagram of Battery Electric Vehicle [31].

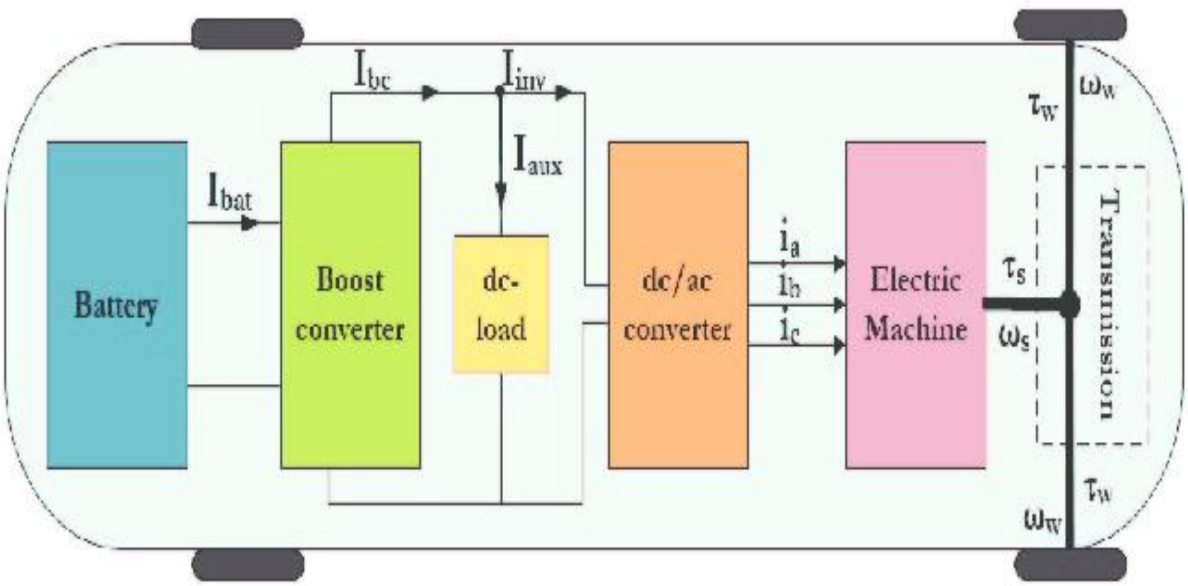

Figure 2: Schematic diagram of the battery electric vehicle

1.2. Dynamic Programming Method

To effectively solve a class of issues with overlapping subproblems and an optimum substructure property, dynamic programming combines mathematical optimization techniques with computer programming techniques [32]. Dynamic programming is a mathematical approach that may be used to solve any issue that calls for assessments to be done sequentially to find a decision route that incurs the least amount of penalty [33]. In the context of this discussion, a "penalty" is a numerical representation of the undesirable consequences that are caused by a decision [34]. The algorithm advances from the end of one duty cycle to the beginning of the next while it simultaneously calculating the penalty caused by different control settings at each time step [35]. The dynamic programming approach cannot be used in practical control methods because it requires prior knowledge of the duty cycle [36]. However, real controllers may be designed and tuned using the dynamic programming algorithm's outputs [37]. The benefit of DP optimization approach are as follows:

- A decrease of about 40 percent in the cost of charging energy in the case when there is a low penetration of Renewable energy sources (RES) and a two-tariff electrical energy pricing pattern [38].
- Greater use of RES capability and, should it occur, a proportionately reduced cost of grid electricity for charging when RES share exceeds local energy demand without EVs [39].

The penalty function that was employed in this research assigned a penalty for the consumption of fuel, for failing to fulfill the duty cycle speed-time trace that was given, and for failing to maintain an end state of charge that was fair [40]. Only a small portion of the whole design space is investigated by the dynamic programming approach in its current form, which was employed for this study [41]. Because of this, the author could not say that the control is optimal, but rather that it is near-optimal [42]. A sort of global optimization approach known as dynamic programming, or simply DP, achieves its purpose by breaking a problem down into several step-based nuzzled subproblems, merging the results found at every level, and moving in reverse from the most recent stage to the one before it [43]. Following the optimality principle, the optimal outcomes are determined at each stage by computing them based on the ideal outcomes of the stage that came before [44]. The cost of charging customers is the primary emphasis of the optimization, with consideration given to pricing changes [45]. Figure 3 depicts the flowchart of Dynamic Programming approach [46].

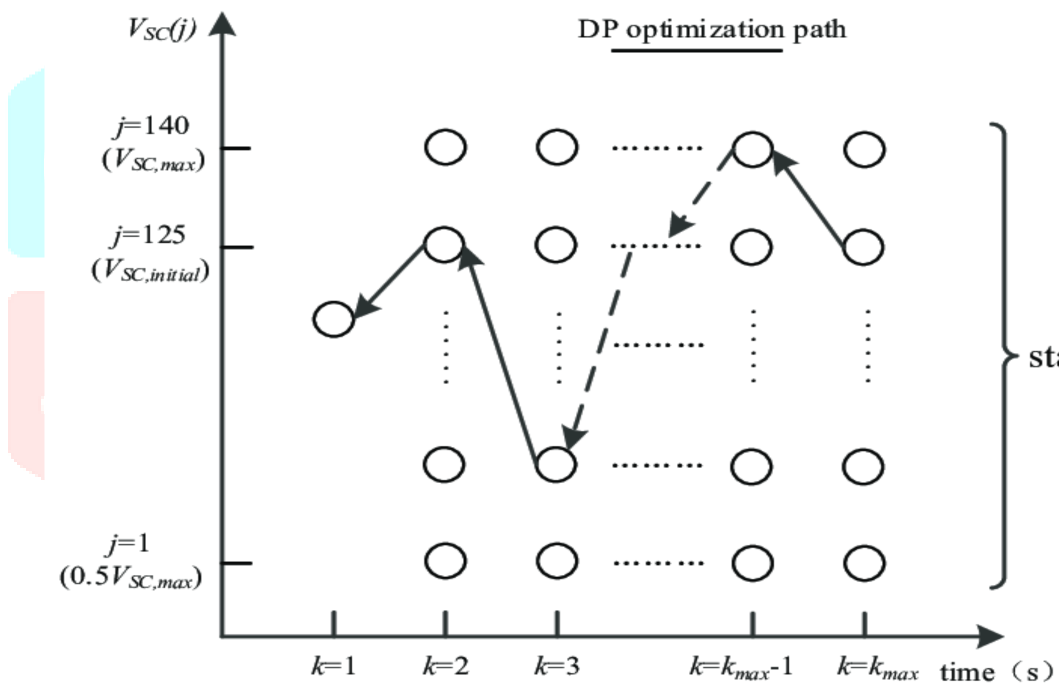

Figure 3: Dynamic programming (DP) approach flowchart

1.3. Renewable energy

One of the most potentially game-changing effects that EVs might have on the electrical system is their capacity to facilitate the incorporation of renewable power supplies into the current energy framework [47]. Coordinating EV charging with other grid demand and renewable production becomes exceedingly difficult due to RESs' intermittent and indispatchable nature [48]. The EV's unpredictable arrival, intermittent renewable energy, and fluctuating grid power prices are all considered and characterized as separate Markov processes [49]. The energy needed to charge each EV, meanwhile, varies randomly [50]. Plug-in electric vehicle adoption and the widespread use of renewable energy (RE) may both contribute to the decarbonization of the transportation and power sectors [51]. The station comprises renewable generating (wind and solar) and a storage system in order to increase the fast-charging stations' profitability and lower the high energy demand from the grid [52]. The transition to a low-carbon, highly integrated renewable society demands initiatives from a variety of sectors and levels [53]. A number of difficulties are noted, mostly as a result of the relevant population growth, the depletion of fossil fuel sources, a lack of energy security, and the expansion of the economy and urbanization [54]. With the aid of FEVs, the rising greenhouse gas emissions may be decreased [55]. The variable output power that is produced by renewable energy sources will be stored in a storage system [56]. A fixed-point digital signal processor applies a power factor correction technique for an inbuilt battery charger for traction propulsion [57]. The battery management system turns on the battery packs' voltage- or current-controlled charging modes [58]. Due to environmental concerns, hybrid power production that is based on renewable energy (RE) has gained popularity [59]. The RE-based power production may be utilized to meet local loads in distant locations without a grid connection and with less transmission loss [60]. In comparison to fossil fuels, wind power producing systems have less of a negative influence [61]. Figure 4 describes the basic representation of Solar Vehicle.

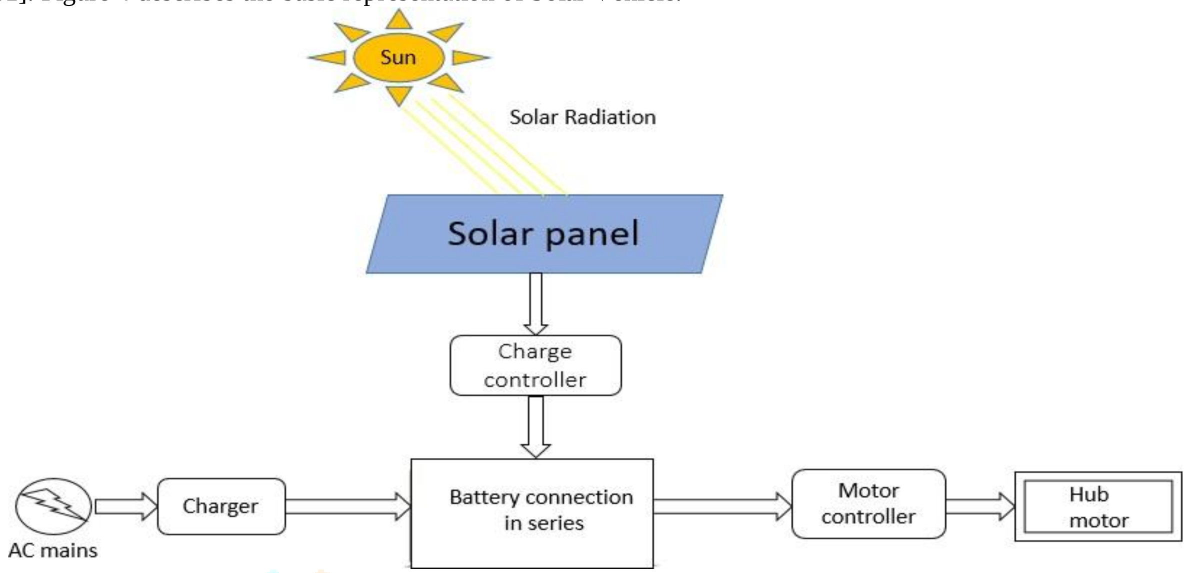

Figure 4: Block Diagram Representation of Solar vehicle [80]

1.3.1. Wind energy

A sixteen-fold expansion in northeastern wind power capability was predicted while modelling the Brazilian electrical sector from 2010 to 2030 [62]. The number of PHEVs (plug-in hybrid electric vehicles) whose batteries might be replenished by the excess wind power output is then calculated [63]. The excess production varies seasonally and happens more often between January and June; hence the authors accept that the automobiles operate on nearby manufactured ethanol during the other months of the year [64].

1.3.2. Solar energy

Combining immediate battery recharging from solar photo voltaic with the parking lot chargers that were discussed before is one way to make use of the benefits offered by this kind of charging [65]. Solar cars are not designed to be utilized for business reasons; however, the Vehicle-integrated Photovoltaics (VIPV) might be used to increase the fuel economy of hybrid and electric vehicles which are already on the road [66]. It is anticipated that this would result in a 10–20% increase in the fuel economy of the car [67].

1.3.3. Biomass energy

The difference between wind and solar energy and biomass energy is that biomass energy may be stored and utilized whenever it is required [68]. The use of liquid biofuels as an alternative fuel for vehicles is one of the most popular ideas that has been offered; nevertheless, bioelectricity has several benefits that biofuels do not [69]. It is possible to generate bioelectricity by employing a variety of different types of biomass feedstocks, such as wastes from forestry and agriculture, woody energy crops, or even by cutting down whole trees [70]. When compared, the gross average driving output of bioelectricity is 112% more than that of biofuels, measured by kilometers focused per hectare of biomass construction [71].

II. LITERATURE OF REVIEW

This part emphasizes various works on the topic of Dynamic programming based optimal controller for charging electric vehicle batteries using renewable energy.

Yang et al., (2021) [72] stated that two global optimization approaches, Dynamic Programming (DP)-based Genetic Algorithm (GA)-based, have been developed to enhance the EV charging program at DC quick charging bases. It is possible to reduce charging costs by changing the final condition of charge State of charge (SOC) of a battery after it has been charged to its maximum capacity in each charging event by using the suggested optimization procedures. If the DP-based recharging schedule or the GA-based recharging plan is used, the overall charging expense might be decreased by 41.5% or 46.3%, respectively, when compared to the charging plan that was used as the baseline. For EV customers that see Direct-current fast charger (DCFC) as the preferred charging method, the suggested charging schedule optimization techniques may be crucial in drastically lowering the cost of gasoline.

Salazar et al., (2020) [73] presented a strategy with the goals of maximizing the utilization of the available solar power and achieving the optimum level of charge for the battery. To accomplish this objective, the management of the Energy Storage System (ESS) has been recast as a stochastic optimal control problem. This considers the nonlinearities that occur throughout the battery discharge process. To make an accurate prediction of the probability distribution of the solar output that would be employed in the stochastic DP formulation, a Markov model has been used. The results of a simulation demonstrate how effective the suggested DP-based technique is in comparison to an algorithm that is based on rules. In the end, a hardware-in-the-loop system has been applied to assess the real-time functionality of the EM algorithm that was developed.

Shibl., et al (2020) [74] stated that the machine learning algorithms could estimate the amount of electricity that would be used by electric vehicle charging stations (EVCS). In comparison to more traditional optimization approaches like quadratic programming, the use of machine learning makes the process of coordinating EVs simpler. Additionally, the use of machine learning makes the process go more quickly since it uses fewer computer resources. The results highlight the significance of the methodologies used and their great potential for offering a dependable answer for the timed coordination of electric vehicle (EV) charging, hence enhancing the efficiency of the power grid, and lowering power losses and voltage fluctuations. However, the ML technique was significantly more time and effort efficient. The results obtained using the Long short-term memory (LSTM) model were equivalent to the results produced from prior studies that employed quadratic programming. With an accuracy rating of 95.3% and an error rate of 0.71%, LSTM was determined to be the best model; this model delivers the greatest results when attempting to forecast the PR that is most suited for EVCS.

Yu et al., (2019) [75] illustrated that through dynamic programming that considers future forecasts of a renewable resource and electrical car required to optimize the stability of energy in the electronic network. Through testing with a fleet of battery-electric commercial cars, the simulations' complete driving, parking, and charging availability patterns were produced. Numerical calculations, hybrid photovoltaic and solar photovoltaic wind technologies reduce yearly grid demand for commercial cars by 24%. The findings demonstrate that owing to the nature of EV use, the mid-morning EV mandate for commercial fleets cannot be moved to another period. Further research revealed that for synchronized charging to be successful, there must be widespread EV adoption in the neighborhood.

Aragón et al., (2019) [76] presented a strategy for the cooperative management of a group of charging stations based on a stochastic optimization model, The plan also prioritizes EV charging with locally accessible renewable energy sources and energy storage. Our proprietary Stochastic Optimization Software Framework (SOFW), which employs dynamic programming to deploy the application as Model Predictive Control (MPC) in a real-time setting, includes the stochastic optimization model. The outcomes of testing five EVs in a parking lot under various driving conditions showed that the SOM can determine the best charging power to provide to the EVs. The EV's battery has adequate power in every situation to complete its driving tasks. The findings demonstrate that the local renewable energy source's power was fully utilized.

Joseph et al., (2018) [77] presented a thorough examination of the various wireless charging topologies used in PHEV charging applications. The initiatives to combine wireless charging with renewable energy sources are presented through a two-dimensional model. Alternative safety requirements for WPT design, battery selection, and magnetic coupler selection are presented in detail.

Skugor et al., (2015) [78] claimed that a specific, well-known cumulative battery-operated was intended for the dynamic programming-centered EV fleet charging system. The primary benefit of the method is that, since the aggregate battery model is of low order, it offers a globally optimum solution at a reasonable computational cost. The DP algorithm's advantages in terms of reducing the charging energy price and meeting the cumulative battery charge maintenance requirements are shown by comparing the results of the DP optimization with those achieved by a remaining heuristic charging approach utilized in the Energy PLAN program. The forecasts of the charging cost made by the DP optimization outcomes created on the regular and to a lesser degree weakly intervals may be too optimistic when applied to longer periods.

Jin et al., (2014) [1] elaborated on the issue of efficiently supplying EVs with energy from renewable sources. The suggested strategy completely considers each EV's specific charging rate cap and deadline and Lyapunov optimization method was used to resolve the issue. The created dynamic control algorithm is independent of the statistical distribution of the demand for EV charging, the price of additional energy, or the time-varying renewable energy production. The study ran simulations utilizing various wind power generating profiles and examined the outcomes. The findings demonstrate that our EV charging development strategy, which is centered on Lyapunov optimization, may lower charging costs as well as the mean time required to complete EV charging requests.

Chen et al., (2014) [79] stated that Dynamic programming is used to study the energy controlling plan for a range-extended electric vehicle (RE-EV), which entails studying the design requirements for the strategy and creating an implementable approach that can be used in real-time. The analysis's findings indicate that although the fuel-energy-loss-oriented technique may improve fuel economy, the battery life would be negatively impacted by its greater battery power shortfalls and standard charging or discharging flows. The suggested technique outperforms the current thermostat control strategy in terms of controlling fuel efficiency and battery protection, according to simulation findings utilizing three untrained driving patterns. These findings suggest that the suggested technique may need less computing time in exchange for improved management of battery and fuel efficiency performance.

O'Keefe et al., (2006) [4] stated two primary control theories were applied to a PHEV. There were an "electric vehicle centric" control strategy and an "engine-motor blended control strategy." The author shows that a PHEV should normally work closer to an electric vehicle centrical handling approach for city driving to consistently achieve considerable fuel savings. This research also reveals that, under ideal management, a mixed management approach uses almost the same quantity of gasoline as an electric vehicle-focused system for the specified objective spaces. Other driving styles and energy capacity sizes, as well as the impact of different driving patterns throughout a particular journey, should be the subject of future study.

Table 1 shows the summarized study of the various researchers engaged in the field.

Author	Technique	Outcome
Yang et al., (2021) [72]	Dynamic Programming (DP)	Compares the GA-centered charging program to the DP-centered charging program and the baseline charging plan, the overall charging cost is lowered by 41.5% and 46.3%, using the two alternative charging schedules.
Salazar et al., (2020) [73]	Stochastic optimization (stochastic DP formulation), time-variant Markov model.	The simulation results are provided to demonstrate how effective the suggested DP-based technique is in comparison to an algorithm that is based on rules.

Shibl., et al (2020) [74]	Machine Learning algorithms	The results are achieved by using the LSTM model comparing quadratic programming; however, the ML approach was much more time and effort efficient. LSTM was found to be the best model, with 95.3% accuracy and a 0.71% error rate; this model delivers the greatest results when attempting to forecast the power rating (PR) that is most suited for electric vehicle charging stations (EVCS).
Yu et al., (2019) [75]	Dynamic Programming	The findings demonstrate that owing to the nature of EV use, the mid-morning EV mandate for commercial fleets cannot be moved to another period.
Aragón et al., (2019) [76]	Stochastic Optimization Software Framework (SOFW) and dynamic programming	The findings demonstrate that the control that was put in place guaranteed that the local renewable energy source's power was fully used.
Joseph et al., (2018) [77]	Wireless charging topologies	Adopted a novel rectangular coil design in place of the standard circular core-winding pair, which yielded efficient charging system.
Škugor et al., (2015) [78]	Dynamic Programming	When extrapolated to cover longer periods, the results drawn from DP optimization established on the regular and, the weakly intervals were too optimistic in their estimations of the charging cost.
Jin et al., (2014) []	Lyapunov optimization method	The findings demonstrated that the EV charging scheduling strategy, based on Lyapunov optimization, may lower charging costs as well as the mean time required to complete EV charging.
Chen et al., (2014) [79]	Dynamic Programming	The suggested technique may need less computing time in exchange for improved management of battery and fuel efficiency performance.
O'Keefe et al., (2006) [4]	A dynamic programming optimization approach	Under optimal conditions, the quantity of gasoline used by a strategy that utilizes mixed control and one that emphasizes the use of electric vehicles is same for a given set of objective distances.

III. COMPARATIVE ANALYSIS

Predicting a Dynamic programming-based optimized controller for charging EV batteries in renewable energies has been a long-term objective of this study, which would explore previous studies done in this field. In comparison to other methods, the Dynamic Programming Optimization (DPO) approach has been found to have the highest accuracy (91%). Machine Learning (ML) algorithms with 90.3 percent of accuracy and stochastic DP formulation (SDPF) with 88.52 percent accuracy comes afterwards. Wireless Charging Topologies (WCT) performs with 88 percent accuracy and Lyapunov Optimization (LO) Method with 72.31 percent accuracy. Table 2 shows the comparative study of various authors based on accuracy and used techniques.

Table 2: Comparative analysis

Author	Technique	Accuracy
Yang et al., (2021) [72]	Dynamic programming Optimization (DPO) Approach	91.0%
Shibl., et al (2020) [74]	Machine Learning (ML) algorithms	90.3%
Salazar et al., (2020) [73]	Stochastic Dynamic programming formulation (SDPF)	88.5%
Joseph et al., (2018) [77]	Wireless Charging Topologies (WCT)	88.0%
Jin et al., (2014) [1]	Lyapunov Optimization (LO) Method	72.3%

Figure 5 shows the comparison graph for the different technique's (Dynamic programming Optimization Approach, Machine Learning algorithm, Stochastic DP formulation, Wireless Charging Topologies, Lyapunov Optimization Method) accuracy in the existing literature.

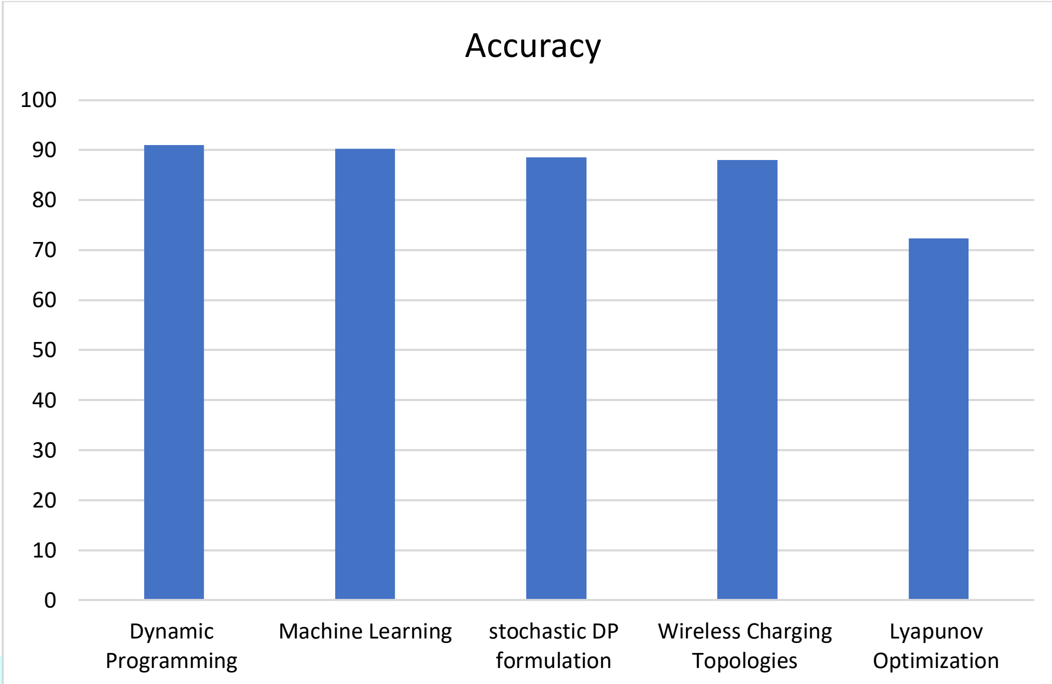

Figure 5: Comparison graph for the classifier's accuracy.

IV. CONCLUSION

This comparison technique for optimizing the controller of charging the electric car batteries using renewable energy sources is proposed in this review study that was conducted with the goal of maximize the use of renewable energy. The Dynamic Programming Optimization (DPO) methodology offers the greatest accuracy of 91 percent when compared to other approaches to optimizing the charging of electric vehicle batteries using renewable energy. In addition, there is a discussion of the well-known methods that are available and these can be utilized to improve the process of charging the batteries of electric vehicles using renewable energy sources. This study's primary objective is to compile all of the pertinent information, such as previous research on Dynamic Programming, electric vehicle batteries, renewable energy batteries, and existing approaches, and provide the details in most comprehensive way.

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