The 2nd IEEE Conference on Power Engineering and Renewable Energy
ICPERE 2014

Synthesis Modeling of 10 kW BLDC Controller for City Electric Car Based on PSIM

Alfi Satria, Veladito Farisi, Arwindra Rizqiawan
School of Electrical Engineering and Informatics
Institut Teknologi Bandung
Bandung 40132, Indonesia
alfisatria@gmail.com

Nana Heryana, Agus Purwadi, Yanuarsyah Haroen
Electrical Energy Conversion Research Laboratory
Institut Teknologi Bandung
Bandung 40132, Indonesia
nana.heryana@yahoo.com

***Abstract*—A model of a 10 kW BLDC motor controller is reconstructed by utilizing PSIM software. This design process starts by identification of the controller characteristics. The identifications includes the work mechanisms, capability work rating and other significant factors that must be considered in utilizing BLDC motor controller as electric vehicle drive. In this controller, there are some modes identified and modeled: torque controlled, speed controlled, regenerative braking, cruise mode, and forward/reverse rotation selection. Through the simulations and analyses, the modeled circuit is tested so it can represent the features of the controller.**

Keywords-BLDC motor controller, city electric car, PSIM model

I. INTRODUCTION

The utilization of electric motor has grown in very diverse application especially in industry. In high industrialized country, the utilization of electric motor can take 60% of total electricity production. In few decades, the proportion can even higher as the electric car industry which its main drive is electric motor grows.

In electric car industry, there are some characteristics that need to be satisfied in electric motor so it can operate optimally. The characteristics could be torque versus speed characteristic, high efficiency, high ratio of power versus size, good dynamic response, long lifetime, and low noise operation. Those characteristics naturally met by using brushless dc (BLDC) motor. So it is undeniable that BLDC is one of the favorite choice of electric car drive selection [1].

Electric motor need a driver that suitable with the motor to function properly. The drive system consists of controller and power converter, besides the motor itself. The driver ensure that the power supplied by power converter is matched with motor demand in fulfilling the load requirement of certain torque and speed criteria [2].

This paper deepens the study of electric car in more specific section that is BLDC motor controller. The BLDC motor controller which had been implemented as the drive of ITB city electric car is going to be reverse engineered to understand the controller work mechanism. The main contribution of this paper is to synthesize the model of circuits inside the black box controller. The modeling process is based on the characteristics of data sampling and relevant literature.

PSIM is a simulation software package specifically designed for power electronics and motor control. PSIM is used for power converter analysis, control loop design, and motor drive studies. It is fast, friendly user interface and can provide waveform processing. It also supports links to other simulation software like MATLAB, JMAG using Simcoupler blocks, and C code through dynamic link library (DLL) block. The package consists of the circuit schematic program, simulator engine, and the waveform processing program SIMVIEW [3] as shown below.

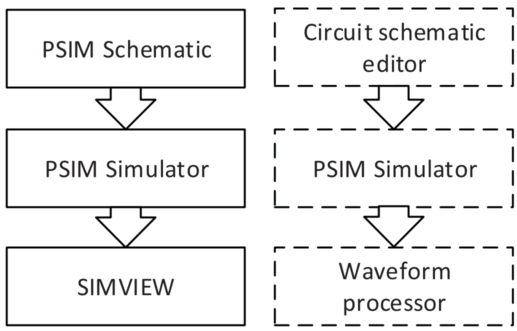


Figure 1. PSIM simulation process

II. BLDC MOTOR MATHEMATICAL MODEL

BLDC motor equation model cannot be transformed easily to *d-q* axis because of the shape of back electromagnetic force (EMF) that is not sinusoid. Tha back EMF shape of BLDC motor is trapezium, so it is easier to built the mathematical model of the motor using intrinsic phase variable of motor [4] with the assumptions:

1. The stator winding is concentrated, equispaced 60^o and Y-connected.
2. The magnetic saturation and hysteresis are neglected.
3. The armature reaction is neglected.
4. The distribution of air gap field is uniform.

The equivalent circuit diagram of BLDC motor is shown in figure 2.

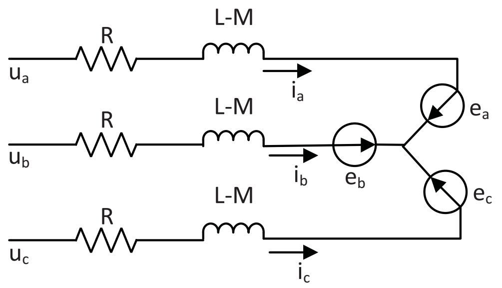


Figure 2. Equivalent circuit diagram of BLDC motor

The voltage equation of three-phase BLDC motor:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

$$i_a + i_b + i_c = 0 \quad (2)$$

$$M_{ia} + M_{ib} = -M_{ic} \quad (3)$$

And electromagnetic torque is

$$T = \frac{1}{\omega}(e_a i_a + e_b i_b + e_c i_c) \quad (4)$$

where

u_a, u_b, u_c	phase winding voltage of stator (V)
i_a, i_b, i_c	phase winding current of stator (A)
e_a, e_b, e_c	phase winding back EMF of stator (V)
L	phase winding inductance (H)
M	phase winding mutual inductance (H)
ω	rotor speed (rad/s)

III. BLDC MOTOR CONTROL SCHEME

The BLDC motor control scheme used in this modeling of BLDC 10 kW controller depicted in figure 3. From the hall sensor signal reading in motor we can get rotor position information. The information is very important to know which phase to be connected to positive dc bus or the negative dc bus for every 60 degrees. From the reading we could also extract the speed information through calculating the rate of change of hall sensor output. In this hall sensor, the output has been processed to return value of 1, 0, or -1. The output 0 is to command the phase to remain inactive. The output 1 is to command the phase to connect to positive dc bus while output -1 to connect to negative dc bus to provide a positive torque.

The reading of hall sensor then fed to part of the scheme that control the motor direction, forward or reverse. If the desired direction is forward then it will multiply the reading by 1. Otherwise, the reading will be multiplied by -1. This multiplication aims to change the polarity of produced torque.

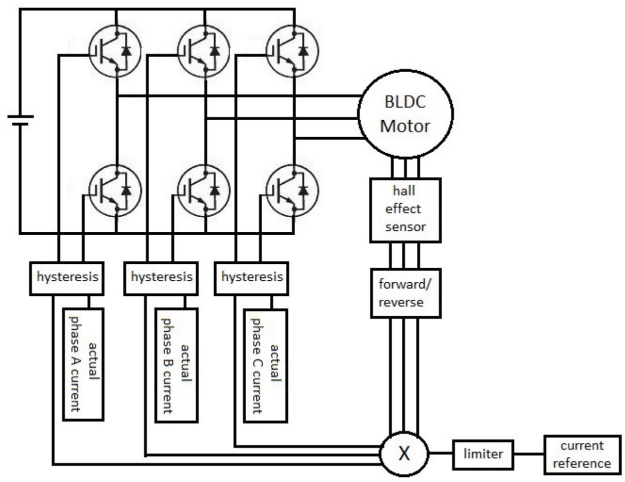


Figure 3. Control scheme of 3-phase BLDC motor

With the same magnitude of phase current flows in opposed direction then will be created a torque with the same magnitude but the direction of torque will oppose the original torque. This principle also could be applied as a brake when BLDC motor is running [5].

The value of processed hall sensor reading which is still 1,0, or -1 then multiplied with reference current produced by torque reference generator circuit. The outcome of the multiplication is the current reference of each phase for various rotor positions. In BLDC motor, the actual torque produced by the machine is proportional to the phase current supplied. The current reference of each phase then fed to current controller to regulate switches so the actual current of each phase is equal to reference current of each phase. On this control scheme, the current control scheme is hysteresis control.

To avoid the potential of phase current flows exceed the capability rating so the current fed to current controller must fed to current limiter first. Limiter aims to limit current to reach certain level. If phase current flows more than the cable and apparatuses can sustain, it will damage the other components.

In controlling BLDC motor there are two kinds of reference value input. First method is to directly input the amount of torque to achieve. It is called torque controlled method. This scheme is the same scheme we use everyday when we want to use our conventional car by varying the throttle. The second method is speed controller. In this method, the input we give is speed reference while the torque reference is generated by speed controller using various ways. The way utilized here is PID method by setting proportional gain only for 1.6 and torque limiter for 50 Nm [6].

The controller that is going to be modeled:

Product name	: HPC500H72500
Manufacturer	: Golden Motor
Rating	: 72 V / 350 A
Dimension	: 117 x 72,5 x 42,5 mm
Mass	: 2,9 kg

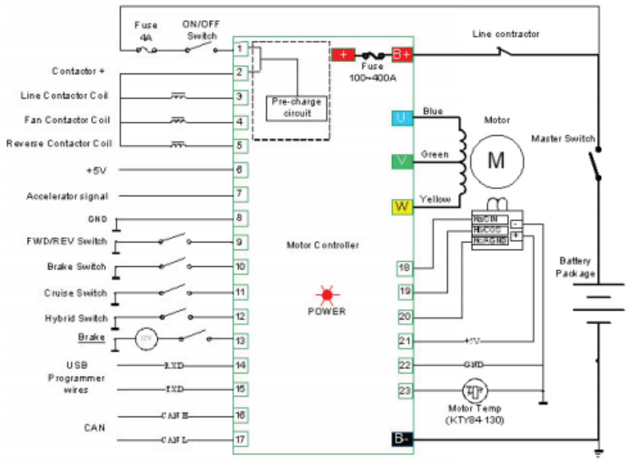


Figure 4. Wiring diagram of 10 kW BLDC controller [7]

The 23 pins available in the controller could be divided into five major parts based on the functions:

Accelerator (pin 6-8)
Motor Hall effect sensor (pin 18-23)
Control (pin 9-13)
Contactor (pin 1-5)
Communication (pin 14-17)

Accelerator pins are responsible to give torque and speed references, as which mode is active. Motor hall effect sensor pins are used to retrieve physical information from the rotor such as rotor position and temperatures. Control pins are used to select which mode to be implemented, such as braking, cruise speed, and forward or reverse rotation selection. Contactor pins are used as safety switch which only close automatically if safety requirement is met. Communication pins allow us to edit the settings of the controller through the computer. The settings include mode selection, speed limit and current limit.

IV. MODELED CIRCUIT

Firstly, the data is collected from city electric car testing to determine the motor characteristics. The testing is conducted in torque controlled mode. In this mode, the actual torque of the motor has to follow the reference torque given by the user by varying gas pedal position. In this operation mode, the reference value has to processed in time delay first to make the change of torque occur gradually so the user does not feel uncomfortable by the acceleration.

Although the data corresponding to speed controlled were not taken but it is shown in this mode that the motor in speed controlled produce the sudden torque reference change to adapt with user speed reference input. Whenever there is difference in actual and desired speed the motor always output a big torque reference so that the actual speed is equal the desired speed.

There are also regenerative braking mode which change the current flow from motor back to battery. In this mode, the selection of current reference is a compromise between the amount of energy to be recovered and the driving comfort. The excessive amount of current regenerative reference could bring opposing torque that is too strong and discomfort user [8].

TABLE I. BLDC MOTOR PARAMETERS

Parameter	Value
Phase resistance	6 mΩ
Phase inductance	0,076 mH
Speed constant	1/58
Torque constant	1/6.65
Pole number	4
Rotor inertia moment	3,84 mg.m^2
No load speed	6000 rpm
Load inertia	1 kg.m^2
Battery nominal voltage	72 V
Current hysteresis band	20 A
Overvoltage shutdown	90 V
Undervoltage shutdown	55 V
Command when throttle =1 • Torque controlled • Speed controlled	 30 Nm 4000 rpm

Table I shows the parameters used to conduct the simulation. Figure 5-7 show the component configuration in operating the BLDC 10 kW. There are several components needed to run the motor besides the motor itself. The components need to be connected to controller are motor itself, battery, throttle, control pins and contactor.

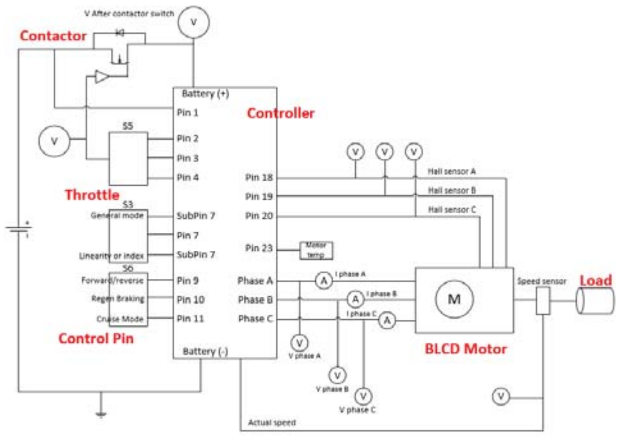


Figure 5. Complete picture of BLDC motor modeling scheme

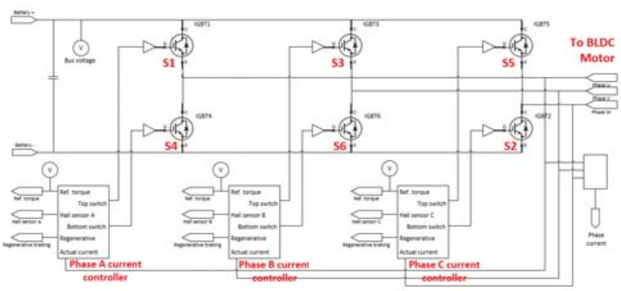


Figure 6. Power circuits inside the controller

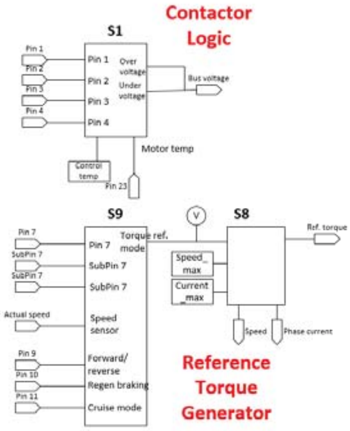


Figure 7. Contactor logic and reference torque generator subcircuits

The observation data regarding torque controlled mode and regenerative braking mode is shown in figure 9-10 based on NEDC driving cycle (figure 8) [9].

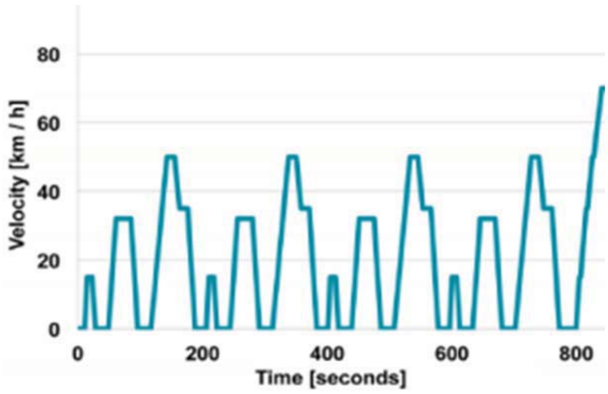


Figure 8. New European Driving Cycle (NEDC) driving cycle

From those circuits, the simulation outputs are yielded, as described below.

The controller is operated in torque controlled mode without activating the cruise mode. So the torque reference only comes from the various throttle position inputted by the user. In the graph also we can see the variation of phase current which is the representation of actual electromagnetic torque produced. So it can be concluded that in torque controlled mode, the actual torque has to be able to follow the variation of pedal gas position as the user input.

The data sampling is conducted by following NEDC driving cycle as its reference. The cycle is a speed versus time graph. So if the user itself is considered as a part of control system which drive the amount of speed want to be achieved we can think this system as speed controlled mode. In this mode, to minimize the difference of actual speed and desired speed, the high amount of torque has to be generated. This phenomenon will be checked in simulation if the result agrees.

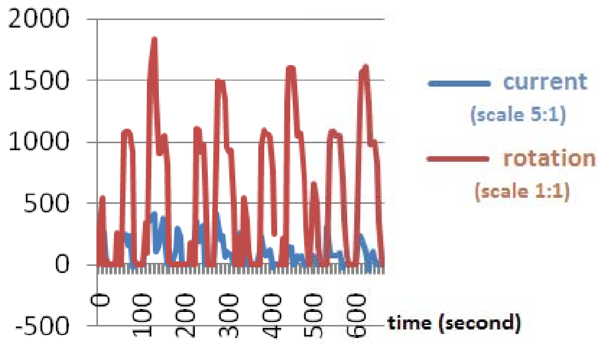


Figure 9. Rotation and current versus time graph in torque controlled mode data sampling

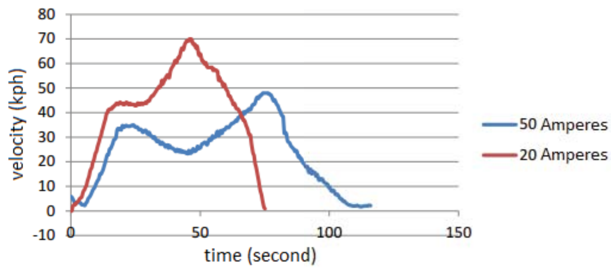


Figure 10. Regenerative braking data sampling

In regenerative braking data sampling there are two graphs with different peaks and time needed to stop. The 20 A current and 50 A current are the value reference current to produce regenerative braking torque reference. It can be seen, when the specified reference current is higher, then the maximum speed produced is lower and the distance needed to stop the car is the same while the time required to stop the car will be longer.

A. Torque Controlled Mode

From the simulation result shown in figure 11 we can see that the amount of actual electromagnetic torque always follow reference torque inputted. The amount of reference torque is proportional to depth of the pedal gas multiplied with amount maximum torque provided. In this simulation, the maximum torque provided is 30 Nm.

B. Speed Controlled Mode

In speed controlled mode, it can be seen that the reference input is speed reference. To minimize the gap between actual speed and desired speed, the controller will regulate electromagnetic torque so the gap will less and maintained in small value. Because in this mode the torque is not controlled directly, compared to torque controlled mode the torque change will be less gradually. The result shown in figure 12.

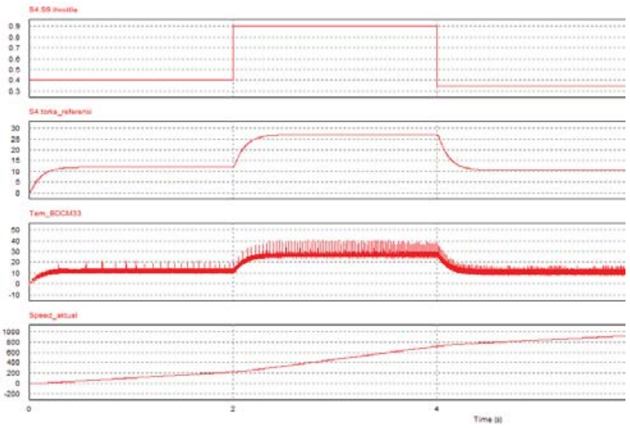


Figure 11. Torque controlled mode simulation output

C. Regenerative Braking Mode

The regenerative braking operation only can be activated when cruise mode is not in use, the speed is not zero and the pedal gas is not being pushed. It is shown in regenerative braking mode, there will be change of torque actual value and dc current from positive become negative. These two changes confirm there are opposing torque which will slow the motor and energy recovered through this mode (figure 13).

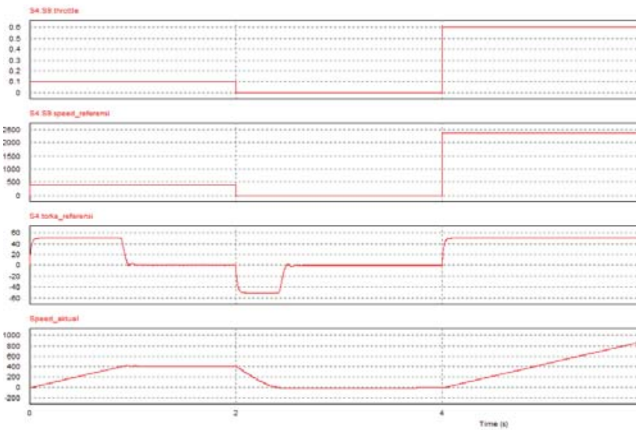


Figure 12. Speed controlled mode simulation output

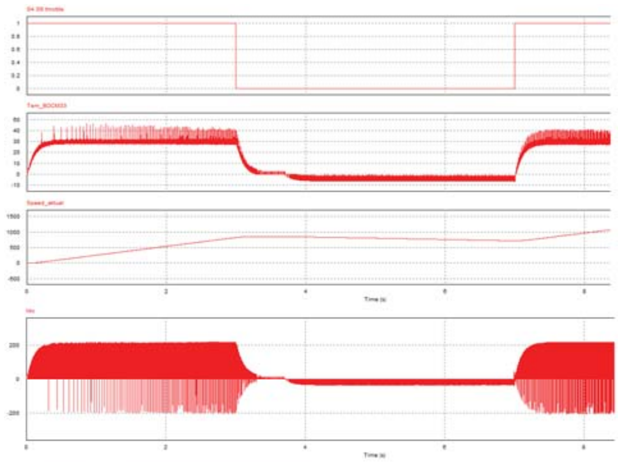
The amount of energy recovered depends on the selection of regenerative current reference. This selection is compromised between the amount of energy to save and amount of opposing torque which still comforts the user.

V. CONCLUSION

The investigated motor controller has torque controlled, speed controlled, regenerative braking, cruise and reverse modes. A PSIM model based on the controller characteristics is designed to represent the features of the controller and the results are shown.

The results of simulation confirm that the torque controlled mode can run well as the amount of electromagnetic torque always be able to follow the pedal gas input. The speed controlled mode also can run well as high amount of torque are applied to minimize the gap between the actual speed and desire speed. And the regenerative braking mode can give the opposing torque to slow the motor rotation and return the phase current back to the battery.

These results of model simulation give help in building hardwares with expected results.



Time From	1.0000000e+000	Time From	4.0000000e+000
Time To	3.0000000e+000	Time To	6.0000100e+000
S4.S9.throttle	9.9980004e-001	S4.S9.throttle	0.0000000e+000
Tem_BDCM33	3.0205045e+001	Tem_BDCM33	-4.0651503e+000
S4.torka_referensi	2.9999920e+001	S4.torka_referensi	-4.4855213e+000
Speed_aktual	5.3912651e+002	Speed_aktual	8.0309303e+002
Idc	6.1796887e+001	Idc	-1.0041580e+001

Figure 13. Regenerative braking mode simulation output

REFERENCES

[1] A. Tashakori, M. Ektesani and N. Hosseinzadeh, "Characteristics of Suitable Drive Train for Electric Vehicle," in *3rd International Conference on Power Electronic and Intelligent Transportation System (PEITS)*, Shenzhen, China, 2010.

[2] R. Khrisnan, Electric Motor Drives: Modeling, Analysis, and Control, New Jersey: Prentice Hall, 2001.

[3] G. R. Kumar, M. A. N. Doss, K. Prasad and K. Jayasankar, "Modeling and Speed Control of Permanent Magnet Synchronous Motor at Constant Load Torque Using PSIM," in *International Conference on Sustainable Energy and Intelligent System*, Tamil Nadu, India, 2011.

[4] H. x. Wu, S. k. Cheng and S. m. Cui, "A Controller of Brushless DC Motor for Electric Vehicle," *IEEE TRANSACTIONS ON MAGNETICS,*

vol. 41, no. 1, pp. 509-513, 2005.

[5] A. S. B. S. Krishan K. Sharma, "Performance Evaluation of a Binary Control Technique for Brushless DC Motor Drives," in *International Conference on Mechatronics and Automation*, Beijing, China, 2011.

[6] U. Ansari, S. Alam and S. M. u. Nabi Jafri, "Modeling and Control of Three Phase BLDC Motor using PID with Genetic Algorithm," in *International Conference on Modelling and Simulation*, Cambridge, UK, 2011.

[7] "Miromax ECO TRANSPORT - ELECTRIC CONVERSION KIT," Miromax, [Online]. Available: http://www.miromax.lt/. [Accessed 1 9 2014].

[8] F. P. a. H. Z. Xiaohong Nian, "Regenerative Braking System of Electric Vehicle Driven by Brushless DC Motor," *IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS,* vol. 61, no. 10, pp. 5789-5808, 2014.

[9] 7 2013. [Online]. Available: https://www.dieselnet.com/standards/cycles/ece_eudc.php. [Accessed 15 8 2014].