A Web-Based Matlab Application for E-Learning and Simulation of Electric Vehicle Performance

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***Abstract*— The paper presents the simulation of a basic electric vehicle motor-drive system and dynamics used to study the performance and the influence of various parameters of the vehicle and the electric drive. The model and simulations are implemented in a specially developed MATLAB application running on a MATLAB application server or in a MATLAB runtime environment. In this way, the program is in the form of an executable file, that doesn't need anything but the runtime environment preinstalled, avoiding any incompatibilities between versions and releases of MATLAB or licensing issues. The purpose of this program is to explore math modelling by students in various disciplines and levels. The motivating example is an electric powered car with a simple torque speed curve, used as a basis and the effects of different model parameters on automobile performance are examined. It was then used to determine the system performance and energy flow over a given set of motoring and regeneration speed/torque conditions. The model could be used to augment instruction in energy conversion or vehicle systems courses.**

Keywords*— *Education, Electric vehicle, DC motor, Sharing application, MATLAB

I. Introduction

In the last years Electric Vehicles (EV) are gaining an ever-growing popularity and attention not only by individuals, but from government institutions as well. Thus, there is a need to include more learning experiences in the student curriculum related to this topic. The 2010 – 2020 time period will be remembered by the transition from the internal combustion engine to electric propulsion systems for personal vehicles. As the industry is heading in this direction, education should also contribute by preparing the engineers with the necessary knowledge and skills. Currently the number of automotive engineering or technology degree programs that cover the topics related to electric vehicles is increasing. However, industry is largely training engineers 'in-house', and educational experiences in this technology are needed now to prepare a well-trained and educated workforce to support the development of Smart Grid and Electric Vehicle applications [1].

The purpose of this paper is to develop a proven methodology (system) for conducting laboratory exercises and experiments when playing around with various EV parameters. It is implemented by using a specially designed application without the need of installing or having a MATLAB license. Another advantage of the developed software is that the student can benefit from using ready-to-run models, being able to run them, trace graphs, and examine the influence of several parameters on the vehicle dynamics and performance without having to create their own models using the MATLAB interface. Students also do not need the knowledge and experience in MATLAB to create and study the models.

II. Overview of the Problem and the Proposed Solution

A. Using MATLAB® software

MATLAB® is a high-level language and interactive environment for numerical computation, visualization, and programming. Using MATLAB, in their studies, researchers can analyse data, develop algorithms, and create models and applications.

When talking about lab experiments that aim to train and teach students in variety of university/bachelor disciplines or other related degrees, a common issue arises that falls immediately into the money-related or investment-related category. This issue is so common nowadays that for some professors and university staff is having the form of painful discussion that leads to decisions that are even more painful. Very often in academic teachings and experimental design in order for students to understand in-depth and get their hands on a given complex new technology, the best most practical choice is to provide students with a version of the MATLAB® computing platform. This is the point where organizations have decide whether to buy licensed copies of the infamous MATLAB software suites. This kind of decision will never be an easy one, because simply MATLAB ® software never comes free. [1] Downloading and installing MATLAB® software suite is usually at no cost whatsoever, but using it with an individual license purchased from the MATLAB portal requires a Mathworks account. The registration in Mathworks website is at no cost, but the individual license or campus-wide licenses are not. On the other hand, this mathematical software is characterized by one of the highest license prices for this type of research platform nowadays. When downloaded and installed from Mathworks official pages, MATLAB software will be fully functional, but for a limited period only, also known as trial version. This is not an option when main goal is to conduct series of lab experiments, researches and simulations on many different laboratory and personal computers.

In order to use it, even with trial license installed, an individual is still required to create (if not already did so) and sign-in with its free Mathworks account. Significant discounts are available to students and university employees when their organization have purchased a site-wide and/or academic license. However, such corporate licenses, allowing installation on multiple machines and logging with the organizational email credentials is a serious investment and not all institutions can afford it.

"Classroom - Concurrent Licenses. For use with shared-environment computers used in classroom/instruction lab machines for student instruction. Licenses are per machine, and each machine requires its own license. Non-networked Computer Licenses. For use with single, off-line computers that cannot connect to the internet to download and activate MATLAB software." [2]

Students can get a cheaper version, but still not free. Some universities may let their employees/students remotely log into a computer within the campus network, which has the software installed, making it essentially free for those users. Some institutions have purchased licenses that allow to all their students to install MATLAB products on personally owned computers. [3]

On a discussion board a topic question "How to get MATLAB software for free?" best answers reveal that the only option for non-student individuals, except using it illegally off course, is simply to use a free alternative [4]. One of the most popular and highly appreciated open source substitutes of the MATLAB platform is the GNU community driven project named Octave [5].

Using open source alternative versions of famous and expensive software is absolutely the best approach when dealing with this kind of trouble. In the case of GNU Octave, designed to be used on Unix systems, some minor differences in the syntax exist, but barely any, positioning Octave to be essentially the best full-featured open source substitute of MATLAB. In certain cases, Octave is even better and can achieve greater functionality thanks to the variety of similar projects available from the community.

All these facts push discussion to the essential problem "Is Octave same as MATLAB?" [6]. A short answer would be that GNU Octave is mostly compatible with MATLAB. However, Octave's parser allows some (often very useful) syntax that MATLAB's does not, so programs written for Octave might not run in MATLAB. Octave mainly built with MATLAB compatibility in mind has many features in common with MATLAB. Some differences do exist though, between Octave and MATLAB, but they can be worked around by using "user preference variables."

Nevertheless, digging deeper into similarity and differences of MATLAB and its alternatives is a topic that is not in the scope of this paper. The research goal is to propose an innovative methodology and solution to the discussed problems. The purpose of the paper is to describe a methodology of legally using MATLAB amazing features without paying for multiple licenses and installations. Although this proprietary technique requires having at least one license of MATLAB and one full, install on developer's computer.

B. *Experimental testbed design*

Apart from sharing *.m scripts directly (which requires installed MATLAB with a valid license on the target computer), there are three ways for creating a shared MATLAB script program:

1) Packaged app
2) Standalone desktop application (executable file)
3) Deployed web app

The application described in this paper has been created as a standalone desktop application. It is also possible to create a web application that can be run on a web server and accessed by the users through LAN or internet connection.

System requirements for packaging and code compilation: The system on which the application will be packaged has to have a valid MATLAB license. The modules required for packaging the application are: MATLAB compiler, MATLAB compiler SDK and symbolic math toolbox. The application created by using the MATLAB app designer that has a simple to use and user-friendly interface.

The requirements for the target computer are: It has to have a configuration that would normally be able to run MATLAB (although no installation of MATLAB is required) and the MATLAB runtime environment installed. In case the runtime environment is not installed, the standalone desktop application can install it automatically on the first run.

C. *Example for a specific course*

The example described in this paper is based on the live script created by Daniel Frey "Modelling the performance of an electric car" [6]. It comprises a set of questions and solutions modelling an electric car with a DC motor. The drivetrain consists of (fig.1): a 120 V battery, DC-DC converter, DC motor and a gearbox. The motor performance is modelled using a simple torque speed curve. The purpose of this example is to explore the modelling and dynamics of an electric vehicle by beginners without sophisticated knowledge in MATLAB programming and mathematical modelling. In the example the effects of different model parameters on the vehicle performance are demonstrated.

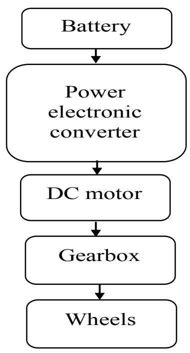

Figure 1. Block diagram of the electric vehicle drive train

First, the students are introduced to the basics vehicle dynamics and the building blocks of an electric vehicle, as well as the operation of the DC motor. After that, they are prepared for a simple set of questions and simulation examples using the executable application described in this paper. The purpose is to let the students run the simulations with different parameters of the vehicle and the electric motor, to obtain several curves of the vehicle speed and the torque of the motor. They also have to analyze the results and answer the questions. In this way, the students will acquire useful knowledge on the subject of vehicle dynamics and the specific particularities of electric vehicles.

One simple of a mathematical model of a permanent magnet DC motor expressed by the equations:

$$T = K_T \, \phi \, I \qquad (1)$$

$$E = K_E \, \phi \, \omega \qquad (2)$$

Where ω is the rotational speed of the wheels in radians per second, T is the torque applied to the wheels in Newton meters, K_E and K_T are parameters of the motor related to the strength of the magnets and number of windings. The equivalent circuit of the motor is presented in fig.1 includes a voltage loop where the input voltage (V) is equal to the voltage drop across the active resistance of the winding (R), its inductance (L) and a back EMF (E) induced by the motor rotation [8].

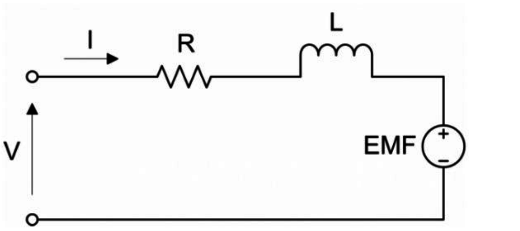

Figure 2. Simplified equivalent circuit of a permanent magnet DC motor

In steady state the voltage drop over the inductor L can be neglected and thus by substituting the torque and back EMF equations this circuit is described by [9]:

$$V = \frac{T}{K_T \varphi} R + K_E \varphi n \qquad (3)$$

Where V is the voltage applied to the terminals of the motor (in Volts) and R is the active resistance of the winding (in Ohms).

Then the studied example is based on the following case study with it's questions:

2.3.1 Exercise 1

If we assume that, the mathematical model of the motor is dimensionally homogeneous (which it is in fact). Then if the rotational speed of the wheels is measured in radians per second, the torque applied to the wheels is measured in Newton meters, the voltage applied to the terminals of the motor in Volts, the electrical resistance of the motor windings in Ohms and the current in Amperes. Then which of the following statements is true?

A) The unit of the parameter K_T must be Newton*meters/Ampere;

B) The unit of the parameter K_T must be Volts/(radian/sec);

C) Newton*meter/sec and Volt*Amp have the same physical dimension;

D) all of the above;

The proposed script combines all the terms into one with the given set of dimensions. The answer in this case demonstrates the dimensional consistency of the studied model. Originally, the MUPAD script presented in Fig. 3 does this.

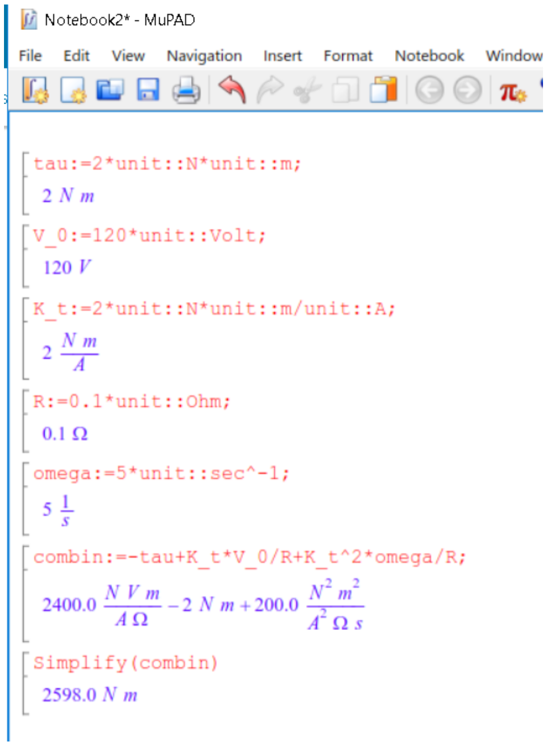

Figure 3. MUPAD script for the solution of exercise 1

2.3.2 Exercise 2

If we were considering a motor for use in an electric vehicle and after an experiment the resulting torque applied to the wheels was about ½ of what we needed. One might say that if we pick a motor with twice as large value of the parameter K_T. Would this have the desired effect? Would it have a consequence for the speed of the wheels under no load?

a) No, it would not have the desired effect of doubling torque;

b) Yes, it would have the desired effect of doubling torque, and it would reduce the speed at no load by a factor of two;

c) Yes, it would have the desired effect of doubling torque, but no, it would not affect the speed at no load;

d) Yes, it would have the desired effect of doubling torque, and it would double the speed at no load;

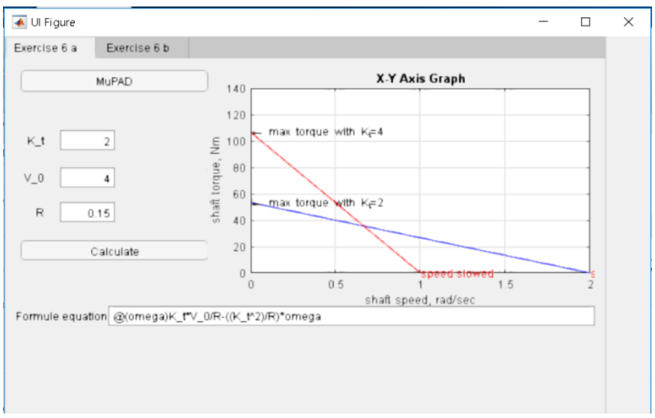

Figure 4. Graphical solution of exercise 2

2.3.2 Exercise 3

This exercise is based on the following scenario: a certain motor has been considered for a particular electric vehicle, but the experiment showed that the resulting torque applied to the wheels is about 1/3 of what was needed. It seems that tripling the number of cells in the battery could solve this issue. Would this have the desired effect? Wouldn't it have a consequence for the speed of the wheels under no load?

a) No it would not have the desired effect of tripling torque;

b) Yes it would have the desired effect of tripling torque, and it would also reduce the speed at no load by a factor of three;

c) Yes it would have the desired effect of tripling torque, but no it would not affect the speed at no load;

d) Yes it would have the desired effect of tripling torque, and it would also triple the speed at no load;

This problem is easy to solve by simulations with a mathematical model. In this case the students are able to perform a variety of simulations with different parameters of the vehicle in order to assess their influence on the vehicle dynamics. On Fig. 5 is presented the graphical solution of exercise 3: their torque as a function of the rotational speed is characterizing the two motors and it is clearly visible that the one with a higher maximum torque also has a higher rotational speed by no load.

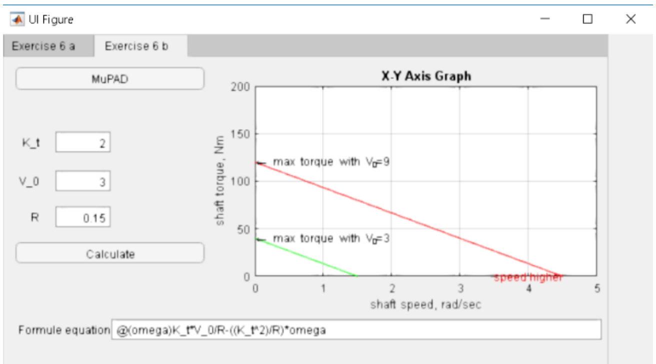

Figure 5. Graphical solution of exercise 3 – comparison between the torque curves of both motors

III. Conclusion

In this paper is presented the implementation of a mathematical modelling and simulations in a course oriented towards to electric vehicles and e-mobility. The model and simulations are implemented in a specially developed MATLAB application running on a MATLAB application server either in a MATLAB runtime environment. In this way, the program is in the form of an executable file and thus doesn't need anything but the runtime environment preinstalled, avoiding any incompatibilities between versions and releases of MATLAB or licensing issues. The purpose of this program is to explore math modelling by students in various disciplines and levels. The motivating example is an electric powered car with a simple torque speed curve, used as a basis and the effects of different model parameters on automobile performance are examined. It was then used to determine the system performance and energy flow over a given set of motoring and regeneration speed/torque conditions. The model could be used to augment instruction in energy conversion or vehicle systems courses.

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