Analysis of Electric DC Drive Using Matlab Simulink and SimPower Systems

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***Abstract*— In this paper model for analysis electric DC drive made in Matlab Simulink and Matlab SimPower Systems is given. Basic mathematical formulation which describes DC motor is given. Existing laboratory motor is described. Simulation model of DC motor drive and model of discontinuous load is made. Comparison of model made in Matlab Simulink and existing model in SimPower Systems is given. Essential parameters for starting simulation of used DC motor drive is given. Dynamical characteristics of DC motor drive as results of both simulation are shown. Practical use of simulation model is proposed.**

***Keywords*— analysis, DC drive, Matlab, SimPower Systems, model, simulation.**

I. INTRODUCTION

The basic problem of this paper is building simulation model of DC motor by using one of programs for modeling called Matlab Simulink. This will provide testing of motor dynamic characteristics and motor performance on model instead original. This is specially desirable for large DC motors over 50 kW, because testing of motor for different kinds of load and testing motors dynamic can prevent some malfunctions and damages of motor. Model can also be used for testing motor performances and for testing motor prototypes because it provides possibility of changing motor parameters. More about essential motor parameters that are crucial for building a motor model will be discussed further in paper. Motor model in Simulink will be compared with motor model from SimPower Systems library which contains different kinds of models for typical power equipment. This library includes models of: electric transformer, asynchronous motor, synchronous motor and generator, DC motor and some other power electronics elements. SimPower Systems provides application for modeling and simulation of electric motor drives in three levels: modeling of simple drives by using classical electrical devices, modeling more complex drives by using semi-conductor elements and circuits and modeling very complex drives by using subsystems for control and regulation of electric machines [1]. Purpose of these two different motor models is analysis and comparison of possibilities that each model gives. Similar comparison of possibilities in model constructing using Matlab Simulink is done by [2]. In that paper model for dynamic testing of asynchronous motor using specified load is made. Dynamic simulation of direct current motor is also made in one other simulation program called

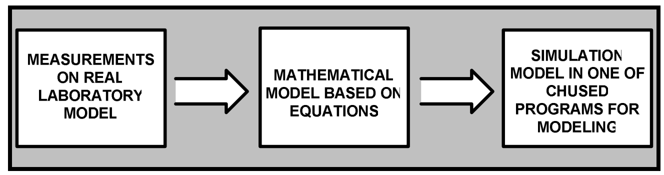

Figure 1. Model building process.

LabVIEW by [3]. The principle of making simulation model in LabVIEW is similar to making model in Matlab Simulink. In LabVIEW there is virtual instrument panel that provides real time control and simulation start. This part is separated from part called Block Diagram where program for simulation is made. In that way all wanted motor parameters, diagrams and schemes are visible [9]. The building of motor model is based on mathematical equations. Process of model building process is shown on Fig.1. These equations can be found in numerous literature. In this paper equations are used from [4], [5], [6] and [7].

II. MATHEMATICAL MODEL OF DC MOTOR

Modeling of any kind of electrical machines such is DC motor starts with measurements on real model because it is necessary to determine motor parameters. The other possibility is to get the motor parameters from manufacturer or determinate our own parameters if motor prototype is being build. After that motor model can be made by using all mathematical equations that describe the motor.

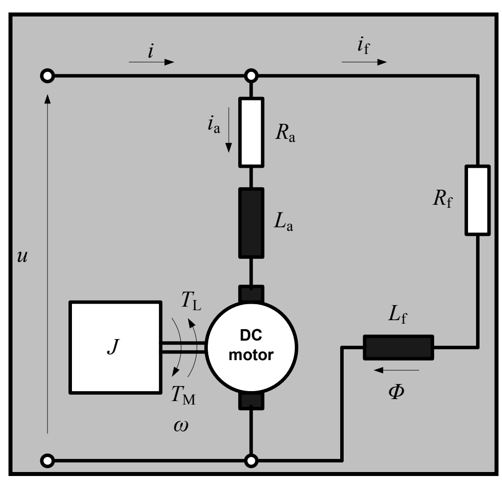

Figure 2. Equivalent circuit of a DC parallel motor [4].

Mathematical equations that describe DC parallel motor derives from equivalent scheme (Fig. 2.). DC parallel motor is the DC motor that has parallel field winding. As shown on Fig. 1, after configuration of mathematical model, simulation model can be made in Matlab Simulink. Functioning of DC motor can be explained by using two electrical circuits. Exciting (field) circuit creates magnetic flux and in armature circuit armature current from power source causes appearance of force on motor windings. Parallel DC motor can be described by using following equations as given in [7]. The equation that describes the armature circuit is:

$$U = E + I_a R_a \tag{1}$$

where U is armature voltage, E is induced voltage, I_a is armature current and R_a is armature resistance. Induced voltage can be expressed with following equation:

$$E = k_e \Phi\, n \tag{2}$$

where k_e is electrical constant of specified DC motor, Φ is magnetic flux and n is motor speed in rpm. The equation that describes field circuit can be expressed as:

$$U = I_f\, R_f \tag{3}$$

where I_f is field circuit current, R_f resitance of field circuit. Torque on motor shaft (T_M) can be expressed as:

$$T_M = k_m \Phi\, I_a \tag{4}$$

where k_m is mechanical constant of specified DC motor. It can be seen on Fig. 1. that sum of currents for parallel DC motor is:

$$I = I_a + I_f. \tag{5}$$

Following equations given above are used for model building in Matlab Simulink. This model is used to obtain motor static characteristics. Motor dynamic characteristic can be obtained from motor model in SimPower Systems. The equations that are used for this model are differential equations as given in [4]. For motor armature and field circuit, field current, field flux and motor torque can be expressed by following equations:

$$u = R_a i_a + L_a \frac{di_a}{dt} + e \tag{6}$$

$$e = k_e \Phi\, \omega \tag{7}$$

$$u = R_f i_f + L_f \frac{di_f}{dt} \tag{8}$$

$$\Phi = f(\, i_f\,) \tag{9}$$

$$T_M = k_m \Phi\, i_a\,. \tag{10}$$

One more equation that describes Newton low for concentrated mass as given in [4] is:

$$T_M - T_L = J\frac{d\omega}{dt} \tag{11}$$

where T_L is load torque, J is moment of inertia and ω is angular speed. Sum of current is represented with instant values of currents in armature and field circuit:

$$i = i_a + i_f. \tag{12}$$

A. *Motor model parameters*

As mentioned, before starting of simulation building it is necessary to have all relevant motor parameters that describe the motor. All this parameters are implemented in mathematical equations that describe the model. Parametars for motor model made in Matlab Simulink are given in Table 1.

TABLE I. MOTOR PARAMETERS FOR MATLAB SIMULINK MODEL

Parametar	Value
P_N	3 kW
U_N	220 V
n_N	1500 min^{-1}
R_a	0.87 Ω
R_f	550 Ω
I_f	0.4 A
I_a	16.5 A

Parametars for motor model made in Matlab SimPower Systems are given in Table 2.

TABLE II. MOTOR PARAMETERS FOR MATLAB SIMPOWER SYSTEMS MODEL

Parametar	Value
P_N	150 kW
U_N	250 V
n_N	618 min^{-1}
J	25 kgm^2
R_a	0.012 Ω
R_f	12 Ω
L_a	0.00035 Ω
L_f	9 H
L_{af}	0.036 H

In Table 2. parameter L_{af} is parameter that is determining mutual inductance.

III. MATLAB SIMULINK MODEL

Simulink is software package or program tool developed in Matlab graphic interface. It provides modeling, simulation and analysis of different kinds of continuous and discrete systems. In that way Simulink can be used for exploring the behavior of a wide range of real world dynamic systems including electrical circuits and many other electrical and mechanical systems [8]. System that is being built in Simulink is consisting of a number of blocks which are connected with signal lines in one functionally group.

In Fig.3. Matlab Simulink library is presented. It consist from

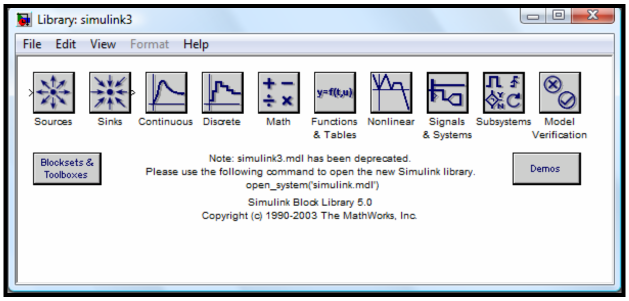

Figure 3. Matlab Simulink library.

different kinds of blocks such as: sources, sinks, subsystems etc. Each block given above represents one group of elements. In Fig. 4, simulation model of parallel DC motor is presented. As mentioned, in Simulink model are directly implemented equations from (1) to (5). Different blocks are used for presentation of different motor parameters that are beeing observed, like motor electric and mechanic power, current, speed, torque etc. With this model it is posible to relate two motor parametars and this reperesents motor static characteristuics.

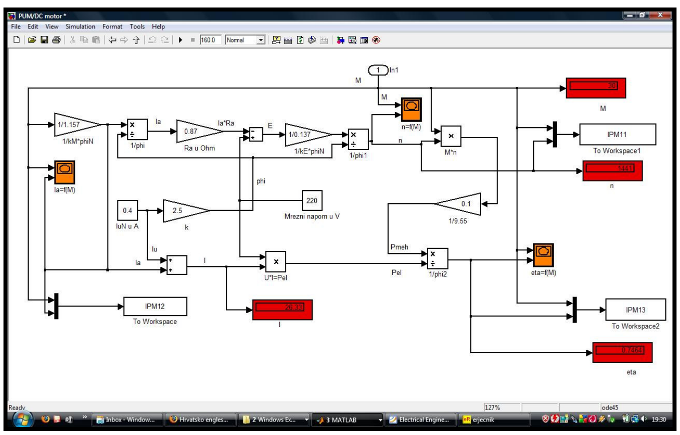

Figure 4. Matlab Simulink model of parallel DC motor.

Fig. 5 presents model of discontinuous load for DC motor. It consists from ramp function, relation operator and block that determines maximal torque. With block Scope instant value of motor torque can be observed. Block Display gives

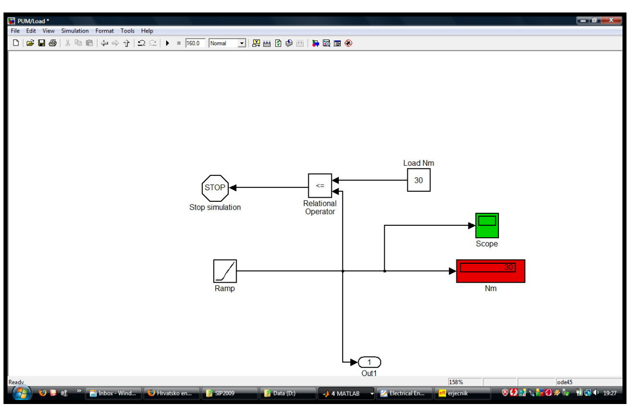

Figure 5. Matlab Simulink model of discontinous load.

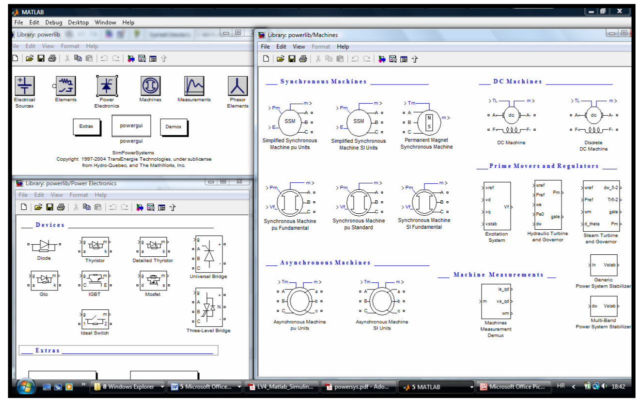

Figure 6. Matlab SimPower Systems library.

information about numeric value of torque.

IV. SimPower Systems Model

SimPower Systems is the part of Matlab Simulink and it operates in Simulink environment [6]. It consists of electrical power circuits and electromechanical devices such as motors and generators. It is supposed to be used for simulation of electrical drive systems, in witch, in combination with machines, elements of energetic and control electronic are present. In Fig. 6 SimPower Systems library is presented together with toolbox that contains all types of motors and generators. In toolbox on the down left side elements of energetic electronics (tiristors, diodes, IGBT transistors etc.) are presented. In each of this modules mathematical model of device is implemented. For simulation start it is only necessary to input parameters for simulated device. In this paper it is necessary to input parameters of DC motor, which is shown on Fig. 7 together with part for motor load, motor source, timer and bracker for simulation start and part for results export.
Fig 8 presents DC motor under the mask. It is now visible that motor consists of all elements that are shown in Fig 2 (elements of equivalent scheme). The subsystem block called Mechanics describes the mechanical equation given in relation (11). In subsystem block called Measurement list all wanted electrical and mechanical values can be presented in diagram, in function of time. These characteristics are motor dynamic characteristics.

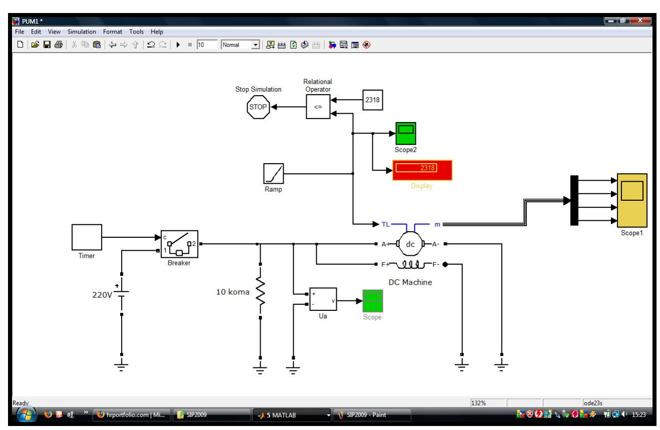

Figure 7. DC motor model in SimPower Systems.

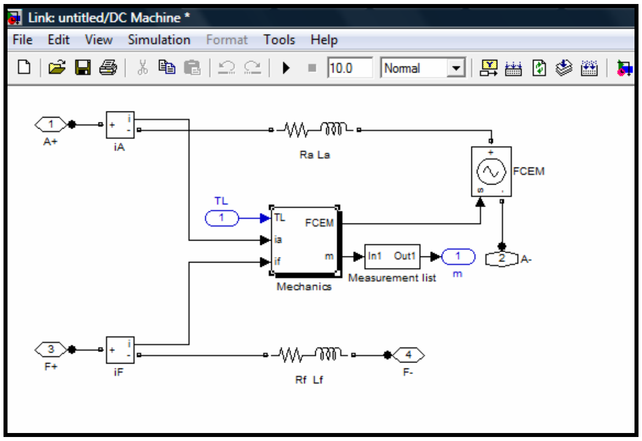

Figure 8. DC motor model under the mask.

V. RESULTS

As mentioned before, the main topic of paper is building simulation model of parallel DC motor in Matlab Simulink and testing the possibilities of DC motor dynamic performance by using SimPower Systems model library, which contains model of DC motor. Motor used for Simulink model is laboratory motor (3 kW) given in Fig. 9. Some parameters for this motor are obtained from manufacturer and some parameters are measured as shown in Table 1. The motor data used for simulation in SimPower Systems is given in [5] and all relevant data are shown in Table 2.

A. Results of simulation in Matlab Simulink

Results of simulation model made in Matlab Simulink are static characteristics. Some of these characteristics are shown in Fig. 10. In Fig. 10 presented characteristics are: speed in function of torque, armature current in function of torque and efficiency in function of torque. It is possible to obtain some other characteristic also, and see their mutual dependence. Fig. 11 presents one experiment with given four different characteristics $n = f(T)$. On these torque characteristics changes which occur during the change of one motor

Figure 9. Paralell DC laboratory motor 3 kW [1].

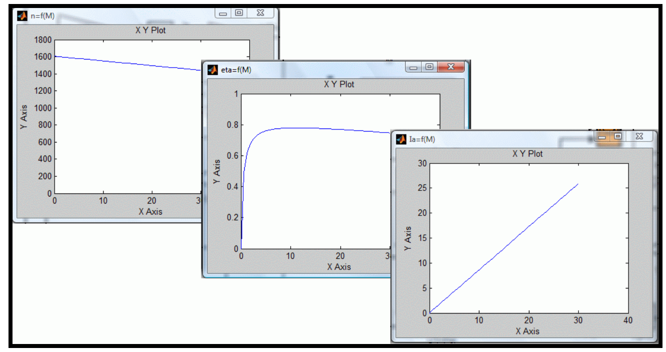

Figure 10. Motor static characteristic: $n = f(T)$, $\eta = f(T)$, $I_a = f(T)$.

parameter are shown. Uppermost characteristic presents the characteristic when field current changes from 0.4 A to 0.35 A. Second characteristic is the nominal characteristic with values from Table 1. The third characteristic is the characteristic with changed armature resistance and the last characteristic is the characteristic with changed source (armature) voltage. From these curves motor behavior during mentioned changes can be observed.

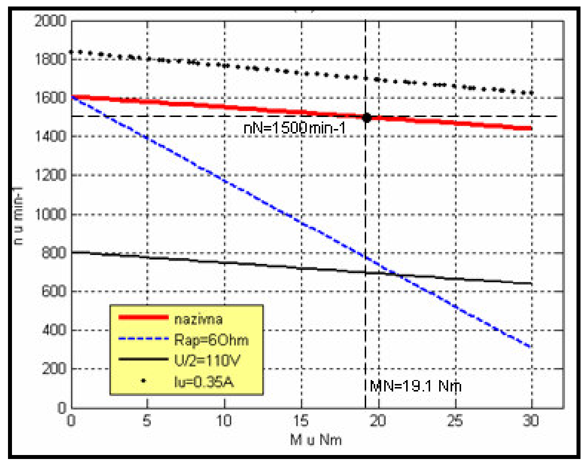

Figure 11. Torque characteristic for different motor parameters [1].

B. Results of simulation in SimPower Systems

Results of simulation model made in SimPower Systems are motor dynamic characteristics. Some of these characteristic are presented on Fig. 12. These characteristics

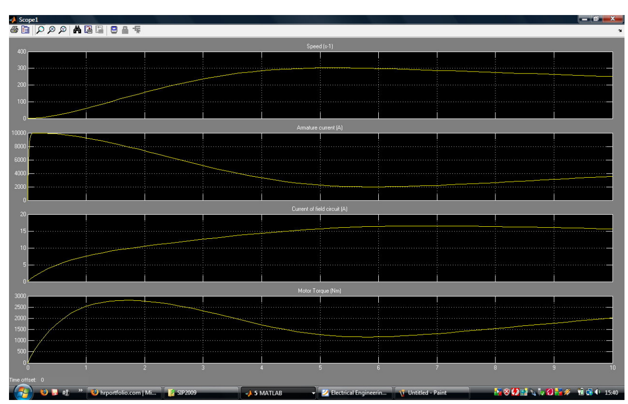

Figure 12. Load characteristics.

present motor behaviour during motor start. All values are in function of time. Because simulated motor is in group of large DC motors (over 50 kW), the time necessary for stabilization of each value is longer. Fig. 12 presents four motor values: speed, armature and field current and motor torque as function of time. It is possible to monitor dynamic changes in small period of time (a few ms) after starting the motor, when armature current has high amounts. This model also gives possibility of changing the motor parameters and testing the motor for different kinds of load.

VI. CONCLUSION

Usage of different kinds of programs, such as Matlab, provides complete static and dynamic state analysis, and testing different kinds of machines by using simulation model instead original.

With analysis of mathematical model expensive and unwanted testing of original can be avoided. Model can also be used for testing motor performances and for testing motor prototypes because it provides possibility of changing motor parameters.

Simulation programs provide understanding DC motor behaviour under transient and stedy-state operating conditions. This can be used to understand starting problems, specialy in case of large motors (like tested, 150 kW) because of appearance of high armature current. Also motor can be tested for different kinds of load torque. In this way many kinds of drives in wich motor could be implemented can be tested before real application in industrial envirement. There is also possibility of testing motor protoypes with easy way of changing motor parameters. In this

paper all mentioned possibilities include work with Matlab Simulink or SimPower Systems tools for modeling. The other avaliable programs can also be implemented because the procedure for modeling is the same. It is important to mention that for good model all parametars have to be reliable. It is good if there exist posibility of testing the simulation model on real laboratory model, so that characteristics can be compared and calibrated. In this way one model of DC motor (in example) can be used for all DC motors with other parameters. Further research will include complete evaluation of real and simulation model, testing of model for different types of load and motor, and determination of dynamical parameters. Also there is possibility of testing the SimPower System program for modelling asynchronous motors and synchronous generators.

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