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Analysis of electric motorcycle basic characteristics with independent *DynPy Python* library

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ABSTRACT: *DynPy* is an open-source library implemented in *Python* programming language which enables the user to model, solve, simulate, and report an analysis of a system described with ordinary differential equations in a single environment. In the paper, an example for obtaining analytical and numerical solutions of the coupled mechanical-electrical electric motorcycle model is presented. To verify the correctness of the implemented code, comparison with *MATLAB/Simulink* was conducted. With the use of *DynPy*, a hybrid analytical-numerical method and fully analytical approach were shown, while in MATLAB/Simulink strictly numerical simulations were ran. The comparison of the results obtained from both tools proved the credibility of the developed library. Also, its superiority in specific conditions was highlighted. The presented tool allowed the authors to create the model, run the simulations and generate a scientifically formatted report in a single *Jupyter Notebook*, confirming its versatility.

KEYWORDS: engineering software, numerical simulations, analytical solution, coupled electrical-mechanical system, Python programming language

1. Scope and aim

Potential benefits to the transition of the transportation means to their greener versions effect in launching governmental policies to encourage consumers to switch from conventional to electric vehicles, including motorcycles [1-4]. The market of electric motorcycles (EM) is observed with very fast growth rate and is expected to generate over 17 billion USD in year 2030 [5]. From the environmental and societal point of view EM provide a great chance for residents of developing countries. The cost of buying and operating a motorcycle is lower than of a car and the vehicle itself due to smaller size finds better fitment to crowded areas, often encountered in the case of progressive industrialization [6,7]. Two general types of EM drivetrains include high-speed geared motor and direct-drive motors. From the point of view of daily commute in highly urbanized areas, the latter offers more advantages, such as smaller mechanical complexity and energy losses, better cruising and regenerative braking, what results in reduced maintenance, longer lifespan and enhanced efficiency.

The article aims to present the abilities of the *Python* implemented *DynPy* ('DynamicPython') [8] library in modelling, conducting simulations and results visualization of dynamic systems with an example of a coupled electrical-mechanical dynamic system analysis. The utilized model represents an electric motorcycle in a straight line propulsion and consists of components representing brushless direct current (BLDC) electric motor and moving mass. To prove a proper functioning of solving algorithms, comparison with *MATLAB/Simulink* is conducted. Due to the factors such as air pollution, noise pollution and traffic density in large cities, electric motorcycles can be found as a promising solution to the rise of highlighted problems. Hence, more reliable, durable, safe, and effective design of such vehicles is needed. An open-source, multipurpose engineering software like *DynPy* might potentially enhance the ability of independent researchers to contribute in the field of green transportation.

2. Modelled system and methodology

The following methodology has been introduced in order to fulfil the stated aim. Firstly, a mathematical model of the BLDC motor was constructed with the use of unique *DynPy* composition system and concurrently in *MATLAB/Simulink*. Simulations were conducted and the level of agreement of results between the two environments was assessed. After positive verification of algorithms implemented in *DynPy* library, further works were continued exclusively in *Python*, and included extension of the BLDC motor model with a mass representing the EM in horizontal movement, obtaining coupled electrical-mechanical system. Its behaviour was studied with NumericalAnalysisDataFrame bulit-in tool, which enables to generate results for multiple values of a single parameter in a few easy steps. It is important to note, that a separate report module of the *DynPy* library delivers comprehensive functionalities to create reports with figures, tables and mathematical formulas - the manuscript for this article was created in the same *Jupyter Notebook* in which simulations were prepared and run.

3. Modelling and simulations

Case under consideration is coupled electro-mechanical model. The equations of motion of the DC motor were derived based on the equivalent circuit (fig. 1) and Kirchhoff's second law and have a following form:

$$U_z - L_w\ddot{q} - R_w\dot{q} - k_e\dot{\varphi} = 0 \quad (1)$$

$$M_l + k_m\dot{q} - B\dot{\varphi} - J\ddot{\varphi} = 0 \quad (2)$$

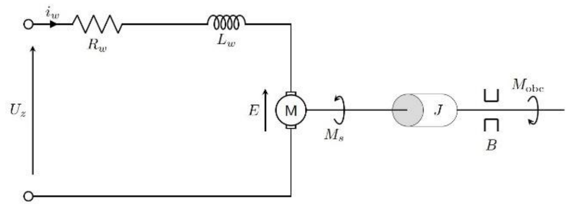

Fig. 1. The equivalent circuit diagram of the BLDC motor

It is possible to obtain both analytical (when applicable) and numerical solutions to Ordinary Differential Equations (ODE) without a change of the model nor environment with *DynPy* module. Moreover a hybrid analytical-numerical (HAN) approach is possible and was utilized for comparison with *MATLAB/Simulink*, as it enables to control an integration step size. The M_l in the equations of motion represents an engine load while U_z source voltage and both have a character of Heaviside functions. To perform HAN type solution, firstly a model without forcing was solved analytically. Then, Heaviside forcing has been introduced to obtained solutions and such system was solved numerically with selected step size of 0.1 s. Similar simulations were ran with strictly numerical *MATLAB/Simulink* model with three different settings: with variable step size, constant step size of 0.1 s and constant step size of 0.01 s. The most interesting results are presented in fig. 2.

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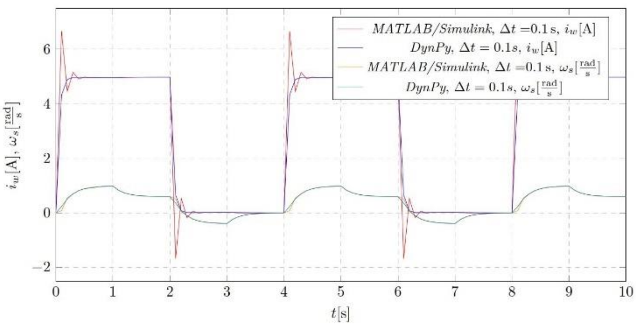

Fig. 2. Comparison of simulations conducted using the DynPy library and MATLAB/Simulink with a fixed integration step size of 0.1 s

4. Analysis of simulation results

Preliminary assessment of the implementation of the algorithms in the *DynPy* library proved their overall correctness. For cases with a variable integration step and a constant step of 0.01 s in *MATLAB/Simulink*, the obtained results are consistent. Quantitative and qualitative discrepancies were observed between the results for a constant step of 0.1 s in *MATLAB/Simulink*. Here, the *DynPy* library responded better to changes in system dynamics despite one order of magnitude bigger integration step, the results being more relevant to ones obtained with 0.01 s step in *MATLAB/Simulink*.

5. Summary and conclusions

Positive verification of the *DynPy*'s ability to generate and solve dynamic equations of a relatively simple, two degrees of freedom system allowed the authors to introduce more complicated model. Currently, the coupled electrical-mechanical model is being constructed and tested in *DynPy*, so a case-study of accelerating and decelerating of an electric motorcycle can be presented.

It can be concluded that proposed environment allows to perform complex simulation analyses and presented model enables to obtain results that are compatible with real objects. The main conclusions are as follows:

1) Presented open-source library allows to model electromechanical problems in convenient way, ensures results convergence with commercial and well-checked environments e.g. MATLAB.
2) Class of practically occurring load or methods of control of electrical motors can be successfully solved with hybrid analytic-numerical methods what ensures high performance and convergence of obtained results with lower computational requirements.
3) Proposed couple electromechanical model is accurate for the analysis of main properties of motion of EV motorcycle e.g. energy demand, regenerative braking or design calculations of cells.

Proposed environment (in form of the *Python*'s library) is Authors innovative contribution in the field of computation mechanics and numerical simulations. Since a direct-drive type is modelled, an aspect of energy harvesting from braking will be tried to be implemented as well.

References

[1] Chakraborty, Abhishek & Mateen, Arqum & Kumar, Rajeev Ranjan & Narayanamurthy, Gopalakrishnan & Srivastava, Abhishek. (2022). Design and Selection of Government Policies for Electric Vehicles Adoption: A global perspective. Transportation Research Part E Logistics and Transportation Review. 10.1016/j.tre.2022.102726.

[2] Rezaei, Rasa & Peng, Huei. (2024). The Growing Business of Electric Vehicles: A Shift Towards Sustainable Transportation. 10.20944/preprints202401.1798.v1.

[3] Sukma, Alfy & Suroso, Arif & Hermadi, Irman. (2023). The Effect of Environmental Concerns and Government Policies on The Intention to Buy Electric Car. Business Review and Case Studies. 4. 10.17358/brcs.4.1.52.

[4] Alanazi, Fayez. (2023). Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread Adaptation. Applied Sciences. 13. 6016. 10.3390/app13106016.

[5] Phuong, Tran Thi Lan et al. "Determinants of Electric Motorbike Purchasing Intention among Consumers in Hanoi City, Vietnam." *Environmental Research Communications* 6.7 (2024): 75016. Print.

[6] Zahedi, Rahim, Ali Asghar Pourezzat, and Mohsen Jafari. "Hybrid Energy Storage System for Electric Motorcycles: Technical and Economic Analysis." *Case studies in thermal engineering* 60 (2024): 104613. Print.

[7] Li, P., Hu, J., Qiu, L., Zhao, Y., & Ghosh, B. K. (2021). A distributed economic dispatch strategy for power–water networks. *IEEE Transactions on Control of Network Systems*, *9*(1), 356-366.

[8] GitHub.bogumilchilinski/dynpy. https://github.com/bogumilchilinski/dynpy. Accessed: 2024-07-30.