Drive Train Optimization of Electric Vehicle with Grey Wolf Optimization

Munish Kumar[1] Ankush Sharma[2]
[1]M. Tech Scholar [2]Assistant Professor
[1,2]Department of Electrical Engineering
[1,2]RPETGI, Bastara, Karnal, India

Abstract— In this work, we developed an EV drive train configuration with the help of AC motors. The developed model contains a battery source, AC motors (Induction squirrel cage) and Synchronous (PMSM), motor controller DTC (Direct torque control) and FOC (field Oriented control), PI control, wheels configuration (Front and Rear) and vehicle body. The three-phase squirrel cage induction motor connected at rear wheels and synchronous motor connected at the front wheels. We proposed two control methods with PI configuration for speed control of AC motors. Grey wolf optimization used to optimize the gain parameters of PI control. GWO based optimized PI controllers can adjust their gains values (K_p and K_i) in correspondence to deviations of EV speed and torque and results in stable speed and torque conditions. The model developed on the Simulink tool of Matlab.

Keywords: GWO, PMSM Motor, PI Controller, Electric Vehicle Drive Train, Battery, Motor, Matlab

I. Introduction

In the present days, the vehicles are heavily used for common transportation applications. The conventional energy sources like oil and gas were used as fuel sources of different vehicles. Since the year 2000, electric vehicles are commonly used in various countries. Within the previous few years, the electric vehicle is a good topic for the research community. The drive train can be the main challenge for the researchers.

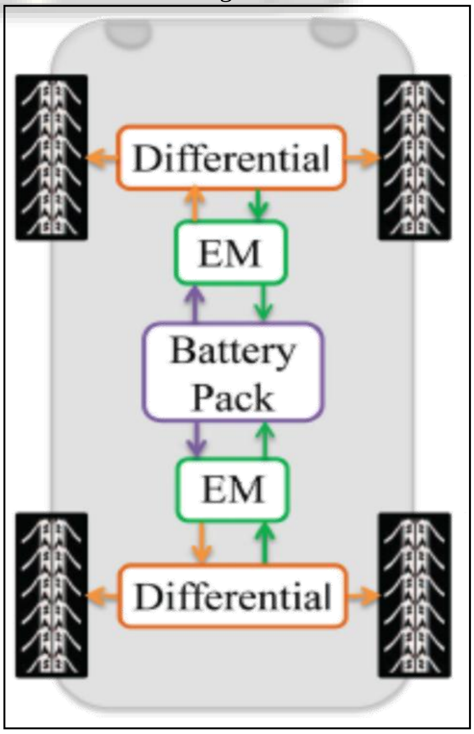

Fig. 1: EV schematic arrangement [3]

Figure 1 shows the schematic arrangement of the Electric vehicle drive train configuration. In this configuration, a battery pack is used to provide the dc energy to the circuit which is further connected to the inverter circuit.

In this basic configuration of EV, the four wheels are used. Two wheels are connected in the front portion called front wheel drive. Rest of two wheels connected at the rear portion of the drive, so it is called real wheel drive. Both the ends wheels are connected through the differential. The differential is provided the balancing to the rear and front wheel drive system. The differential portion represents a gear mechanism that allows the driven shaft to spin at different speeds. The fidelity of the gear model improved by specifying the parameters of the differential gear system like gear inertia, meshing, and viscous losses.

A battery pack is used as the source of the electric vehicle model. A lithium-ion battery fixed in the modeling of Electric Vehicle (EV) which provides input supply both the motors connected across the front and rear end of the model.

The induction motor and synchronous motor used for the driven portion of the electric vehicle due to their several advantages as studied earlier. On the rear wheel, a squirrel cage induction motor is connected due to high efficiency and high starting torque requirement. An induction motor has both characteristics efficiently. The high starting torque demand is complete by the induction motor which helps the electric vehicle in the initial stage. At front wheel portion, the synchronous motor is connected due to their high power density and constant speed characteristics. The control operation performed by the inverter which provides three phase ac supply to the induction and synchronous motor.

II. Objectives

The EV performance is dependent upon the battery of EV; less is the battery consumption more is the performance. Battery discharge of EV mainly depends upon the vehicle configuration and driving style. Driving style is very unpredictable though ideal driving behavior is defined in each scenario like in the city, on highways, etc. So researchers mainly focused on optimizing the vehicle configuration. Previously the configuration was optimally designed by weighted Genetic Algorithm by J. J. Eckert (2017). But the GA is very old and local optimization algorithm which stuck at local minima. The optimal configuration at the output of GA may not be optimal in actual. GA lacks in case of multi-objective and multi-constraint optimization problems whereas EV vehicle configuration optimization is a multi-constraint and multi-objective problem.

Considering the following points, objectives of proposed work are;

– To minimize the battery discharging to improve the EV performance

- To use global heuristic optimization name Grey Wolf optimization Algorithm (GWO)to minimize the battery discharge considering the tire torque, wheel torque, number of electric motors, drive train torque and speed as dependent parameters.
- To compare the results of improved vehicle performance with GA and GWO.

III. RESULT AND DISCUSSION

The proposed EV prototype structure is shown in figure 2 that consists of independently controlled front and rear wheel drive systems to enhance the driving performance and to keep the anticipated torque and speed conditions in EV is verified in Matlab/Simulink environment. As formerly mentioned, to increase the steering ability in traffic congestion and the requirement of efficiently generated torque at the low-speed permanent-magnet synchronous motor (PMSM) is used in the front drive system. To maintain driving torque under high speed and overload conditions induction motor (IM) in the rear drive system is preferred. The rotor of these motors is straight coupled with a respective differential gear, and with the help of these gears, the generated motor driving torques are transmitted to the respective wheel sides.

Parameters	Values
Total EV mass	980 kg
Wheels per axel	2
Gravitational acceleration	9.83 m/s^2
Vehicle frontal area	1.8 m^2
Differential efficiency	0.9
Drag coefficient	0.33
Wheel radius	0.406 m
Tire peak friction coefficient (μ)	0.9
Inertia for drive shaft	12 $kg.m^2$
Lateral inertia	4.12$kg.m^2$
Beta value	15
Engine RPM	1600

Table 1: Simulated EV body parameters

A. *System Parameters*

The used parameters for EV body, front and rear wheel drive systems and controllers in proposed EV simulations are with this given in this section. Firstly, the EV body parameters are similar to the reference [3] with some necessary modifications are given by using table 1.

The rear wheel drive system parameters used for the simulation and their values are shown by using the table 2

Parameters	Values
Stator resistance; R_s (p.u)	0.0139Ω
Stator leakage inductance;L_{ls}(p.u)	0.0672 H
Rotor resistance, referred to the stator side;R_r(p.u)	0.0112Ω
Rotor leakage inductanc referred to the stator side;L_{lr}(p.u)	0.0672 H
Magnetizing inductance;L_m(p.u)	2.717 H
Moment of inertia;H	0.2734$kg.m^2$
Number of pole pairs;p	2
Friction coefficient; F	0.0106
Rated frequency, f_n	60 Hz

Table 2: rear wheel drive system parameters

The front wheel drive system parameters used for the simulation and their values are shown in table 3

Parameters	Values
Permanent magnet flux linkage	0.03 weber-turns
d-axis inductance;L_d	2e-4H
q-axis inductance;L_q	2e-4H
0-axis inductance;L_0	2e-4 H
Stator resistance,R_s	0.013Ω
Moment of inertia; J	0.2$kg.m^2$
Number of pole pairs; N	6
Nominal frequency, f_{rom}	60 Hz

Table 3: front wheel drive system parameters

Furthermore, the wheel drive systems are controlled with the help of individual controller and PWM inverters. EV management controller throughout supervised the considered wheel drive systems. Moreover, it appropriate controls the front and rear wheels distributed torque rendering to running conditions and result in enhanced EV operating efficiency overall speed regions.

B. *Simulation*

To describe the behavior, speed and torque characteristics of the proposed EV wheel drive system, simulations are carried out using the model built in Matlab/Simulink which is shown in figure 2.

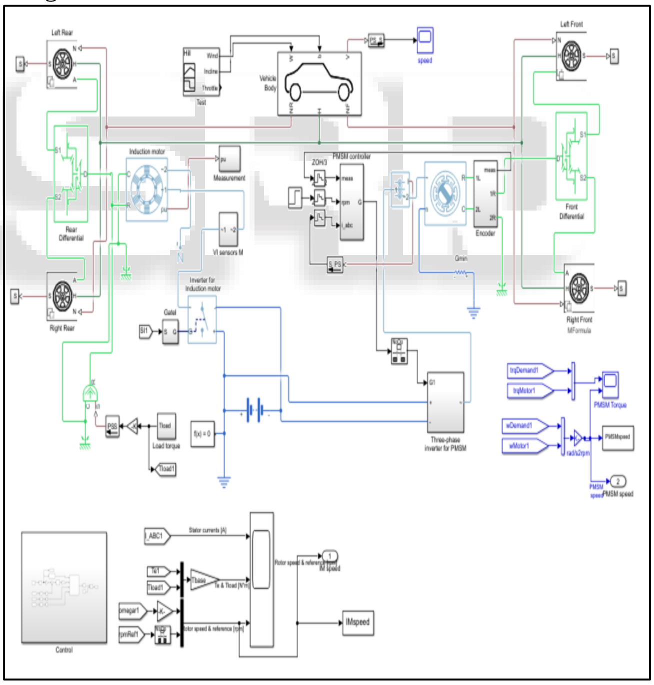

Figure 2 proposed EV wheel drive system Simulink model

The simulation results of the proposed EV wheel drive system are presented into two phases. Firstly, simulations are carried out to get the EV performance with the help of individual PI controllers for both front and rear wheel drive systems. \Also, the direct torque controllers (DTC) are tested MATLAB/Simulink environment and their impact on the four-wheel drive (4WD) Electrical Vehicle system model to achieve the desired torque and speed conditions is presented. The DTC gives a fast response of flux and torque control for used drive systems. The speed for both front and rear wheel drive systems are calculated independently for getting better tuning of used PI controllers.

Also, their differential systems that distribute power and torque to the connected wheels as per the requirements and adapts according to the actual driving speed. As we are using PI controllers, the control performance of these is very easy to understand and is very easy to implement in practical applications. However, a lot of skills and time is required for the tuning of PI controllers gains in the actual environment and every time we have to change the values of proportional and integral gain under different conditions to ensure optimal performance of 4WD-EV.

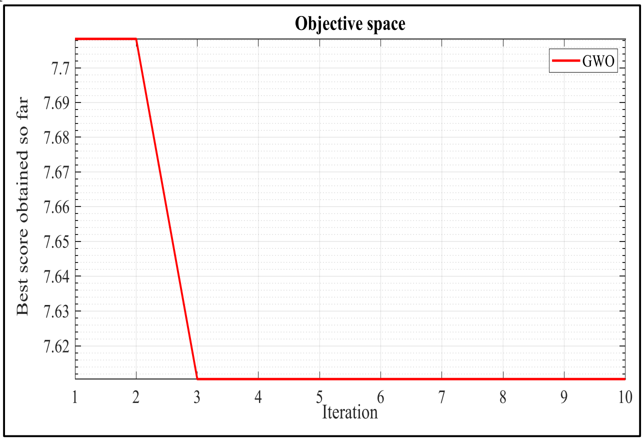

Fig. 3: GWO optimizer convergence curve

In the second phase, a "Grey Wolf Optimizer" (GWO) along with PI-based DTC controllers in proposed EV drive system model is used. With the help of this optimizer, the problems associated during the tuning procedure of PI controllers are minimized. The help of GWO increases the possibility of achieving quick and accurate control on speed and distribute torque. Also, this optimizer helps in getting better speed and torque stability performance for the considered EV. The optimization process, theory, and working of GWO considered for EV are mentioned in the previous chapter.

The simulation results of both controlling phases, i.e., with and without GWO optimization analyzed to show the feasibility of the proposed EV drive system model. The speed and torque control of EV is executed through the torque distribution in front and rear wheel drive by the following running modes. Figure 3 shows the GWO optimizer convergence curve.

1) Initial Starting mode

At starting this mode appears, when the key connected with the battery source is turned on the front, and rear wheel drive motors get the supply and start functioning. And EV starts accelerating and the generated reference torque from the accelerator distributed to rear wheel drive system. Instantaneously after sensing the rotor position, it shifts to normal mode operation, and that is favorably distributed to the front drive system. Figure 4 shows the comparison of un-optimized and GWO optimized front wheel drive system speed. In this figure, it is seen that un-optimized speed is oscillating to its reference speed; this is because we conventional PI controllers are used in this phase. This can result in unstable steering and seed operations and a lot of efforts are required to make EV stable. This oscillating speed also creates a safety issue for the passengers. Also, the un-optimized EV drive system requires almost 4 seconds making the speed constant. On the other hand, by using an optimized controller, we can obtain stable speed which is almost equal to the front wheel drive reference speed. Also, to the reduced speed error, the controller takes the very small time of 0.25 seconds to attain its reference value. And also, by the help of GWO optimizer generated oscillation in EV speed is eliminated. In rear wheel drive, system speed curves are shown in Figure 5. This figure shows that this speed becomes stable in very less time and rear wheel drive speed also becomes synchronized with the front wheel speed of 1600 rpm.

2) Normal Running mode

In this phase, the generated reference torque is mainly distributed to the front wheel drives and results to attain the steering stability on poor road conditions. Also, the distribution of torque in the rear wheels is done in such a way, that rear wheels are always in agreement to the speed of the front wheel drive systems. In figure 4 and 5 we can observe that during normal running conditions the speed of both front and rear wheels are becoming stable having a value of 1600 rpm. And we can easily saw the synchronization between these wheel drive systems.

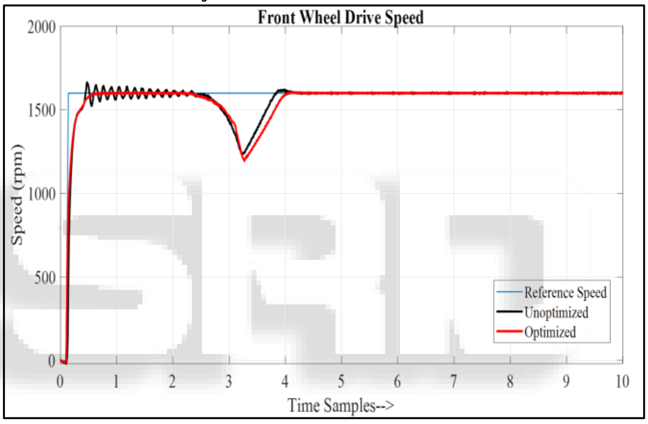

Fig. 4: Front wheel drive speed

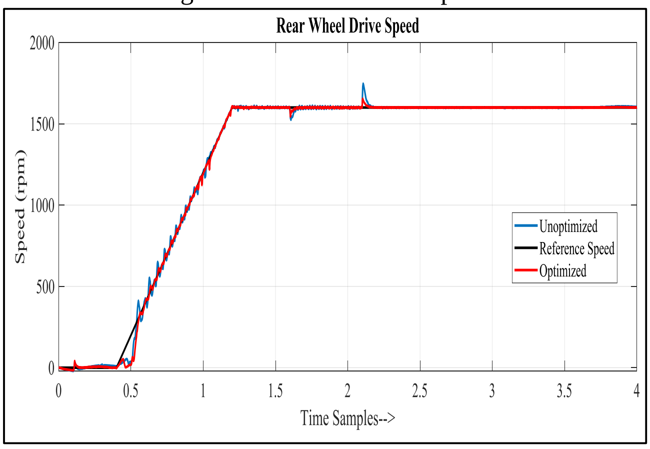

Fig. 5: Rear wheel drive speed

Figure 6 shows the optimized total EV speed, in this figure from 0to 4 seconds, i.e. in initial starting and acceleration mode the speed of the EV is increasing. After a time of 4 seconds, the speed of the EV becomes almost stabl, i.e. EV is running in normal mode.

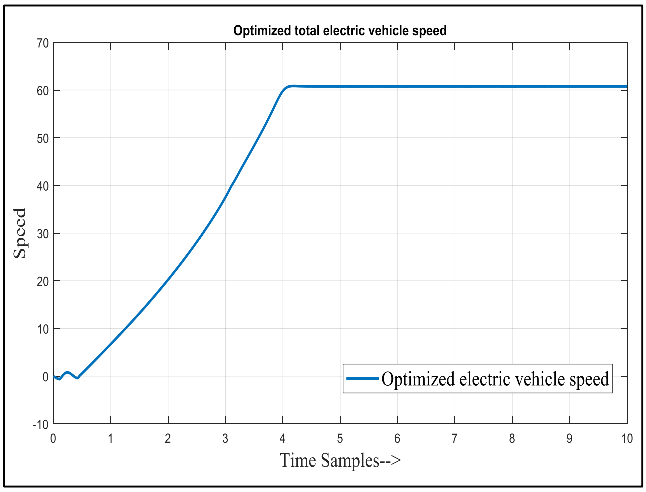

Fig. 6: Optimized total electric vehicle speed

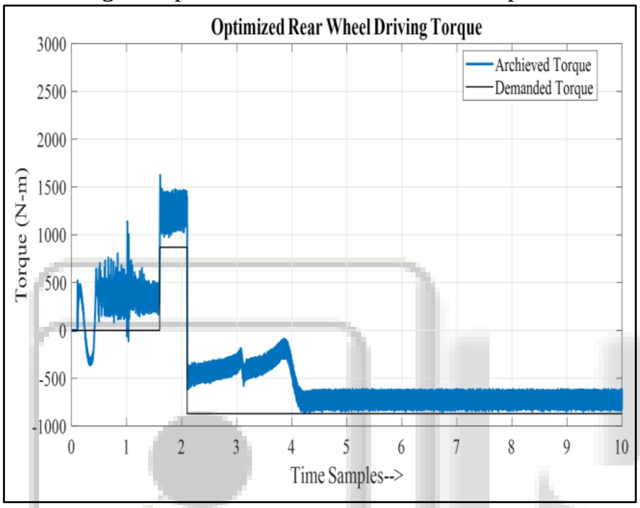

Fig. 7: Optimized rear wheel driving torque

Figure 7 and 8 shows the optimized generated rear wheel driving torque and front wheel driving torque respectively. During initial starting mode and acceleration mode as large torque is required, in this acceleration period both wheel drive system act simultaneously and supports each other at every instant of time and provides large torque as shown in figures. EV optimized management controller throughout supervised the considered wheel drive systems. Moreover, it appropriate controls the front and rear wheels distributed torque rendering to running conditions and result in enhanced EV operating efficiency overall speed regions.

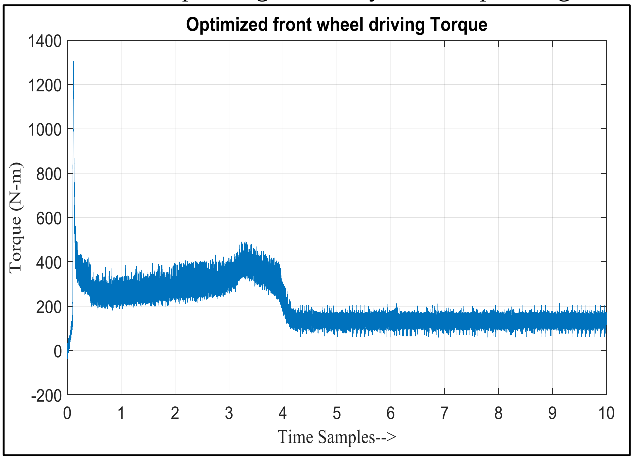

Fig. 8: Optimized front wheel driving torque

IV. Conclusion

The Proposed EV wheel drive system which is having individual front and rear control, improves the EV performance such as torque and speed stability, steer ability, drivability, and safety at low speed and high-speed operations. Also, the wheel drive systems were founded in such a way that above stated EV performance requirements attained more efficiently. The drive systems are also successfully synchronized in such a way that, if in some adverse conditions torque generated from the front wheel drive is found insufficient to drive the EV at desired speeds at the same time rear wheel drive system provides the adequate torque to the EV. In this work, firstly this synchronization and controlling of the drive system are achieved by conventional un-optimized PI controllers. Then later on the performance of drive controllers are further increased by the help of GWO along with DTC.

The simulation results also show the effectiveness of used optimization over PI controllers. Optimized EV system model achieves stable speed and torque in starting and normal running mode operations very quickly. Also, the results with GWO optimization are very accurate as compare to un-optimized controls. Thus the implementation of GWO in EV wheel drive control system is found successful.

References

[1] N. Janiaud, F. Vallet, M. Petit and G. Sandou, "Electric vehicle powertrain simulation to optimize battery and vehicle performances," 2010 IEEE Vehicle Power and Propulsion Conference, Lille, 2010, pp. 1-5.

[2] Y Mastanamma, Dr M Aruna Bharathi, “Electric Vehicle Mathematical Modelling and Simulation Using MATLAB-Simulink” IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), Volume 12, Issue 4 Ver. I (Jul. – Aug. 2017), PP 47-53.

[3] J. J. Eckert, L. C. A. Silva, E. S. Costa, F. M. Santiciolli, F. G. Dedini and F. C. Corrêa, "Electric vehicle drive train optimization," in IET Electrical Systems in Transportation, vol. 7, no. 1, pp. 32-40, 3 2017.

[4] Wang, Y., Lü, E., Lu, H., Zhang, N., & Zhou, X., “Comprehensive design and optimization of an electric vehicle power train equipped with a two-speed dual-clutch transmission” Advances in Mechanical Engineering, vol-9, no.-1,2017, pp 1-13.

[5] M. W. Salehen, P & Su'ait, Mohd&Razali, H & Sopian, Kamaruzzaman, “Battery management systems (BMS) optimization for electric vehicles (EVs) in Malaysia” AIP Conference Proceedings, 2017, pp 1-7.

[6] Tengku Mohd, Tengku Azman & Hassan, Mohd Khair &A Aziz, Wmk, “Mathematical modeling and simulation of electric vehicle using matlab-simulink” research gate, 2014, pp 1-10.

[7] A. Bhatt, "Planning and application of Electric Vehicle with MATLAB/Simulink," IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Trivandrum, 2016, pp. 1-6.

[8] David McDonald, “Electric Vehicle Drive Simulation with MATLAB/Simulink” Proceedings of North-Central Section Conference Copyright © American Society for Engineering Education, 2012, pp. 1-24.

[9] N. Mutoh, Y. Miyamoto, T. Horigome and K. Takita, "Driving characteristics of an electric vehicle system with independently driven front and rear wheels," IECON'03.29th Annual Conference of the IEEE Industrial Electronics Society (IEEE Cat.No. 03CH37468), Roanoke, VA, USA, 2003, pp. 931-938 vol.1.
[10] J. Kang, J. Yoo and K. Yi, "Driving Control Algorithm for Maneuverability, Lateral Stability, and Rollover Prevention of 4WD Electric Vehicles With Independently Driven Front and Rear Wheels," in IEEE Transactions on Vehicular Technology, vol. 60, no. 7, pp. 2987-3001, Sept. 2011.
[11] L. C. A. Silva, J. J. Eckert, F. M. Santiciolli, E. S. Costa, F. G. Dedini and F. C. Corrêa, "A study of battery power for a different electric vehicle propulsion system," 2015 International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles (ESARS), Aachen, 2015, pp. 1-6.
[12] Eckert, Jony&Santiciolli, Fabio & Silva, Ludmila& S. Costa, Eduardo &Corrêa, Fernanda & G. Dedini, Franco, “Co-simulation to evaluate acceleration performance and fuel consumption of hybrid vehicles” Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2014, pp-1-14.
[13] P. Liu and H. P. Liu, "Permanent-magnet synchronous motor drive system for electric vehicles using bidirectional z-source inverter," in IET Electrical Systems in Transportation, vol. 2, no. 4, pp. 178-185, December 2012.
[14] X. Yuan and J. Wang, "Torque Distribution Strategy for a Front- and Rear-Wheel-Driven Electric Vehicle," in IEEE Transactions on Vehicular Technology, vol. 61, no. 8, pp. 3365-3374, Oct. 2012.
[15] T. Hofman and C. H. Dai, "Energy efficiency analysis and comparison of transmission technologies for an electric vehicle," 2010 IEEE Vehicle Power and Propulsion Conference, Lille, 2010, pp. 1-6.
[16] Jiankun Peng, Hongwen He and Nenglian Feng, “Simulation Research on an Electric Vehicle Chassis System Based on a Collaborative Control System” Energies 2013, 6, 312-328.
[17] R. Das, K. Thirugnanam, P. Kumar, R. Lavudiya and M. Singh, "Mathematical Modeling for Economic Evaluation of Electric Vehicle to Smart Grid Interaction," in IEEE Transactions on Smart Grid, vol. 5, no. 2, pp. 712-721, March 2014.
[18] L. Pieltain Fernandez, T. Gomez San Roman, R. Cossent, C. Mateo Domingo and P. Frias, "Assessment of the Impact of Plug-in Electric Vehicles on Distribution Networks," in IEEE Transactions on Power Systems, vol. 26, no. 1, pp. 206-213, Feb. 2011.
[19] Michael A. Roscher, Jens Vetter, Dirk Uwe Sauer, Characterisation of charge and discharge behavior of lithium ion batteries with olivine based cathode active material, Journal of Power Sources, Volume 191, Issue 2, 2009, Pages 582-590.
[20] A. Wicaksono and A. S. Prihatmanto, "Optimal control system design for electric vehicle," 2015 4th International Conference on Interactive Digital Media (ICIDM), Bandung, 2015, pp. 1-6.
[21] Jian Zhou, Xiangming Shen and Dong Liu, "Modeling and simulation for electric vehicle powertrain controls," 2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific), Beijing, 2014, pp. 1-4.
[22] Y. Hori, "Future vehicle driven by electricity and Control-research on four-wheel-motored "UOT electric march II"," in IEEE Transactions on Industrial Electronics, vol. 51, no. 5, pp. 954-962, Oct. 2004.
[23] Faris, Hossam & Aljarah, Ibrahim & Al-Betar, Mohammed & Mirjalili, Seyedali, “Grey wolf optimizer: a review of recent variants and applications” Neural Computing and Applications, 2017.

