

Control Systems for High Performance Electric Cars

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Abstract

Electric vehicle technology opens doors to a wide range of research and improvement possibilities which can be used to develop a High Performance Full Electric Competition Car. However, in our modern-day society, there are numerous prejudices against electric vehicles which lead to their slow introduction in the market.

In this context, IDIADA has been commissioned to build Volar-e with the aim to help overcoming the current technological and social barriers of electric vehicles and to set new standards in their behaviour. In order to achieve this target, Volar-e incorporates four independently controlled electric motors. What is more, a central concept to the vehicle is the integration of an intelligent torque distribution strategy to enhance road holding, handling and performance.

Applus IDIADA's knowledge of torque vectoring technologies has led to further developments and, thus, to the incorporation of four active systems in the prototype: iTORQ+, iTORQ-, Traction Control and Launch Control. These systems have been designed with the objective of both maximizing lateral acceleration while maintaining vehicle stability and drivability and, in the overall, minimizing lap time around IDIADA's tracks.

This paper highlights the improvement of Volar-e's behaviour thanks to implementing in it the previous mentioned control systems. A detailed model of Volar-e has been parameterized in *CarSim*®, encompassing not only a thorough powertrain model obtained from testing Volar-e's electric motors on a test-bench, but also a complete suspension model defined from K&C tests. By means of different simulation manoeuvres, the systems have been finely developed and adapted to fulfil the premise of achieving a high performance electric vehicle and to define the best initial set of parameters before passing from theory to practice. Last but not least, some conclusions are presented.

Keywords: Control system, EV (electric vehicle), traction control, torque, vehicle performance

1 Introduction

In our days of *green politics*, electric vehicles (EV) play a vital role. In 2009, EU and G8 leaders agreed that global warming cannot exceed an increase of 2°C and therefore CO₂ emissions must be cut by 80 % by 2050 [1]. The transportation sector accounts for 44 % of total CO₂ emissions. Hence, transportation needs a dramatic change: as an 80 % decarbonisation overall requires 95 % decarbonisation of the road transport sector [2]. With the number of cars set to rise to 2.5 billion worldwide by 2050 (according to EC 2010 [3]), this is not achievable through improvements of Internal Combustion Engines (ICE).

Nonetheless, a major issue is that society is still reluctant to believe in EV's potential. On the one hand, a main concern is the vehicle range and, on the other hand, the battery charge and management. With existing internal combustion powertrains we can drive our cars for more than 500km and we can rapidly fill them up anywhere. What is more, in contrast with ICE, the ratio time driven vs. recharge time of an EV is really low, which all together sets a quite high bar for the new EV market entrants [4, 5]. In this frame of reference, Volar-e (see Figure 1) appears as a ground-breaking prototype. Not only has it been designed to have the highest range possible while being very powerful, but it has also been dimensioned to handle an ultra-fast charge

Taking this into consideration, Volar-e also aims to go a step further. On conventional vehicles with combustion engines, distributing and varying wheel-torques is always synonymous to weight, complex hardware and costs. Volar-e is an EV with four independent on-board wheel electric motors. Hence, by means of a controller, it is possible to instantly and accurately distribute torque around the vehicle using a much simpler method than the mechanical devices currently used.

Bearing the previous paragraph in mind and with the objective of making from Volar-e a referential high performance EV, four active systems have been implemented in it: iTORQ+, iTORQ-, Traction Control and Launch Control. Not only are they samples of the latest technologies in active systems, but they also represent the way to take the behaviour of Volar-e to new levels. Taking this into account, a brief description of each system is presented.



Figure 1: Volar-e

1.1 iTORQ+

Volar-e incorporates an adapted and adjusted version of iTORQ, IDIADA's Torque Vectoring technology for electric vehicles, to properly distribute the torque among the four wheels [6, 7]. iTORQ+ is designed to maximise cornering performance, increasing both upper lateral acceleration levels as well as enhanced transient performance under high-throttle inputs [8]. It is intended to intervene during all vehicle operating ranges up to the limit.

1.2 iTORQ-

iTORQ- is a complementary function to iTORQ+ designed to intervene while braking. One of its main targets consists of improving the vehicle behaviour during corner entry in order to obtain a more stable and predictable turn-in [9]. Moreover, as it is integrated into the regenerative braking functions, it works to convert as much kinetic energy as possible into electric energy and hence increase vehicle range.

1.3 Traction Control and Launch Control

With the intention of minimising the consequences of losing traction, two systems have been implemented in Volar-e: Traction Control System (TCS) and Launch Control System (LCS). Both of them intend to prevent the wheels from slipping, but there is a main difference between them that must be underlined. On the one hand, Traction Control (TC) is an active system based on doing closed-loop control around wheel slip [10]. If wheel slip is detected, then TC automatically reacts and actuates over the torque. On the other hand, Launch Control (LC) prevents the wheel slip at a launch manoeuvre by distributing the wheel torque according to a calibration map obtained, at a first stage, by means of simulations.

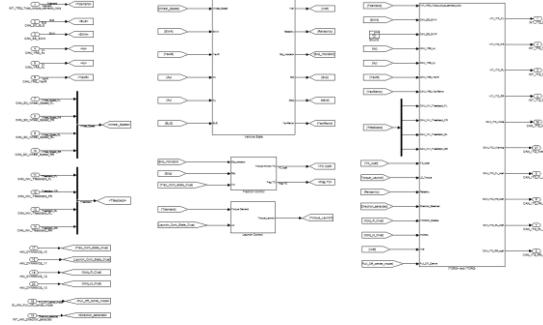


Figure 2: Overview of the *Simulink* model for the control systems

2 Simulink Models

The design for the different control systems has been carried out in the latest *MatLab/Simulink* environment. Furthermore, they have been developed as an open architecture platform suitable for further research. Figure 2 represents the subsystem containing all the control systems.

2.1 iTORQ+

Regarding iTORQ+, working from driver inputs like throttle or Steering Wheel Angle (SWA) and vehicle state parameters such as Yaw Rate, lateral acceleration (A_y) and longitudinal acceleration (A_x), wheel speeds and wheel torques, the algorithm calculates the best torque distribution to optimize Volar-e's behaviour and sends torque orders to each individual motor. Figure 3 shows the structure designed for iTORQ+.

Firstly, in the *Mode Selector* subsystem, the dynamic driving conditions of the vehicle (vehicle state inputs) are considered so as to assess which iTORQ+ mode should be activated to obtain a better handling and a safer operation of the vehicle: On Centre, Off Centre or Blend Out. Each of these modes stands for a certain iTORQ+ operating zone which mainly depends on a predefined range of lateral acceleration (A_y) values. Once the mode is selected, the torque is distributed among the wheels in the subsystem *Modes*. Finally, these torques are post processed taking into account the state and outputs from the TCS and the LCS.

It is important to highlight that the different dynamic control systems do not act independently from each other. There is an internal relation between them that must be respected. A clear example is that TC can actuate always when a wheel is slipping, regardless if iTORQ+ is active or not.

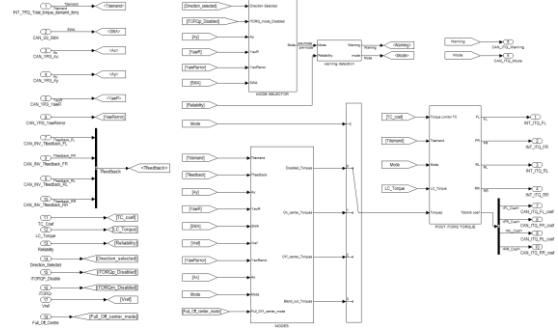


Figure 3: iTORQ+ *Simulink* model

2.2 iTORQ-

Due to the fact that iTORQ- is a complementary function to iTORQ+, a similar strategy has been followed to design its model. The subsystem *Modes* in Figure 3 takes into account if the torque input refers to brake torque or not and, depending on the case, iTORQ- or iTORQ+ is triggered. However, a main difference must be remarked: iTORQ- is only centred in distributing the brake torque between the left and right sides of Volar-e. First and foremost, iTORQ- is only focused on braking manoeuvres while being in a **turn**. Secondly, it works hand in hand with the regenerative braking functions, which already take into consideration brake torque distribution between front and rear axles. Last but not least, Volar-e is a racing vehicle, that is, it is designed for being driven in **high speed** situations. At high speeds, because of the drag resistance [11], more weight is placed on the rear axle compared to low speed situations. Therefore, rear wheels are more capable of transferring brake torque, although during braking there is indeed a load transfer from the rear axle to the front one.

It needs to be pointed out that, although Volar-e does not have ABS, brake torques can be used as an alternative to actively control it via preventing the wheels from locking up. By correctly proportioning the brake torque between the foundation brakes and the engine brake torque, Volar-e's performance can be optimized.

2.3 Traction Control

To prevent wheel slip and hence loss of traction, the TC system of Volar-e has been designed to intelligently limit the amount of power supplied to the wheels. If loss of adherence occurs, the TC will immediately decrease the torque applied on the wheels necessary to maintain traction between wheel and road surface. As can be observed in Figure 4, the TCS outputs a flag which indicates if

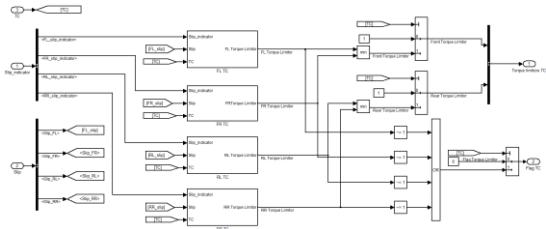


Figure 4: Simulink model developed for TCS

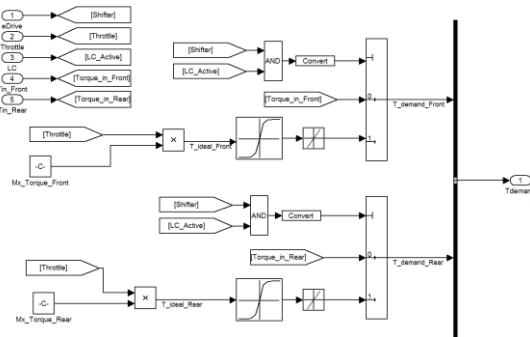


Figure 5: Simulink Model for the LCS

the system is working or not and torque limiting coefficients.

Moreover, although the torque limiting coefficients are calculated independently for each wheel, they are equally applied on the wheels of a certain axle. To be more precise, the minimum coefficient between the two wheels of an axle is chosen and applied to both of them, regardless of the fact that one of the wheels might not be slipping. The reason for implementing this strategy is to maintain the torque proportion between the wheels of the same axle constant. In this way, the creation of an additional yaw moment that could destabilize Volar-e is avoided.

2.4 Launch Control

As for the LC system (Figure 5), it consists of a torque distribution between the front and rear axle specifically designed for being implemented in a hard acceleration action carried out from a stationary position.

The aim is to make Volar-e accelerate smoothly and as fast as possible, avoiding the spinning of the driven wheels. In racing cars, this feature is only available at the start of the race, when the car is standing still in the starting grid. After the car is running at a certain speed, the system is disabled. Such an idea is implemented in Volar-e too. When LC is activated and the driver is

taking off, iTORQ+ and TC must be inactive, since LC entails its own torque distribution. However, as soon as the limit speed is reached, LC stops functioning and iTORQ+ together with TC start actuating if necessary. It has already been mentioned above that the dynamic control systems are internally related.

3 Simulations

First and foremost, Volar-e has been developed and parameterized in *CarSim*© in order to obtain the most reliable vehicle simulation model. The overall *Simulink* scheme, together with the connection to *CarSim*©, can be seen in Figure 6.

Secondly, simulations have been carried out with the objective of assessing the behaviour of the previous mentioned systems and, thus, to see how they affect the performance of Volar-e. Moreover, thanks to simulations, the dynamic behaviour of Volar-e can be evaluated and characterized depending on different kinds of inputs and driving situations.

Furthermore, simulations are vital regarding the acquisition of experience with the systems and experimentation with their calibration and overall strategy. Although final tuning will always be conducted on the track, a good feeling and initial calibration can be obtained.

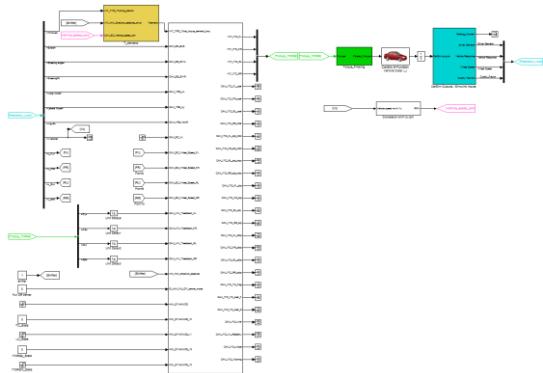


Figure 6: Scheme of the overall system model



Figure 7: Acceleration test in *CarSim*©.

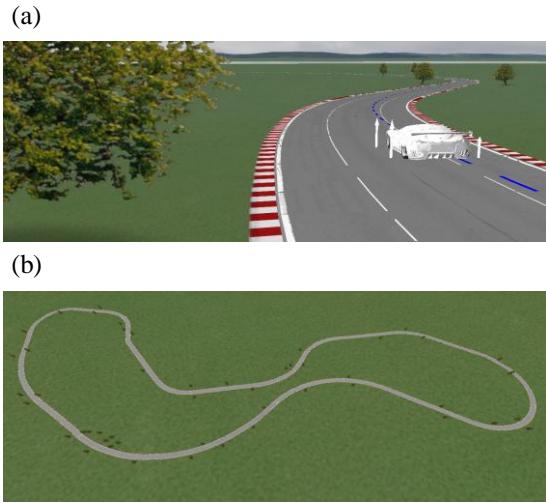


Figure 8: Dry Handling test in *CarSim*®. (a) Volar-e on the track. (b) Aerial view of IDIADA's Dry Handling track.

The driving manoeuvres reproduced in simulations to stress the differences between having the systems (Electronic Chassis Control Systems – ECCS- on) or not (ECCS off) are Steady State Constant Radius, Straight Line tests and closed loop tests on IDIADA's Digitalized Proving Ground (IDPG) such as the Dry Handling track. Thanks to this technology, the systems can be tuned so as to make Volar-e meet the previous mentioned targets: maximal lateral acceleration, stability and predictability during cornering and minimum lap time. Figure 7 and Figure 8 show two examples of the tests carried out in *CarSim*® environment: Acceleration test and a lap around IDIADA's Dry Handling track respectively.

4 Results

Regarding the Constant Radius manoeuvre, by having iTORQ+ and TC active, the understeering limit of Volar-e is modified favourably, as can be seen in Figure 9, demonstrating that both a higher limit Lateral Acceleration (A_y) can be obtained and better linearity up to 8m/s^2 . In addition, from Figure 10, it can be observed that agility is enhanced with the incorporation of the iTORQ+ and TC systems: for the same A_y , with iTORQ+ and TC on, Volar-e needs less degrees of steering wheel angle (SWA) than when these systems are deactivated, making the vehicle more easy to drive and predictable even up to high levels of A_y . As for Figure 11, it represents the wheel torques. In effect, they vary when

iTORQ+ is on and remain equally distributed among all the wheels when it is off.

From simulating a lap around IDIADA's Dry Handling track, the improvement of the vehicle handling can be emphasised. In Figure 12, it can be observed that, in effect, the SWA needed along the lap is smaller when the ECCS are on. What is more, such result can be considered as a remarkable milestone bearing in mind that Volar-e is a racing vehicle.

Referring to LC, the aim is to make Volar-e accelerate as fast as possible by avoiding the spinning of the driven wheels. With LC on, the slip is indeed reduced, as can be noticed in Figure 13, which entails two remarkable facts. On the one hand, the maximum longitudinal velocity (V_x) is higher (see Figure 14). On the other hand, looking at the slopes of V_x , it can be seen that longitudinal acceleration is also higher. In consequence, it can be said that the launch is improved.

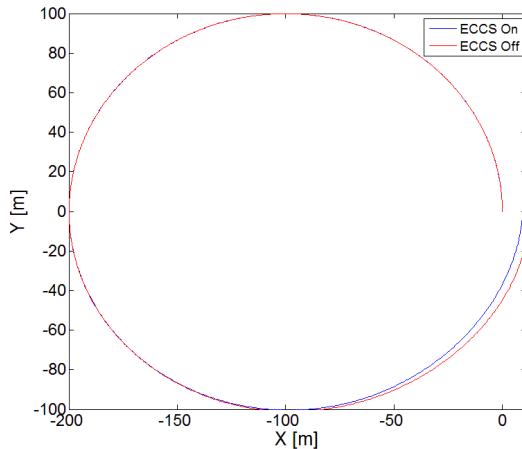


Figure 9: Trajectory resulting from the Constant Radius manoeuvre with ECCS on and off.

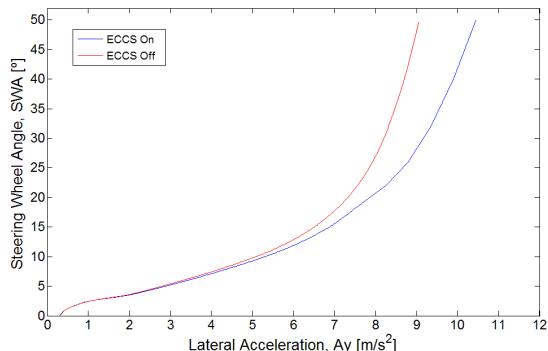


Figure 10: SWA vs. A_y resulting from the Constant Radius manoeuvre with ECCS on and off

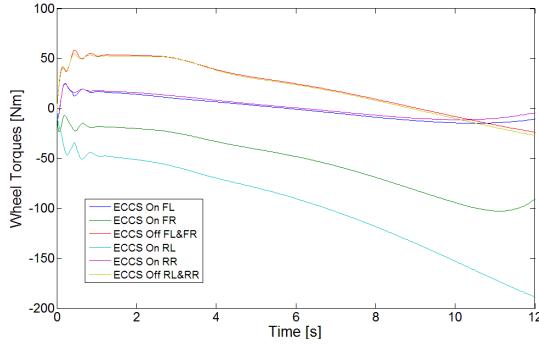


Figure 11: Wheel Torques resulting from the Constant Radius manoeuvre with ECCS on and off (Front Left, FL; Front Right, FR; Rear Left, RL; Rear Right, RR)

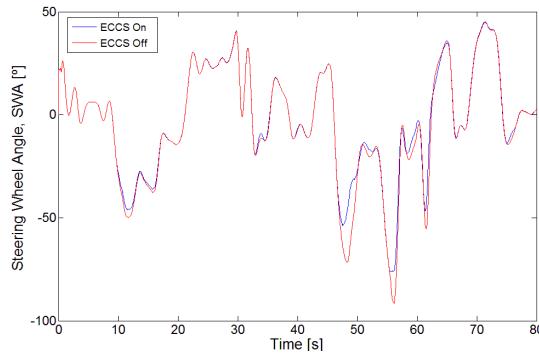


Figure 12: SWA during a lap along IDIADA's Dry Handling track with ECCS on and off.

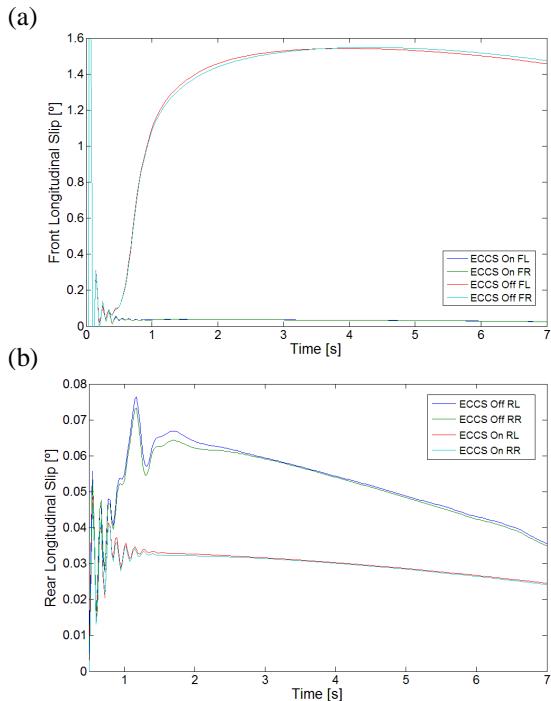


Figure 13: Longitudinal wheel slips from an acceleration test with the LCS on and off. a) Front wheel slips (Front Left, FL; Front Right, FR). b) Rear wheel slips (Rear Left, RL; Rear Right, RR)

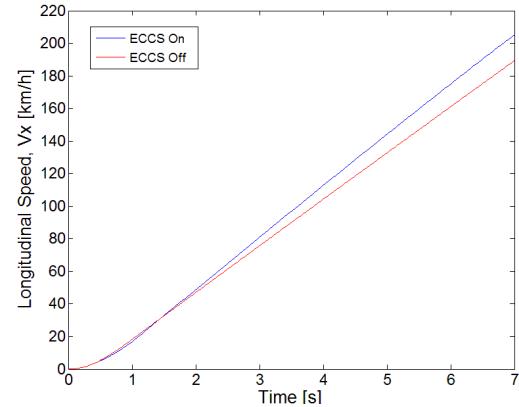


Figure 14: Longitudinal speed, V_x , from an acceleration test with the LCS on and off.

5 Conclusions

From the results shown in the previous section, it can be certainly concluded that Volar-e's handling is significantly affected by using a torque distribution strategy. More specifically, the following points have to be highlighted when it comes to handling and cornering:

- Improvements measured by SWA and lateral acceleration and lateral slip.
- Enhanced vehicle handling by reducing the SWA needed along IDIADA's Dry handling track.
- With iTORQ+ on, under-steering is decreased.

It can also be determined that there is an improvement of Volar-e's safety by preventing the wheels from slipping. Additionally, by reducing the slip, Volar-e's handling and stability can be maintained enabling an easier and safer driving.

When it comes to the LCS, it represents the implementation in Volar-e of a common element in high-performance vehicles. What is more, it has proven to indeed improve the launch of Volar-e by guaranteeing a better grip as soon as the throttle is pressed: less slip, more longitudinal acceleration and higher longitudinal velocity.

To summarise then, Volar-e is more predictable and behaves better with iTORQ+, iTORQ-, LC and TC implemented in it. Thanks to these four control systems, Volar-e's performance and handling are improved up to an exceptional good extent.

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References

- [1] Europa Press Releases, http://europa.eu/rapid/press-release_MEMO-07-16_en.htm?locale=en%3E, accessed on 2013-05-01
- [2] ECF: Roadmap 2050, *A practical Guide to a prosperous, low-carbon Europe*, www.roadmap2050.eu, accessed on 2013-05-01
- [3] European Commission, *The world in 2025, Rising Asia and socio-ecological transition*, ISBN 978-92-79-12485-3, Luxembourg, European Communities, 2009
- [4] MIT Technology Review, <http://www.technologyreview.com/featured/story/422133/will-electric-vehicles-finally-succeed/>, accessed on 2012-11-29
- [5] C. C. Chan, *The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles*, Proceedings of the IEEE, ISSN 0018-9219, April 2007, 704-718
- [6] B. R. Hoehn, K. Stahl, P. Gwinner, F. Wiesbeck, *Torque-Vectoring Driveline for Electric Vehicles*, Proceedings of the FISITA 2012 World Automotive Congress, ISSN 1876-1100, 191(2012), 585-593
- [7] M. Graf, M. Lienkamp, *Torque Vectoring Control Design Based on Objective Driving Dynamic Parameters*, Proceedings of the FISITA 2012 World Automotive Congress, ISSN 1876-1100, 196(2012), 1787-1796
- [8] Y. Shibahata, T. Tomari, *Direct Yaw Control Torque Vectoring*, AutoTechnology, ISSN 1616-8216, 2006-05-01, 34-38
- [9] M. Ehsani, Y. Gao, S. E. Gay, A. Emadi, *Modern electric, hybrid electric, and fuel cell vehicles: fundamentals, theory, and design*, ISBN 0-8493-3154-4, Boca Raton, Florida, CRC Press LLC, 2005
- [10] P. Kachroo, M. Tomizuka, *Vehicle Traction Control and Its Applications*, UCB-ITS-PRR-94-08, ISSN 1055-1425, March 1994
- [11] T. D. Gillespie, *Fundamentals of Vehicles Dynamics*, ISBN 1-56091-199-9, Warrendale, SAE, 1992

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