A Wireless Driving Cycle Test Observation Method for Electric Vehicles

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Abstract—In the course of the ongoing debate about the limited availability of fossil fuels and environmental impact of internal combustion engine powered vehicles, battery electric vehicles have been receiving increasing attention as an eco-friendly alternative. With the increase of the vehicles with smart units, it can be ensured that the vehicles communicate with the environment and other vehicles. This study focuses on the combination of two major trends, electric vehicles and vehicle to everything communications technology. On the Controller Area Network communication line of the vehicle, a gateway is physically implemented to transmit and receive the necessary signals of the vehicle wirelessly. Another gateway is located at a certain distance from the vehicle and allows the vehicle to be monitored in real time in driving cycles defined in EU regulations.

Keywords-*electric vehicles, vehicle-to-everything, short range communications.*

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I. INTRODUCTION

The electric vehicle concept has been used since the early days of the automotive industry. In fact, electric vehicles were more than vehicles equipped with internal combustion engines until 1910. At present, environmental factors and the rate of atmospheric pollution from internal combustion vehicles tailpipe emissions provide a high level of motivation for the use of electric vehicles [1]. Electric vehicles can regenerate the energy lost during braking by means of regenerative braking and provide improvements in vehicle range. However, despite the developing battery technology, electric vehicles offer a limited range of vehicles to the user [2-10].

Vehicles with an internal combustion engine are advantageous in the range due to the high energy density of the fuels and in contrast to the battery charging time, a rapid increase in range can be achieved due to charging capability within minutes. For these reasons, the production of electric vehicles remained limited.

The number of automobiles with only mechanical functions is decreasing considerably today and replacing with electromechanical system. The percentage of electronic and embedded components used in electric vehicles increases exponentially [6]. Electronic components are an important part of today's automobile technology and this trend is likely to increase in the future [11]. Today, there are around 20 electronic control units in middle class vehicles. In addition, there are many sensors and actuators (relay, motor, solenoid, etc.). Some of these systems increase vehicle safety while others are used only for comfort purposes.

In older vehicles the cable lines were drawn to control the sensors and actuators but information is now transmitted via only a few buses. Thus, advantages are obtained both in vehicle weight and cost. In addition, the data is sent digitally so the data is less likely to be corrupted. The number of controllers per vehicle is increasing rapidly over the years and the most commonly used networks for connecting these units are CAN (Controller Area Network) and LIN (Local Interconnect Network). In addition, networks such as Flexray, MOST, Ethernet are available.

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Nowadays, the vehicles became smarter. They can process faster and the vehicles have the opportunity to communicate with each other or other factors. It is expected to have significant benefits for electric vehicles, especially in areas such as determining charging strategies by communicating with smart grids [4]. Recent research has focused on how V2X (Vehicle-to-Everything) technology can be applied and developed in the automotive industry. One of the most important issues is the V2G (Vehicle-to Grid) technology, which communicates with the network for electric vehicles and aims to prevent charging and range. There are also sub-fractures such as vehicle-to-home (V2H), vehicle-to-load (V2L) and vehicle-to-vehicle (V2V) [3].

In this paper, a wireless communication system has been developed and implemented for real time observation and recording of New European Driving Cycle test results of a full electric vehicle prototype shown in Figure 1.

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A gateway is integrated in the vehicle as a physically to transmit and receive the necessary signals of the vehicle from CAN communication line. This allows to connect wirelessly to the vehicle under test and to control and intervene all signals of the vehicle in real time.

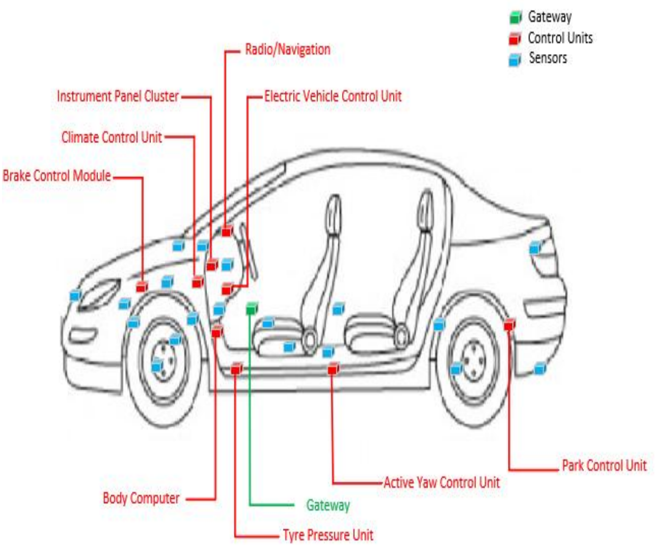

Figure 1. Electric vehicle control units and sensors

The vehicle network in which the developed communication system is integrated and the general topology of the network are described in Section 2. Section 3 describes the technical specifications of the gateway and the data transfer method used. Section 4 includes vehicle integration and test results assessment. The results are compared with the reference vehicle test results and the accuracy of the wireless controlled signals are investigated. Finally, the results and potential future benefits of the study are discussed in Section 5.

II. VEHICLE NETWORK AND GENERAL FEATURES

The electronic control units are connected to the vehicle communication network via the CAN protocol. CAN, which is a typical vehicle network, has a bandwidth of less than 1 Mbps and a maximum packet size of 8 bytes [8]. Communication buses are classified in 4 different ways according to their speed. They are named as Class A, B, C and D. Figure 2 shows the communication buses and some units connected to it, for the prototype electric vehicle of which the gateway is integrated.

Class A is the data transfer range up to 20kbps. The most common example is LIN, which requires low data transfer and is used for simple control purposes. In the prototype electric vehicle where the developed communication system is applied, the circulation pump is controlled by LIN. Class B is the data transfer range from 20-125 kbps. It is used in applications that require more data transfer than Class A, but are not critical. It is used for non-real-time data in the vehicle with "status" information such as radio, instrument panel. Class C (125 kbps-1 Mbps) is used in control applications where real-time data transfer is required. In the prototype vehicle, the electric vehicle control unit and the Brake Control Module (BCM) operate in the Class C range. Class D refers to data transfer over 1Mbps. It is used in systems where both real-time data transfer and high network reliability are required. It is also used in communication applications which require a wide bandwidth, such as transferring audio and video. Flexray and MOST networks are some examples for this class. It is not used in the current vehicle.

Figure 2. Communication buses

In the LIN communication protocol, a central unit manages all communication. There is a master / slave relationship. There is no superior unit in the Flexray protocol. Each unit broadcasts its own message in its own time zone. There is no superior unit in the CAN protocol. If the messages overlap, the message with highest priority is transmitted. The message priority is decided according to ID. The most important reason why all data communication in vehicles is not established at a single speed and with a single network is the cost. As the speed of the vehicle network increases, so does the cost per Electronic Control Unit (ECU). Table 1 shows the main protocols in the vehicle network.

TABLE I. VEHICLE NETWORK MASTER PROTOCOLS

Protocol	CAN	LIN	FlexRay
Bitrate	1 Mbps	20 Kbps	10 Mbps
Payload length	8 byte	8 byte	254 byte

There are several methods for interconnecting the units within a network. These are the Ring, Star and Bus topologies. Each has its own advantages and disadvantages. They can be selected according to the location and application. Bus topology is used to connect the control units on the vehicle. Figure 3 shows the network topology and protocols of the electric vehicle prototype.

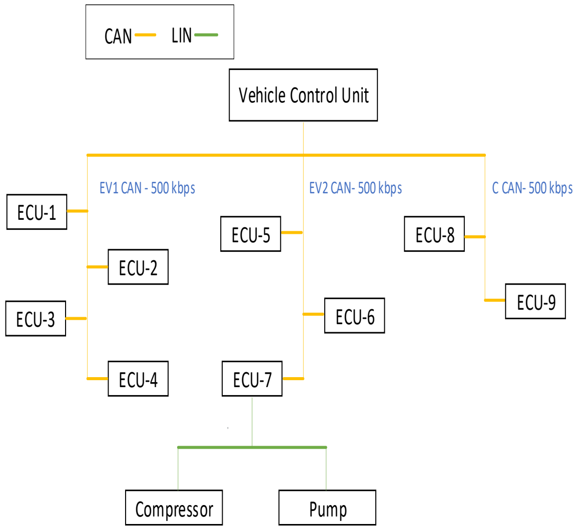

Figure 3. Vehicle network topology of the electric vehicle prototype

The maximum data transmission speed of a CAN network is 1Mbps, but this speed decreases with line length. Figure 4 shows the data rate limits corresponding to the network length. According to the test results obtained in the laboratory, the network can maintain a speed of 1 Mbps up to 40m as shown in Figure 4. Thus, the networks with up to 50 m length is used in the electric vehicle prototype.

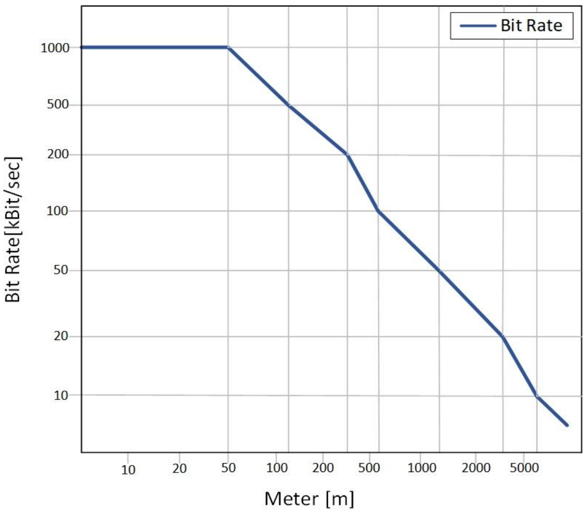

Figure 4. Data rate change versus network length

III. V2X COMMUNICATION SYSTEM

Modern intelligent transport technologies aim to apply information and communication technologies to develop safer, more efficient and more energy-efficient transport systems. One of the important research areas of today is the development of V2X communication systems not only in the wireless connection points but also in the areas of inter-vehicle (V2V), vehicle infrastructure communication (V2I) and vehicle pedestrian (V2P) communication [7].

Electric vehicle development, optimization and calibration processes are very costly and highly demanding. For performance optimization and sustainability of the developed vehicle, the vehicle must be tested by different scenarios in different driving cycles. Significant investments are being made by Original Equipment Manufacturers (OEM) in electric vehicle projects and it is expected to have a large area in the market in the coming years.

In this work, the programmable units integrated in the electric vehicle CAN communication network enable bi-directional operation of the vehicle in real-time driving cycle (NEDC) to monitor and record the performance of the vehicle and in the meantime, to intervene in the instantaneous state of the vehicle, when necessary. The gateway used applies to wireless LANs with the IEEE 801.11g protocol and is used for transmission in the 2.4 GHz bands. In the programming interface functions such as routing, message filtering and bi-directional or uni-directional operation are set.

The electronic control units used in the vehicle follow the data transfer process defined by the ISO 7498-1 (Open Systems Interconnection) norm [9]. The application layer contains the relevant data that you want to send. This data can come from sensors or related components connected to the electronic control unit. The incoming data is placed in a standard frame in the Data Link layer. The dimensions of the frame, the amount of data it can carry, and the information to be written on the frame are determined by the Data Link layer standard [5]. The physical layer converts the required bits into electrical signals and places them on the cable, while the physical layer on the receiving side separates these signals into bits.

In the literature, gateways were first used wirelessly for test cycles. Figure 5 shows the network layers and data transfer protocol that are used in the testing process. The gateway used has an i.MX257 processor that can operate between 8-30 V and can provide communication up to 200 meters.

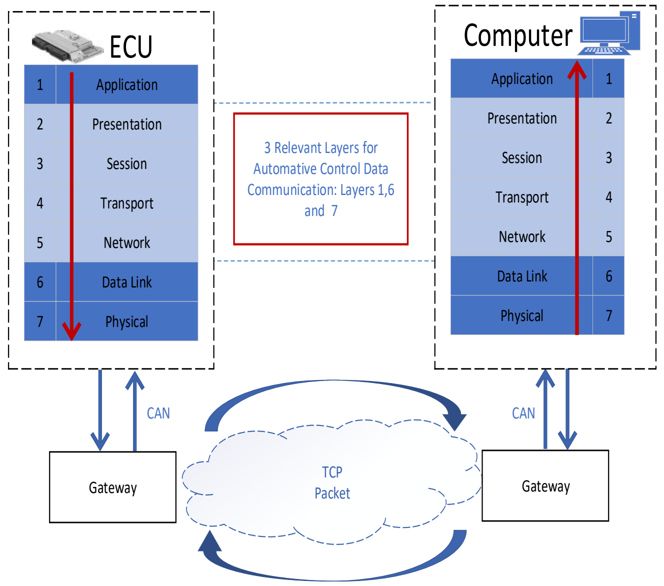

Figure 5. Network layers and data transfer protocol

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IV. Vehicle Integration and Performance Evaluation

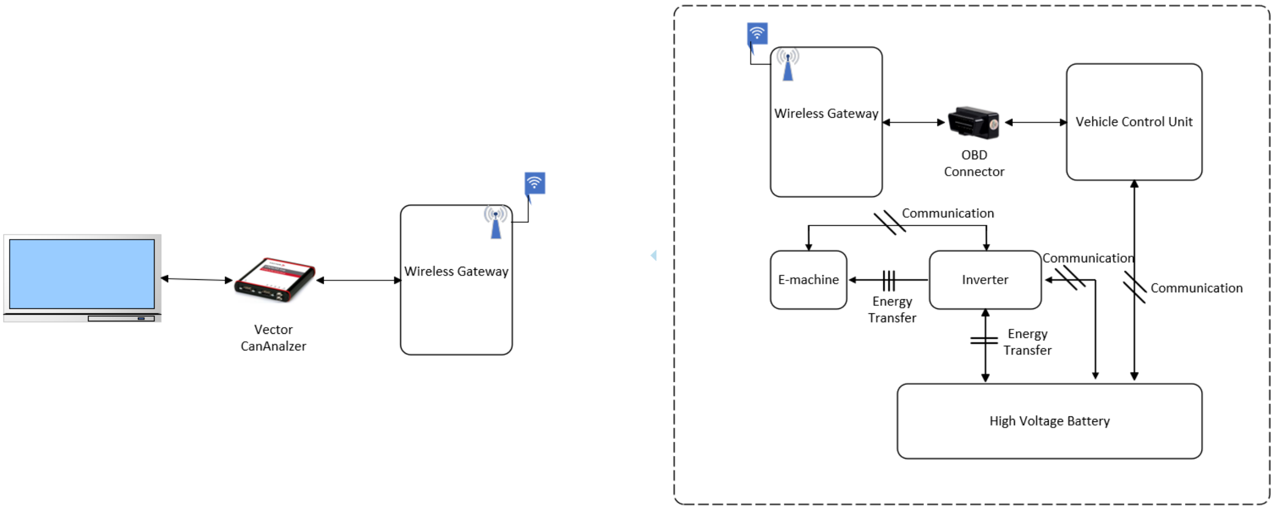

Figure 6. Electric vehicle communication architecture

Performance evaluation of the developed architecture was carried out by using NEDC cycle on vehicle chassis dynamometer. The unit integrated in the CAN line of the vehicle's on-board diagnostics output communicates wirelessly with the other unit in the control room and logs the vehicle data in real time during the test cycle,and is then compared to the test results logged by wired link. Figure 6 shows the vehicle and the communication architecture. Negative forces that prevent the vehicle accelerating under road conditions must be entered as a roll value in the test bench to create a test scenario under real conditions before the vehicle is tested.

Negative forces applied to the vehicle while driving are defined as 3 main parameters: F0 as rolling drag, F1 as mechanical force and F2 as aerodynamic force. The testing process was carried out with the verification of the prototype electric vehicle on vehicle chassis dynamometer firstly. F0, F1 and F2 values of the homologized prototype electric vehicle were entered from the control room to the vehicle as the test bench roll parameters during the verification stage.

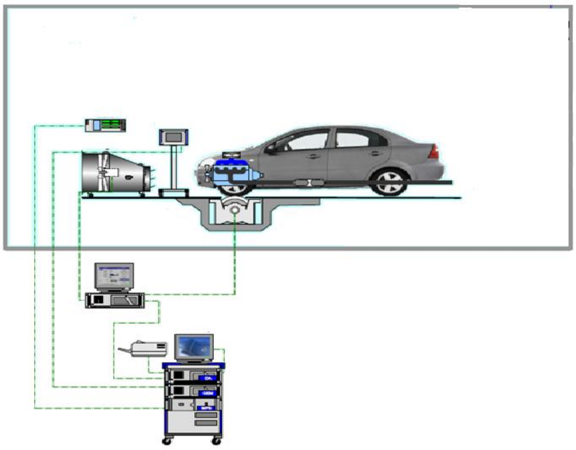

Figure 7. Electric vehicle on vehicle chassis dynamometer

In the second stage, the pre-test section, the vehicle was pre-tested in a given cycle to eliminate the differences in the instant condition of the vehicles and to increase the accuracy of the test result. After the pre-test, the vehicle was allowed to stand at ambient temperature of 23° C for 6-36 hours. In the last phase of the test, the prototype electric vehicle followed the NEDC cycle was monitored in real time with the gateway integrated into the vehicle. Figure 7 shows the vehicle on the test bench cycle on vehicle chassis dynamometer. The torque demanded by the vehicle controller in order to accelerate or decelerate to the required speed by the NEDC test cycle is calculated by the vehicle control unit by checking the necessary functions of the vehicle. The calculated torque is transmitted to the electrical machine via the inverter and the required torque is generated.

During the test, the gateway integrated into the vehicle's on-board diagnostics connector enables wireless transmission of the relevant components of the vehicle and signals related to the current state to the other gateway in the control room. The gateway in the control room received the signals and transmitted them with the CAN controller, and the instantaneous state of the vehicle was recorded and monitored instantly.

The IEEE 802.11g standard operates in 2.4-GHz band, and bandwidth of channel is 20MHz. Its allows an increase in the maximum physical layer bit rate to up to 54 Mbits/s.

Channel capacity in the established communication system expressed by:

$$C = \Delta f \times \log_2(1 + S/N) \tag{1}$$

$$\log_2 x = \ln x / \ln 2 \tag{2}$$

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Where C is the channel capacity of the wireless network, Δf is the bandwidth of the channel and S/N is the signal to noise ratio of the channel. 24 Mbps is calculated as channel capacity by using equations described in above.

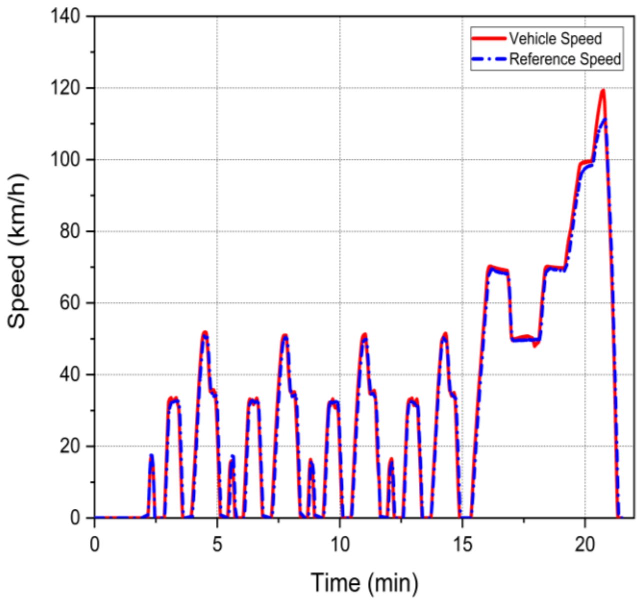
In Figure 8 (a), the speed signals of the reference vehicle speed and the wireless communication management applied are compared. The reference vehicle values were obtained by the currently used in-vehicle cable recording method. In Figure 8 (b), vehicle speed values are examined within a certain range in the test scenario and the success of the method is demonstrated.

The expanded view in Figure 8 (b) shows some differences in speed variation between vehicle and reference speed. Factors such as the conditions under which wireless communication is applied or distance may cause some delays in the signal. However, there are no significant differences in the characterization of the signal and noise level.

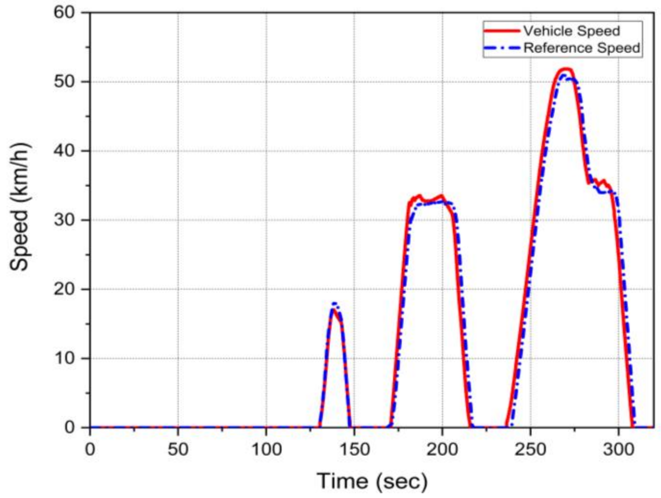
To evaluate the quality of the fit between the speed signals, the following error term is used:

$$Accuracy = 1 - \frac{\sum_{k=1}^{n} |u_{n,ref} - u_{n,veh}|}{\sum_{k=1}^{n} u_{n,ref}} \quad (3)$$

where $u_{n,veh}$ is the speed observed during the test with wireless communication and $u_{n,ref}$ is the in-vehicle cable recording results. n is the total number of data. 94.09 % accuracy is observed between reference and vehicle speed within the 23 minutes test period data. It increases up to %97.14 when the delay due to wireless link is compensated in the calculations.



(a)



(b)

Figure 8. Variation of speed as the function of time (a) During the test period (b) Within a certain time window

In Figure 9, the battery charge status is checked during the vehicle's test period in percent. The battery charge status signal, which is an important parameter in calculating the range of the vehicle, has been obtained wirelessly and the results show that there is almost no deterioration in the signal.

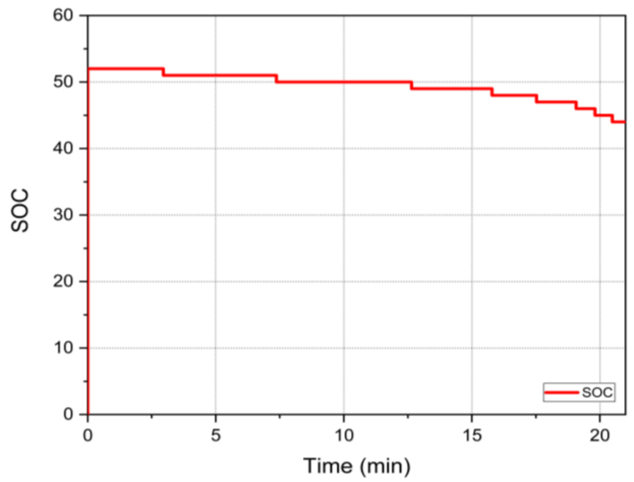


Figure 9. Battery charge status

The vehicle torque time graph during the test period is given in Figure 10. Negative torque values at the moment of braking indicate that the vehicle regenerates from regenerative braking, and the positive torque values generated at the moment of acceleration indicate the values that the vehicle requires to reach the desired speed. In the new communication architecture, it is possible to use the vehicle in different modes wirelessly and thus to improve the development processes of the prototype electric vehicle in different test scenarios.

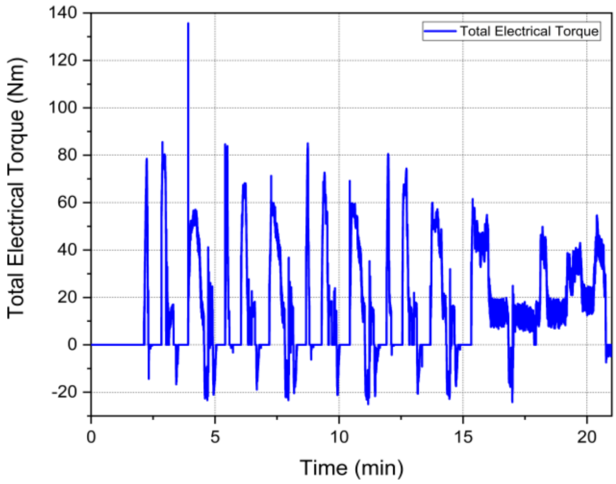


Figure 10. Total electrical torque as the function of time

V. CONCLUSIONS

Today's environmental conditions and regulations reveal the necessity of the use of electric vehicles in the future. There is not much work on the development and optimization of electric vehicles with the parallel V2X technology. The vehicle that is able to perform test cycles such as NEDC without driver assistance provides time and cost opportunities for OEMs. In this work, a wireless driving cycle test observation method for electric vehicles is introduced. The test cycle is controlled and logged by wireless gateways and constitutes a step for the driverless test cycle. To prove the performance of the proposed technique, the results are compared to reference vehicle. The results show that the proposed V2X technology could be used by OEMs in vehicle development processes.

REFERENCES

[1] V. Sreedhar, "Plug-In Hybrid Electric Vehicles With Full Performance" in *IEEE Conference on Electric and Hybrid Vehicles,* Pune, India, 2006

[2] T. Tielert, D. Rieger, H. Hartenstein, R. Luz , S. Hausberger, "Can V2X Communication Help Electric Vehicles Save Energy" in *12th International Conference on ITS Telecommunications,* Taipei, Taiwan, 2012

[3] Zishan Liu, Zhenyu Liu, Xinyang Yang, Lin Pu, Lin Zhang, "Implementation and performance measurement of a V2X communication system for vehicle and pedestrian safety", *International Journal of Distributed Sensor Networks*, vol 12, 2016

[4] C. Corchero , M. Sanmarti, "Vehicle-to-Everything (V2X): benefits and barriers" in *15th International Conference on the European Energy Market (EEM),* Lodz, Poland, 2018

[5] *Controller area network (CAN) – Part 1: Data link layer and physical signaling,* ISO 11898-1, 2015

[6] J. Wang , D. Yang, X. Lian, "Research on electrical/electronic architecture for connected vehicles" in *IET International Conference on Intelligent and Connected Vehicles,* Chongqing, China, 2016

[7] I. Kabashkin, "Reliable v2x communications for safety-critical intelligent transport systems " in *Advances in Wireless and Optical Communications (RTUWO),* Riga, Latvia, 2017

[8] Y. Onuma , M. Nozawa, Y. Terashima, R. Kiyohara, "Improved Software Updating for Automative ECUs: Code Compression" in *IEEE 40th Annual Computer Software and Applications Conference (COMPSAC),* Atlanta, GA, USA, 2016

[9] *Information technology-Open Systems-Interconnection-Basic Reference Model: The Basic Model*, ISO/IEC 7498-1, 1994

[10] W. J. Sweeting, A. R. Hutchinson, S. D. Savage, "Factor affecting electric vehicle energy consumption", *International Journal of Sustainable Engineering,* vol. 4, no. 3, pp. 192–201, 2011

[11] G. L. Gopu, K. V. Kavitha, J, Joy, "Service Oriented Architecture based connectivity of Automotive ECUs" in *International Conference on Circuit, Power and Computing Technologies (ICCPCT),* Nagercoil, India, 2016