Optimization of Power in Electric Vehicle

Rashmi Priya[1]
[1]Assistant Professor, Department of Electrical and Electronics Engineering
Motihari College of Engineering, Motihari, Bihar, India

Abstract-

Due to their low exhaust emissions and growing viability in terms of battery technologies, electric vehicles (EV) are swiftly acquiring a footing in international markets. Although EV power trains don't produce any pollutants while they're moving, their efficiency hasn't been fully optimized, in part because of the typical single-speed transmission. Since EV power trains use multispeed discrete transmissions, continuously variable transmissions, and multi-motor topologies, this paper presents a thorough review of the most recent work done to optimize the power flow in these systems. Using a keyword search linked to EV power train in the Science Direct and Scopus databases, the pertinent literatures were narrowed down. The review concentrated on works in the field that have been published since 2018. The publications' approaches for enhancing the power train's efficiency and driving performance were examined. The important discoveries from these literatures were then reviewed and contrasted. Several significant future research areas in EV power train efficiency and performance are highlighted based on the review.

Keywords— *Drivetrain of an Electric Vehicle, Continuously Variable Transmission, Multispeed Discrete Transmission, Two- or Four-Motor Arrangement.*

DOI Number: 10.48047/nq.2020.18.6.NQ20187 NeuroQuantology 2020; 18(6):81-88

INTRODUCTION

Since they produce no emissions while driven, electric vehicles (EVs) are becoming more and more popular. This trend can be attributed to recent technological developments, particularly in the fields of energy storage and charging systems. In contrast to conventional vehicles with internal combustion engines (ICEs), the market share of electric vehicles (EVs) is anticipated to grow further in light of recent advances in global pollution standards. According to the most recent Deloitte prediction, the share of EVs in the worldwide market is predicted to reach 32% by 2030. This prediction was based on four factors: the improvement in customers' perceptions of EVs due to their practicality and lower cost of ownership; supportive policies from the government, primarily in the form of financial incentives and easy access to charging stations; the increased focus on EV-related technologies by automakers; and assistance from non-automotive businesses in implementing EVs on a large scale. When looking only at tailpipe emissions, this trend seems good for the environment because it is predicted that transportation would steadily lower its emissions of hazardous CO, CO2, and NOx. Simultaneously, it creates opportunities to investigate other frontiers, including autonomous technology, innovative materials for energy storage, and vehicle connectivity (vehicle-to-vehicle, vehicle-to-grid, and vehicle-to-infrastructure). But as EVs become more and more common, other problems will also arise, and these need to be adequately researched and handled. Electric vehicles (EVs) introduce environmental advantages when compared to conventional gasoline-powered vehicles. They reduce air pollutants and greenhouse gas emissions while contributing to energy security through reduction in oil imports. Market penetration of EVs is foreseen to grow significantly in the future. However, the limited amount of on-board energy storage and electric range of plug-in electrical vehicles are of great concern. Besides the battery technology improvement, there is a need for an algorithm that optimizes the vehicle movement to make the most efficient use of the energy stored in the vehicle battery. The conventional gasoline vehicle technology has reached near saturation, the focus is now on the optimization. Various optimization methods for driving speed on different routes have been studied. Different algorithms to optimally manage the energy flow between the fuel source and batteries have been developed for hybrid electric vehicles (HEVs). This raises a question whether the plug-in EVs can have a similar optimal driving strategy taking into account the impact of vehicle movement on the batteries' state of charge (SOC). SOC is defined as the percentage of the remaining charge inside the battery compared to the full charge. The accurate value of SOC is one of the prerequisites to develop optimal control. Although it is difficult to build accurate mathematical model due to its nonlinearity, the SOC control strategy for EVs has been discussed in some papers. The driving range of a plug-in EV is highly dependent on the driving profile during a trip including battery SOC, as well as vehicle performance, power consumption of key components, drivers' behavior, etc. There are also external factors such as road conditions, road slope, speed limit, rolling resistance, and aerodynamics that affect the driving range. Papers have developed algorithms to predict, maintain or extend the available driving range. An optimization algorithm to search for global optimum to specific objective functions, which take into account the battery autonomy, driving comfort indices and the travel time, is described in the driving condition has been estimated. Some approaches rely on the prior knowledge or prediction of the future driving condition, while some monitor the real time operation. Some standard or designed driving cycles for different purposes are described in this paper does not specify the driving cycles, but analyze different driving cases by changing the variables which enables the study to be carried in a more general sense.

THE RISE IN POPULARITY OF EVS CREATED NEW CHALLENGES

EVs' increasing popularity leads to numerous new challenges that must not be conveniently ignored. These challenges can be categorized into three classes, namely; challenges in ensuring the sustainability of the EV production, challenges in meeting the increasing demand of electricity due to EV penetration, and, challenges in managing the migration of ICE-to-EV in terms of number of vehicles and the industry eco-system. In the context of EV production sustainability, it was argued in that, although EVs emit zero emission, the same cannot be said for their production. This is because the production process involves a significant amount of delectable materials, like heavy rare earth materials, for the production of motors and batteries. Moreover, the process also leads to higher amounts of emissions of heavy metals like lead, nickel and molybdenum, as compared to the production of ICE vehicles, and this was claimed to be detrimental to human health. According to the study by, the carbon footprint from these activities is currently very high due to their localization. At the moment, these activities are mainly located in China, South Korea and Japan, where a significant portion of the power is generated by fossil fuels, resulting in a high carbon footprint. To address this, refs. proposed either diversifying the production locations to places with high concentration of renewable power generation, or intensifying the amount of renewable power generation at the existing locations. At the same time, ref. also suggested stopping the trend of increasing the battery size because it has direct relationship with the aforementioned carbon footprint issue. This suggestion can be achieved by improving the efficiency of EV power trains. The increasing demand for EVs also causes electricity demand to shoot up and this leads to the second challenge emerged from the increasing EV popularity. According to, the amount of electricity used for EVs, on a daily basis, is about the same as the average daily electricity usage of a typical household in the United States. As such, when EVs reach 20% of a total vehicle market share globally, the electricity peak demand is expected to increase by 36%. In some countries, like China, research by indicated that the popularity of EVs will strain not only its national grid, but also to its national water supply. This is because in China, two major contributors to power generation are hydroelectric and coal power plants that rely heavily on the national water supply. Thus, building and operating additional hydroelectric dams and coal power plants to meet the demand for EVs will divert vast amounts of water away from household usage, causing water scarcity if not properly planned. To address this challenge, two fundamental strategies must be seriously evaluated; efficient power grid management, which can be achieved via either implementation of vehicle to grid technology or implementation of extensive battery swapping activity, and efficient, sustainable and economical EV power trains, which include the application of optimum motors, transmissions and batteries, with, possibly, a significant amount of carry-over technologies from ICE vehicles. Finally, it is also critical to properly manage the ICE-to-EV migration so that a smooth transition phase can be realized. Simply increasing the market share of EVs alone is not enough if the total number of existing ICE vehicles, especially those that have low emission standards, is not drastically reduced. Besides, such migration must also be managed from the perspective of the existing industrial supply chain. For instance, an appropriate strategy has to be planned for the existing ICE-related manufacturing plants which are expected to face redundancy once EVs take over ICE vehicles' market share. In this aspect, one of the strategies is to repurpose the existing manufacturing plants to focus on EV-related products. This, however, is less popular due to the high costs involved in training the existing workers and upgrading the plants. Market readiness is also another major challenge in ICE-to-EV migration, especially for emerging countries. To address this, one option is to implement bridging technologies, like hybrid vehicles, that implements technologies from both ICE and EV, or the use of bio fuels. The advantage of the former is that it is more practical since it also uses gasoline for operation, which is widely available especially in the emerging markets. The advantage of the latter, on the other hand, is its renewability. Nevertheless, implementing these technologies might not lead to the desirable reduction target for the carbon emissions. One strategy that can be applied to accelerate the ICE-to-EV migration is EV power train retrofitting of existing ICE vehicles. The idea here is not only to accelerate the market penetration of EV, but also to utilize the existing resources; in this case, the existing ICE vehicles on the road, which leads to, ideally, no increase in the net number of vehicles on the road. A study by investigated the potential as well as the challenges of widespread EV retrofitting with an emphasis on public and business perceptions. The investigation, conducted based on the current situation in Germany, highlighted some challenges in terms of public acceptance and vehicle homologations. In general, public acceptance of EV retrofitting can be improved gradually through effective communication between the government, technology providers and the public, by highlighting the benefits in terms of sustainability, long term financial savings and reduced emissions. Simultaneously, the compatibility and flexibility of EV power trains should also be improved so that initial retrofitting cost can be reduced. Such power trains can also contribute in the aspect of homologations, which is a major hurdle in implementing EV retrofitting. Therefore, it can be summarized here that, an increasing EV market share, although from one angle it reduces the carbon emissions globally, still leads to several major economic and overall sustainability challenges. If these challenges are not properly addressed, they will negate the aforementioned benefits of EVs. **Figure 1** shows a summary of these challenges, and based on the figure, optimizing the performance, efficiency and sustainability of EV power trains is the key to guarantee positive economic effects and carbon neutrality in transportation.

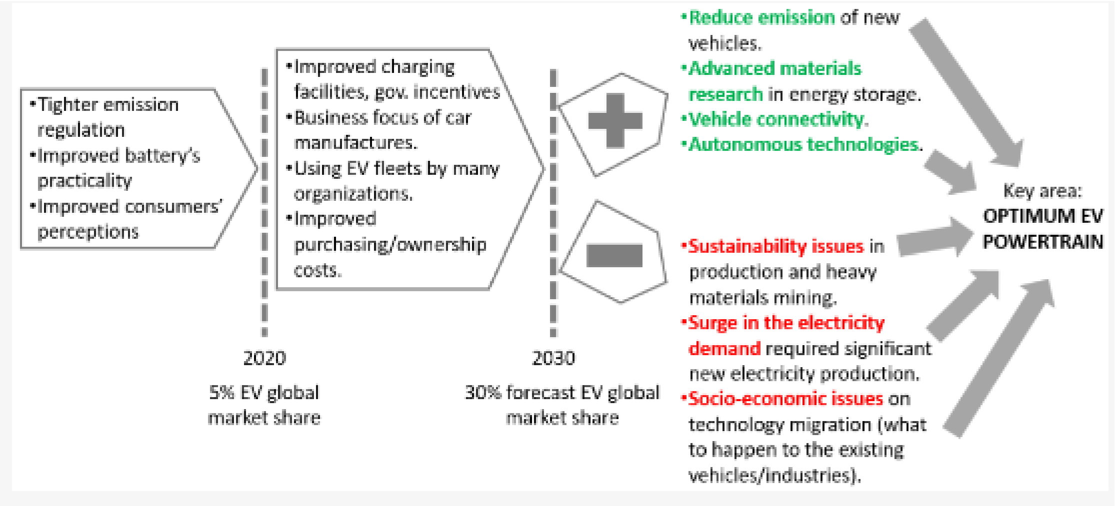


Figure 1- Summary of potentials and challenges of EV regarding environmental

MAIN COMPONENTS OF EV POWERTRAINS

EV power trains mainly consist of batteries, an electric motor and transmission and their performance can be defined in terms of efficiency and practicality. A highly efficient EV power train means that its power consumption (kWh) per distance (km) can be kept as low as possible, thus allowing the vehicle to increase its driving mileage. For practicality, the target is to ensure that the power train components are cost effective; the cost for production and operation (i.e., maintenance) can be kept as low as possible, and sustainable, i.e., with a low carbon footprint from production until application. The purpose of the battery, the first component of an EV power train, is to store electricity for the electric motor's operation. To ensure that the power train is highly efficient and practical, the battery needs to have high energy density so that it can store high amounts of electric power without affecting its weight. Achieving this involves implementation of new cathode, anode and electrolyte materials. One of the options, suggested by, is to increase the nickel content in the cathode. However, this method inevitably leads to the reduction of the cathode's thermal stability, hence risking thermal runaway or damage to the battery. However, according to, a high battery temperature, if properly managed, also presents an opportunity to enhance its performance in delivering the electricity to the motor. Because of this, many researchers have proposed either active cooling methods so that the battery's temperature can be optimized to suit various driving conditions, or emerging materials for the anode surface. Nonetheless, such cooling methods require extra management complexity and additional power consumption for operation, while the usage of emerging materials, though promising, usually involves a significant investment for new mining and manufacturing process. This is consistent with the findings by, which estimated that new investment of 100 Euros is required to increase the battery capacity by 1 kWh. In short, increasing the battery energy capacity, even though can avoid the increase of weight, has its own challenges in terms of safety, complexity and cost. The next major component of an EV power train is the electric motor which is responsible for converting the electricity from the battery into mechanical power to move the vehicle using the electromagnetic induction principle. The motor is controlled by an inverter that regulates the required current flow from the battery to suit the driving conditions. There are two typical types of motor used in EVs: permanent magnet synchronous motors (PMSMs) and induction motors (IMs). In PMSMs, the magnetic field required to rotate the rotor is generated using permanent magnetic materials in either the stator or the rotor. On the contrary, in IMs, the electromagnetic field is produced using a current flow in the rotor conductor. Compared to ICEs, the volume of both types is relatively more compact, and, they also have a higher power to weight ratio. Even so, there are still continuous studies carried out to explore the implementation of advanced materials, like ultra conductive copper for motor windings, and grain boundary diffusion processed magnets, with the intention to increase the motors' power density even further. The compactness and high-power density contribute positively to the power consumption of an EV. Not only that, but these motors also offer high torque capability at low motor speed (RPM) which eliminates the requirement of high gear ratios for vehicle start-stop. This explains the typical omission of multispeed transmissions in the existing EVs. Between these two types of motor, some researchers argued that IM ones are more robust, sustainable and low cost, partially due to the absence of a permanent magnet, while others prefer PMSMs due to their high-power density and no issue of current losses in the IMs' rotor to induce the magnetic field. In terms of efficiency, both PMSMs and IMs have a very high peak efficiency, ranging from 85% up to 97%. However, such efficiency is available only within a limited motor speed range, hence, for diverse driving conditions, the power train's efficiency usually falls significantly below that value. Not only that, but the construction of motor also involves the usage of heavy rare earth materials, which causes issues of high cost and less sustainable production. Therefore, sustainable and cost-effective approaches to realize the actual EV power trains' potential in terms of driving range and performance is desired. The final major component of EV power trains is the transmission, responsible for ensuring that the power can be transmitted from the motor to the wheels efficiently. Because of the characteristics of the typical electric motors used in the existing EVs, the transmission used usually only provides a single speed ratio. The main benefit of using single speed transmissions is their simple construction that leads to relatively low cost for production and maintenance. However, this limits the flexibility of the electric motor to operate optimally to suit diverse driving conditions. Therefore, it is difficult to realize the actual potential of EVs in terms of driving mileage and power consumption. A summary of the areas that can be improved to enhance the performance of an EV power train is illustrated in Figure 2. This figure indicates that transmission, or any method to manage power flow between the motor to the wheels optimally, is crucial in optimizing the EV power train performance. Once the power flow is optimized, the electric motor will have the flexibility to operate more efficiently and effectively, resulting in less power consumption from the battery. This presents a promising and cost-effective prospect of increasing EVs' driving mileage without expanding the battery size or capacity. Thus, this paper reviews and discusses the latest and most significant research works carried out to optimize the power flow in EV power trains.

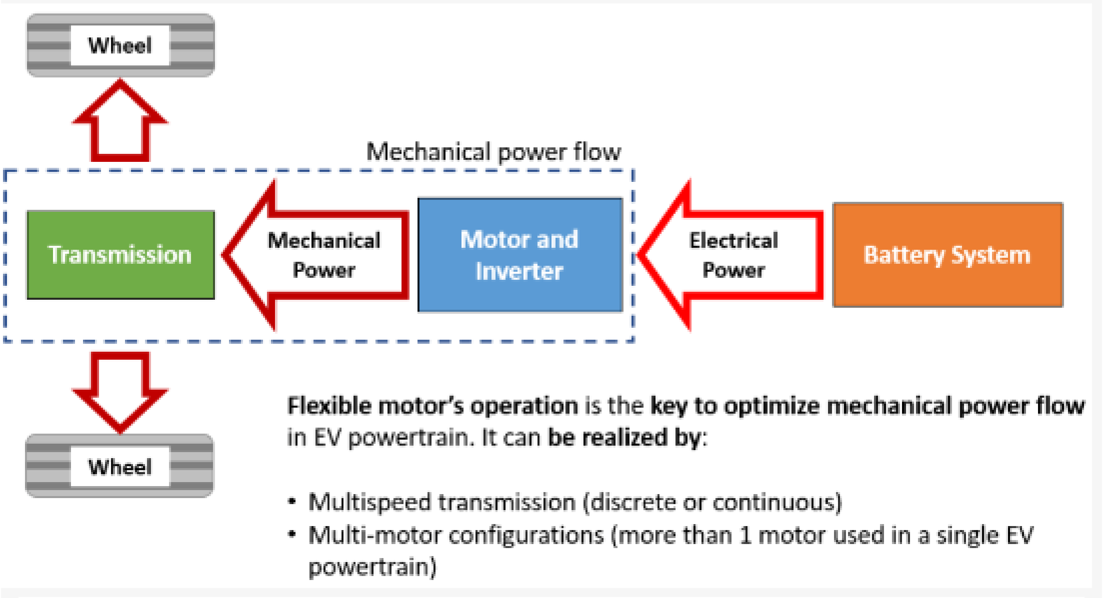
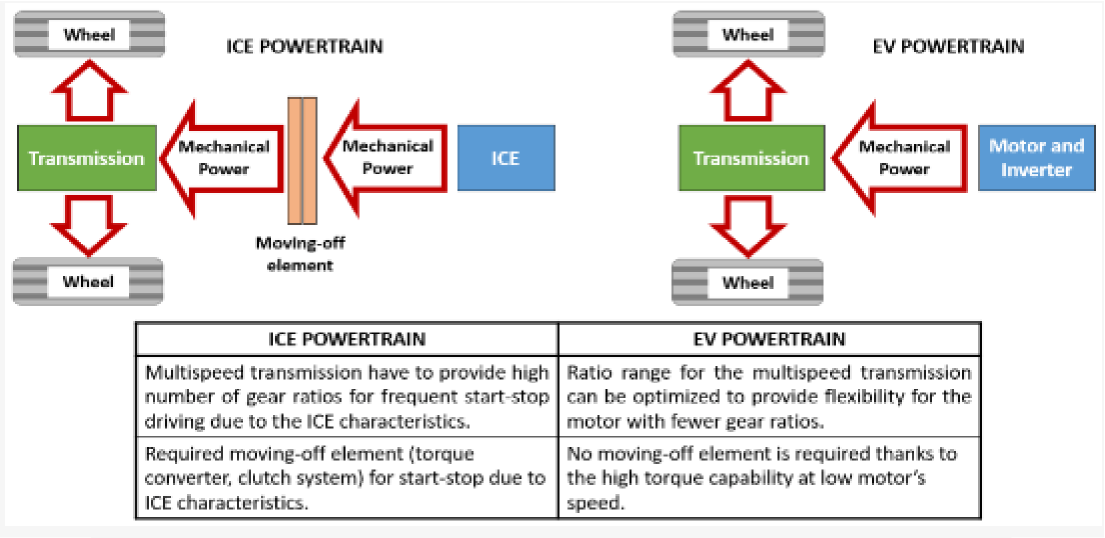


Figure 2- Various methods recently proposed to optimize EV power trains' performance

OPTIMIZING POWER FLOW IN EV POWERTRAINS

Ensuring that a single motor EV power train can operate optimally for various driving conditions, especially when the vehicle is travelling at high speed and low load, is very challenging and because of that, their efficiency normally falls to only around 60% from about 90% for the best-case scenario. One of the possibilities to avoid this is by allowing flexible power flow configurations in the power train. Studies support this argument, where it is found that the power train efficiency and driving performance (in terms of acceleration time and comfort) can be optimized for the full EV driving experience if the driving loads can be properly distributed to two electric motors in the power train configuration with different transmission ratios. In the study, the possibility of implementing different hybrid EV (HEV) power train configurations was evaluated, and the configuration was defined in terms of coupling between the motors to the ICE, and also in terms of different transmission ratios. When the loads are properly distributed, the motors' speed can be reduced drastically during high vehicle speed, and this contributes to increasing the power train efficiency while ensuring the acceleration can be performed smoothly. Hence, it can be summarized here, that, flexible motor's power flow, optimized power train components and control are the key to optimize EV power trains, and this can be achieved by optimizing multi-motor configurations, or by implementing multispeed transmission in the EV power train. In terms of design complexity, the multispeed transmission in an EV should be less complicated than the one used in the existing ICE-powered vehicles. This is because of several factors; most notably the requirement of moving-off elements in the conventional ICE vehicles. Generally, because of the ICE idling speed condition, a moving-off element; like a dry friction clutch, or, torque converter, is required to facilitate the vehicle's start-stop condition. For an EV, however, because of the availability of the motor's torque from as low as 0 RPM, the implementation of moving-off elements is no longer required. On top of that, the elimination of moving-off elements also opens up the chance to implement a much simpler transmission control algorithm, since now it is no longer necessary to control the moving-off element to achieve desirable driving comfort during start-stop conditions (**Figure 3**). As a result, only ratio shifting control is required in an EV, although, if a discrete multispeed transmission is used, then a clutch or brake system is still required for the shifting. This is contrary to the conventional ICE vehicles, where it is absolutely critical to optimize both moving-off control and ratio shifting control. In this paper, the works related to the implementation of multi-speed transmission in EV are divided into two categories: multispeed discrete transmissions and continuously variable transmissions (CVTs). In addition, the possibilities of implementing multi-motor configurations are also reviewed here, since this approach can also lead to optimization of the motor operation for various driving conditions, which according to some scholars, is more effective than the implementation of multi-speed transmissions.



ICE POWERTRAIN	EV POWERTRAIN
Multispeed transmission have to provide high number of gear ratios for frequent start-stop driving due to the ICE characteristics.	Ratio range for the multispeed transmission can be optimized to provide flexibility for the motor with fewer gear ratios.
Required moving-off element (torque converter, clutch system) for start-stop due to ICE characteristics.	No moving-off element is required thanks to the high torque capability at low motor's speed.

Figure 3- Differences in the power train requirements for ICE vehicle and EV

CONCLUSION

Global EV market adoption is anticipated to pick up speed in the near future due to a number of causes, including governments' emission regulations, lower ownership costs, and more practicality. This development is anticipated to have the effect of lowering greenhouse gas emissions from newly manufactured vehicles. However, in other respects, the growing market share of electric vehicles also brings with it new difficulties, like issues with technological transfer, excessive increases in electricity use, and sustainable production. In addition to putting manufacturers and consumers at unnecessary financial risk, these issues have the potential to undo the environmental benefits of lower tailpipe emissions. To overcome such obstacles, then, the EV power train's power flow must be optimized using one of three techniques: discrete multi-speed transmission, CVT with multiple motor arrangements. The most recent research on the three approaches has been thoroughly addressed in this work with regard to methodology and important conclusions. The approaches are then contrasted in order to evaluate their benefits and drawbacks. To put it briefly, multispeed discrete transmission particularly two-speed discrete transmission has a useful small design that makes it ideal for electric vehicle power trains. Consequently, the extra weight that comes with having a gearbox in an EV may be reduced, and the shifting technique can be made easier to use and more efficient to prevent too many gear changes that could impair driving comfort.

REFERENCES

[1] Salmasi F.J., ”Control Strategies for Hybrid Electric Vehicles: Evolution, Classification, Comparison, and Future Trends”, IEEE Transactions on Vehicular Technology, vol. 56, 2007, pp 2393-2404

[2] Wirasingha S.G. , Emadi A., ”Classification and review of Control Strategies for Plug-In Hybrid Electric vehicles”, IEEE Transactions on Vehicular Technology, vol. 60, 2011, pp 111-122

[3] LeeH.andKooE.,SulS.,kimJ.,”Torquecontrolstrategyforaparallel- hybrid vehicle using fuzzy logic”, IEEE Industry Applications Magazine, vol. 3, 1998, pp 1715-1720

[4] Philips A.M. , Jankovic M. , Bailey K.,”Vehicle system controller design for a hybrid electric vehicle”, IEEE International Conference on Control Applications, 2000, pp 297-302

[5] Banvait H. , Sohel S. , Chen Y.,”A rule-based energy management strategy for plug-in hybrid electric vehicle (PHEV)”, American Control Conference, 2009, pp 3938-3943

[6] Delpar S. , Lauber J. , Guerra T.M. and Rimaux J.,”Control of a parallel hybrid powertrain: Optimal control”,IEEE Transactions on Vehicular Technology, vol. 53, 2004, pp 872-881

[7] Moura, S.J. , Fathy H.K. , Callaway D.S. , Stein J.L. ,”A Stochastic Optimal Control Approach for Power Management in Plug-In Hybrid Electric Vehicles”,IEEE

Transactions on Control Systems Technology, vol. 19, 2010, pp 545-555

[8] M. Moeini-Aghtaie, A. Abbaspur, M. Fotuhi-Firuzabad, and P. Dehghanian, “PHEV's Centralized/Decentralized Charging Control Mechanisms: Requirements and Impacts”, The 45th North American Power Symposium, NAPS, 22-24 Sep. 2013, Kansas State, USA

[9] Y. Jingyu, X. Guoqing, X. Yangsheng, and X. Benliang, "Battery state-of-charge estimation based on H ∞ filter for hybrid electric vehicle," presented at the Control, Automation, Robotics and Vision, 2008. ICARCV 2008. 10th International Conference on, 2008

[10] P. Dehghanian, S. H. Hosseini, M. Moeini-Aghtaie, and S. Arabali, “Optimal Siting of DG Units in Power Systems form a Probabilistic Multi-Objective Optimization Perspective”, International Journal of Electrical Power and Energy Systems, vol.51, pp.14-26, October 2013

[11] Cheng Wang, "Prediction of battery-SOC of pure electric vehicle," Computer Science & Education (ICCSE), 2012 7th International Conference on , vol., no., pp.466,469, 14-17 July 2012

[12] Xudong Liu; Qingwu Fan; Kun Zheng; Jianmin Duan; Yu Wang, "Constant SOC control of a series Hybrid Electric Vehicle with long driving range," Information and Automation (ICIA), 2010 IEEE International Conference on , vol., no., pp.1603,1608, 20-23 June 2010

[13] Zhu Daowei; Xie Hui, "Control strategy optimization of the hybrid electric bus based on remote self-learning driving cycles," Vehicle Power and Propulsion Conference, 2008. VPPC '08. IEEE , vol., no., pp.1,5, 3-5 Sept. 2008

[14] Weimin Li; Guoqing Xu; Zhancheng Wang; Yangsheng Xu, "Dynamic energy management for hybrid electric vehicle based on adaptive dynamic programming," Industrial Technology, 2008. ICIT 2008. IEEE International Conference on, vol., no., pp.1, 6, 21-24 April 2008

[15] Lot, R.; Evangelou, S.A., "Green driving optimization of a series hybrid electric vehicle," Decision and Control (CDC), 2013 IEEE 52nd Annual Conference on , vol., no., pp.2200,2207, 10-13 Dec. 2013

[16] M. Miyatake and H. Ko, “Optimization of train speed profile for minimum energy consumption,” IEEJ Transactions on Electrical and Electronic Engineering, vol. 5, no. 3, pp. 263–269, 2010.

[17] Mk Rizzo, D.M.; Parker, G.G., "State of charge optimization for military hybrid vehicle microgrids," Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES , vol., no., pp.1,6, 24-27 Feb. 2013