Physical Model of an Electric Vehicle for Research of Dynamic Operating Modes

Gergana Vacheva [1], Rad Stanev[2], Nikolay Hinov[3]
[1] Technical University of Sofia, Department of Power Electronic, Sofia, Bulgaria, e-mail: gergana_vacheva@tu-sofia.bg
[2] Technical University of Sofia, Electrical Power Engineering Department, Sofia, Bulgaria, e-mail: rstanev@tu-sofia.bg
[3] Technical University of Sofia, Department of Power Electronic, Sofia, Bulgaria, e-mail: hinov@tu-sofia.bg

This paper presents mathematical and physical model of permanent magnet synchronous machine which enable simulation and experimental studies of various dynamic modes of operation of electric vehicle in laboratory environment. The mathematical model is realized in Matlab programming language. It provides useful information for investigation of the dynamic modes including control strategies related to recuperation modes. Several operation modes are experimentally studied and analyzed using the physical model.

Keywords—electric vehicles, modeling, dynamic modes, permanent magnets synchronous motors (PMSM)

I. INTRODUCTION

There is an increased demand for electric vehicles due to the development of the modern technologies and the desire for the nature preservation. The substantial studies in operating conditions are not achievable due to the nature of the examined subject and the impact of the consequences in a case of an adverse development in the operating modes [1-4]. The above statement imposes that majority of studies need to be performed with the aid of models that represent the distinctive properties of the elements and the connections between them. The mentioned reasons led to a solution to make an experimental physical model, which represents the performance of the electric vehicle under different test modes but in safe conditions.

II. METHODOLOGY

It is accepted that the representation of the actual physical objects is to be performed with the aid of descriptive physical and/or mathematical models [6, 7].

The descriptive models provide general overview about the content and essence of the particular issue. The actual physical objects are superseded by mathematical models with mathematical descriptions and algorithms. For the time being the mathematical models have received the most broad dissemination by the reason of their outstanding advantages in terms of their applicability for structured approaches for analyzing systems with a large number of different types of elements, the lack of spatial-temporal constraints, economic efficiency, speed, ease, convenience upon presentation of results, etc.

The physical models replace the processes in the actual physical objects with experiments, which are conducted on specialized scaled objects in a laboratory environment. Those models are space and time constrained, limited in their connectivity and the ability to provide similarity etc., but they feature the significant advantage that they are imminent and present in a comprehensive and visual way processes in actual physical objects and systems.

III. DESCRIPTION OF PERMANENT MAGNET SYNCHRONOUS MACHINE

The most effective from all the electrical motors are the permanent magnets synchronous machine in electric vehicles. The reason for that is the usage of permanent magnets which don't consume power after they have been initially excited. The lack of mechanical switches and brushes leads low level of energy losses during mechanical friction and therefore better energy efficiency.

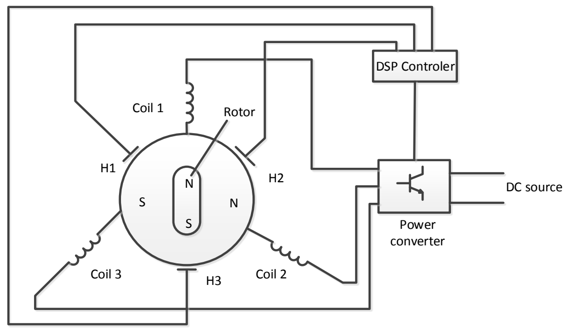

Fig. 1. Permanent magnet synchronous machine, along with its control and power scheme

The analysis of the motor is based under the following suppositions: the motor is not saturated, the resistances of all of the stator coils are equal and the self and mutual inductances are constant. The losses must be negligible and the power switches in the converter are ideal. The experimental stand is composed based on this type of motor [5, 8]. The type of supplied DC converter is buck-boost in such a way is ensured his work under a wide range of change in the input voltage.

IV. MATEMATHICAL MODEL

A mathematical model for research of the work of the developed stand under alternation of the outer resistances is invented for the purpose of this work. The following equations represent the work of the permanent magnet synchronous machine in the rotor.

$$R_s i(t) + \frac{L_s di}{dt} + C_e \omega(t) = V(t) \quad (1)$$

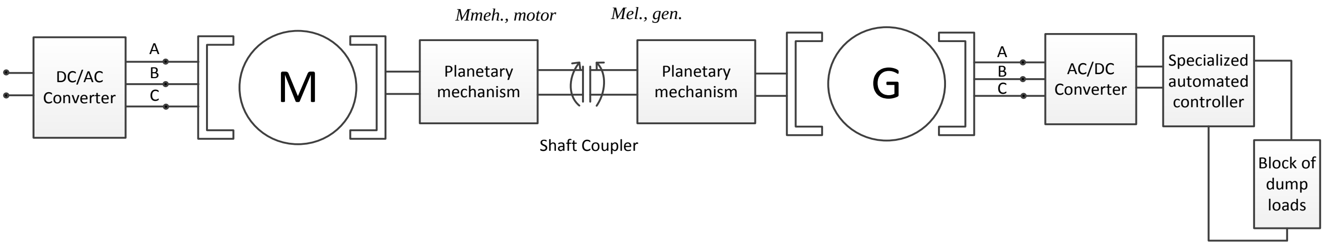

Fig. 2. Block scheme of physical model

$$J\frac{\omega(t)}{dt} = C_m i(t) - M_c(t) \qquad (2)$$

Where Rs is the resistance of the anchor of the motor, L_s is the inductance of the motor, C_e and C_m are constants, ω is the angular velocity, J is the inertia and M_c is the torque moment.

The created model is composed in the environment for visual programming Matlab. The work of the electric vehicle is described utilizing the fundamental laws of physics. True the represented code below the model realization is shown in Fig.3.

```
Mw=Mdvg*k;
Fw=Mw/r;
Ffr=m*fr*g;
Fa=0.5*RoV*Ka*S*y(1)^2;
if t<10
   dy(1)=(Fw-Ffr-Fa)/m;
   else
   if t<=20
      dy(1)=0;
   else
      if y(1)>0
         dy(1)=(-Fw-Ffr-Fa)/m;
      else
         dy(1)=0;
    end
  end
```

Fig. 3. Source code, described the model of motor

Where

- *Mdvg* - momentum of the motor;
- *k* - Transmission coefficient;
- *r* - Radius of the wheel;
- *Mk* - Wheel momentum;
- *Fw* - Force acting on the wheel;
- *Ffr* – Friction;
- *fr* - Road friction coefficient;
- *m* - |The mass of the vehicle;
- *RoV* - Air density;
- *Ka* - The coefficient of the aerodynamic resistance;
- *S* - Surface of the vehicle;
- *Fa* - The force of the aerodynamics resistance

Various dynamic work modes are described by the constructed model: acceleration to a reference movement speed – 10 s., establishment – from 10 to 20 s. and decrement of the velocity – from the 20[th] to the 30[th] s. That way at certain specification it is possible to simulate the power and the energy used from the motor as shown on Fig. 4.

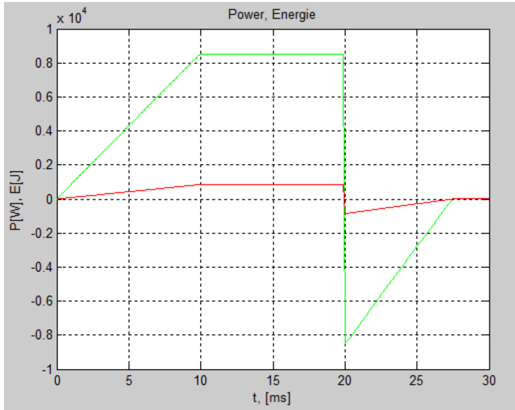

Fig. 4. The power and energy while accelerating, astablishing and cease.

V. Description of Experimental Model

The experimental model is consists by two permanent magnets synchronous machines with a planetary gear mechanism. The motor stator winding is fed by a DC/AC inverter. The nominal DC voltage of the DC/AC converter is U=48 V. The nominal power is P=500 W, the nominal rounds per minute are 2800. The machines are three phase and have the ability to operate as a motor or a generator. A specialized stator winding load controller similar to the one presented in [10-12] is used to represent the load change due to the road inclination.

A configuration of a specialized automated converter of power and voltage is composed by a controller, power electronics switches and a block of dump loads. The external resistance in the circuit of the three phase synchronous machine in a generator mode is changed by setting the inclination of the road. The consumed power by the shaft of the coupled motor with permanent magnets is this way regulated. A general block scheme of the experimental model is represented of Fig. 2 where the motor (M), the generator (G), the specialized automated controller and the block of dump loads are represented.

The following equations representing the operation of the model in both directions are used:

$$M_{meh.,motor} = M_{el.,gen.} \qquad (3)$$

$$P_{meh.,motor} = P_{el.,gen.} \qquad (4)$$

Where $M_{meh.,motor}$ is the mechanical moment of the motor and $M_{el.,\ gen.}$ is the electrical moment of the generator. Accordingly $P_{meh.,\ motor}$, $P_{el.,\ gen.}$ are the losses in the motor and the generator. Fig. 4 and Fig. 5 depict the experimental model.

Fig. 5. Photo of the physical model

VI. FUNCTIONAL CAPABILITIES OF THE PHYSICAL MODEL

The following operating modes can be completed using to the physical model:

- motor mode;
- recuperation mode;
- dynamical changes of the operation load;
- reverse mode.

The model allows testing of various power electrical converters for energy recuperation under motor mode with different scale of loads based on the profile of the road, the mass of the electric vehicle and the resistances.

The power supply of the motor is realized by frequency controller thus the operation mode is examined in different frequencies. The modeling of the slope of the road and the power losses at the movement of the electric vehicle is developed by the connection of coupled machine with the load.

A couple basic cycles of movement defining the dynamics in different kinds of electric vehicles are presented on Fig. 5 and Fig 6. The first case is an imitation of a transportation in an urban area with frequent departures and braking. On the other hand the suburban transportation cycle is reviewed that is without ceasing but only with velocity variation. The case when the usage of a recuperation while braking would be effective is defined by the analysis of those two cycles.

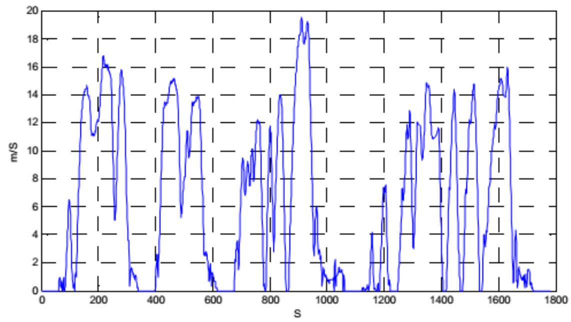

Fig. 6. Movement cycle CSHVR (City Suburban Cycle and Route)

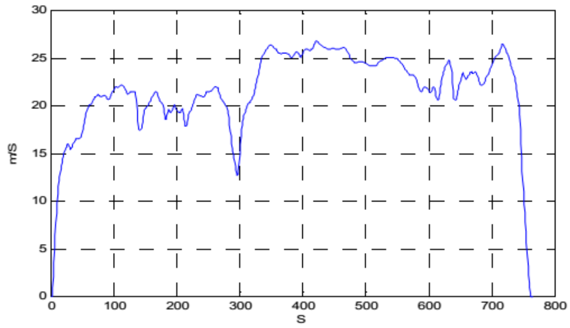

Fig. 7. Movement cycle HWFET (Highway Fuel Economy Test Cycle)

VII. RESULTS

On Table 1 are exhibited the results from the conducted experiment of the working modes of the physical model while idle. The input current and voltage during plenty work frequencies are measured.

TABLE 1

DC		AC		
U_{in}[V]	I_{in}[A]	U_g[V]	I_m[A]	F[Hz]
49.2	0.1	1.88	0.16	4
48.8	0.57	7.18	0.36	50
48.4	1.22	14.06	0.37	100
48	2	21.29	0.32	150
47.8	2.87	27.82	0.27	200
47.5	3.92	34.57	0.16	250

The output current and voltage at minimal work frequency – 4 Hz of the physical model are shown on Fig. 7 and Fig. 8.

While on Fig. 9 and Fig. 10 is the representation again of the output current and voltage but on the maximal work frequency of 250 Hz. The form of the output voltage close to sinusoidal is observed at given values. That consideration respond to the physic process in the machine. On the other side the efficiency of the conversion is increased with the augmentation of the work frequency.

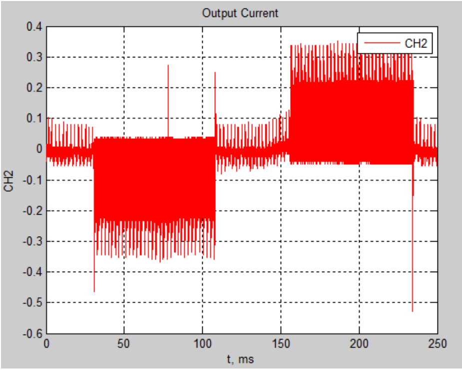

Fig. 8. Motor current at 4 Hz

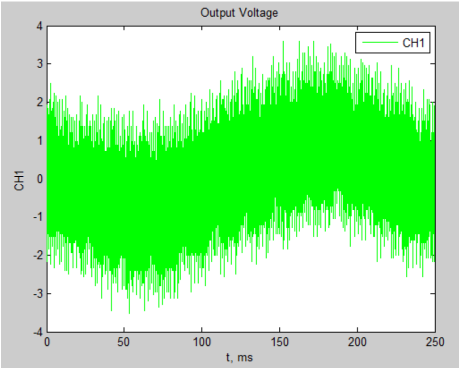

Fig. 9. Generator voltage at 4 Hz

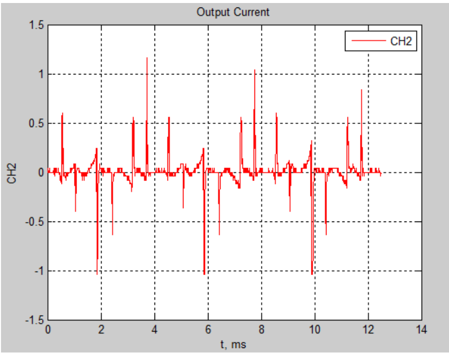

Fig. 10. Motor current at 250 Hz

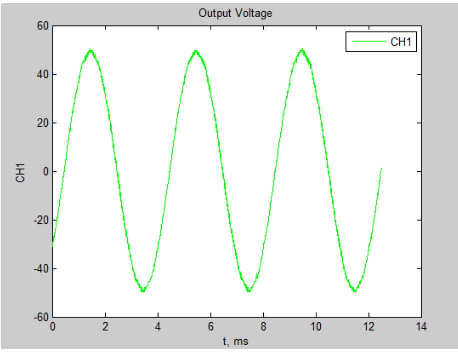

Fig. 11. Generator voltage at 250 Hz

With the aid of electronic oscilloscope Tektronix are realized the measurements and the results are analyzed with applied software Matlab. That allows the definition of parameters which is necessary for the research like harmonic analysis, effective and average values of currents and voltages, etc. through the usage of different functions.

VIII. Conclusion

A new construction and realization of an experimental physical model of an electric vehicle for study of dynamic modes is proposed. The proposed solution allows a wide range of experimental researches under various loads while using only one single physical model. The model can achieve a various applications on analysis of dynamic modes due to its flexibility, convenience and multi-functionality.

The velocity, power and energy of the electric vehicle could be defined by simulation that is possible with the aid of the mathematical model. By controlling the motor rounds per minute without load are conducted the measurements of the input and output data during a variation of the work frequency.

In future experiments the review of the work of the physical model at different loads will be achieved with the purpose of research and analyze of the optimal dynamic modes.

The establishment of automated system for collection and processing of measured data is predicted with the purpose of facilitate the work modes of the physical model.

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