Integration of Real-Time Electric Power Steering System Matlab/Simulink Model into National Instruments VeriStand environment

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***Abstract*—The purpose of this research is to develop the control logic for an electric power steering system (EPS) and to test this control logic in different scenarios to prove his functionality. The EPS was built using the equations of the dynamical model of the steering system. The Permanent Magnet Synchronous Motor (PMSM) is providing the assist torque needed to steer the vehicle. The control applied to the motor is torque control with PI regulators for d and q axis currents. In the electronic control unit (ECU) the control logic was implemented. This logic is taking into account the input torque from the steering wheel and the velocity of the vehicle. Depending on these two inputs a certain amount of assisting torque is applied based on the linear pattern assistant characteristic. The complete model was converted to run on the Embedded Controller NI PXI-e 8135 processor where different scenarios are applied using NI VeriStand. The scenarios applied to the EPS are obtained from LMS Amesim simulation environment where real steer scenarios are simulated on a vehicle.**

***Keywords*—EPS; VeriStand; PMSM; ECU.**

I. INTRODUCTION

During the past ten years, EPS has been introduced in gradually increasing numbers. Although electric power steering system offer significant advantages over their hydraulic counterparts, electric motor technology and controls had not reached the point where they could be used in this application until just recently [1]. Electrically assisted power steering is replacing the traditional hydraulic system where the pressure is provided via a pump driven by the vehicles engine. The hydraulic system is constantly running and by using the EPS the fuel consumption can be reduced. In electric and hybrid vehicles, the engine does not run continuously so electric power steering is the only possible solution [1]. The newest technology in the steering systems is the Steering-By-Wire (SBW) system. In this system the connection between the steering wheel and the steered front wheel is eliminated [4], [5]. In the EPS the electrical motor is assisting the steering motion directly by driving the rack and pinion arrangement to steer the vehicle using the power from the battery. The steering wheel input torque is measured by a torque sensor which is incorporated in the steering column and connected into an electronic control unit (ECU). The ECU controls the inverter using a specific algorithm to provide the necessary steering assistance.

Different types of electrical motors are used for the EPS. They are divided into two main categories: brushed DC motor and permanent magnet brushless motor. According to the back-EMF the permanent magnet brushless motors can be divided into brushless DC motor (BLDC) drove by a square wave and permanent magnet synchronous motor, drove by sin wave. Comparing this types of motors with the same capacity, PMSM is smaller, lighter and has lower rotary inertia, which it make it suitable for high torque response and high performance requirement from the EPS [2].

The heart of the EPS system is the torque sensor. The sensor output signal is then passed in to a motor controller to develop the torque that is required to assist the driver. The magnitude of the required torque is determined by the driver who is in the control loop. The relationship between the output of the torque sensor and the developed torque of the motor should be linear. The vehicle speed must be used to adjust the sensitivity of the torque controller [1].

The focus of this paper is to replicate a complete electric power steering system in Matlab/Simulink and to test this system in different scenarios. The PMSM implemented in this paper is an existing motor of an EPS [3]. In [3] the motor model was created using finite element analysis (FEA) and operational and parameters identification was carried out. The motor model was implemented using the equations in d-q rotating reference frame. The mechanical system of the EPS is based on the dynamical model. These dynamical equations of motion describe the entire system, from the steering wheel to the pinion which steer the wheel. The friction between the tire and the road is not taking into account. The ECU contains the control logic of the EPS. Torque control is applied for the steering assist motor. The assisted steering torque needed to be developed by the assistance motor is calculated based on the steering wheel input torque and the vehicle speed.

II. ELECTRIC POWER STEERING SYSTEM

A. EPS Dynamic Model

Figure1 illustrates the physical structure of a steering system. The structure components are a column type steering system which include the steering wheel, steering column, the rack and the pinion mechanism. The assistance motor is a permanent magnet synchronous motor, connected to the

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steering shaft through gears and provides the assisting torque needed by the driver to steer the vehicle. The input torque from the steering wheel is measured by a torque sensor mounted on the steering column and connected to the electronic control unit. The assistance torque produced by the motor act on the wheel via rack and pinion system. Different amount of assistance torque is applied depends on the driving conditions, which is realized with a specific control logic implemented in the ECU.

The dynamic equations from the steering wheel to steering column:

$$J_s\ddot{\theta}_s = T_d - K_s(\theta_s - \theta_r) - B_s\dot{\theta}_s \tag{1}$$

The assistant section is described by the following equation:

$$J_m\ddot{\theta}_m = T_m - K_m(\theta_m - i_m\theta_r) - B_m\dot{\theta}_m \tag{2}$$

Rack and pinion section is governed by the equation:

$$m\ddot{\theta}_x = \frac{1}{r_p}[K_m(\theta_m - i_m\theta_r)i_m + K_s(\theta_s - \theta_r)] - B_r\dot{x} - K_r x \tag{3}$$

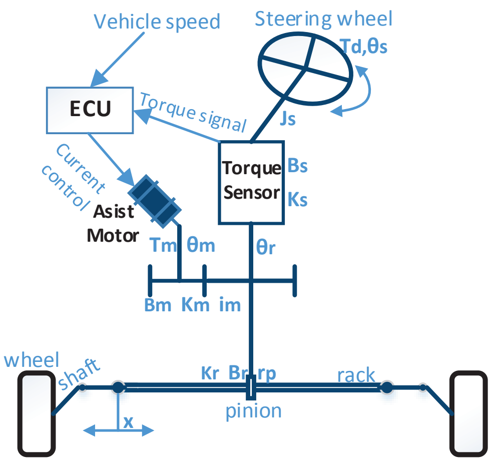

Fig. 1: EPS system structure.

B. The PMSM assistance motor

The assist motor is a 10 poles interior permanent magnet motor. Motors performance and parameters are evaluated using finite element analysis (FEA) in [3]. The equations of the PMSM in d-q axis are implemented in Simulink.

$$\frac{di_d}{dt} = \frac{u_d - R_s i_d + \omega L_q i_q}{L_d} \tag{4}$$

$$\frac{di_q}{dt} = \frac{u_q - R_s i_q - \omega(L_d i_d + \lambda_{pm})}{L_q} \tag{5}$$

$$T = p(\lambda_{pm} i_q + i_{dq}(L_d - L_q)) \tag{6}$$

$$T = J\frac{d\omega}{dt} + B\omega + T_{load} \tag{7}$$

Where u_d, u_q, i_d, i_q are the stator winding voltages and currents in d-q axis; L_d, L_q, R_s, are the inductances and resistance of the stator; ω is the motor angular speed;λ_{pm} represents the permanent magnet flux and p the number of pole-pairs. In the mechanical equation, J is the inertia of the motor, B is the friction coefficient and T_{load} is the load torque.

TABLE I: EPS Parameters

Symbol	Value	Name
J_s	0.0012[kg · m^2]	Inertia of steering wheel and steering column
B_s	0.26[Nm · rad^{-1}]	Deboost of steering colum
K_s	115[Nm · rad^{-1}· s]	Rigidity of steering column
θ_s	[rad]	Turn angle of steering wheel
θ_r	[rad]	Turn angle of steering column
T_d	[Nm]	Input torque of steering wheel
T_m	[Nm]	Output torque of motor
B_m	[Nm · rad^{-1}]	Friction factor of the assistant motor
K_m	125[Nm · rad^{-1}]	Rigidity of the motor and reducer
i_m	7.225	Reduction ratio of the reducer
θ_m	[rad]	Turn angle of motor
K_r	91061.4[N/m]	Linear rigidity
B_r	653.203[N · s]	Deboost of the pinion and rack
r_p	0.007783[m]	Pinion radius
x	[m]	Displacement of rack
m	32[kg]	Mass of the pinion and rack

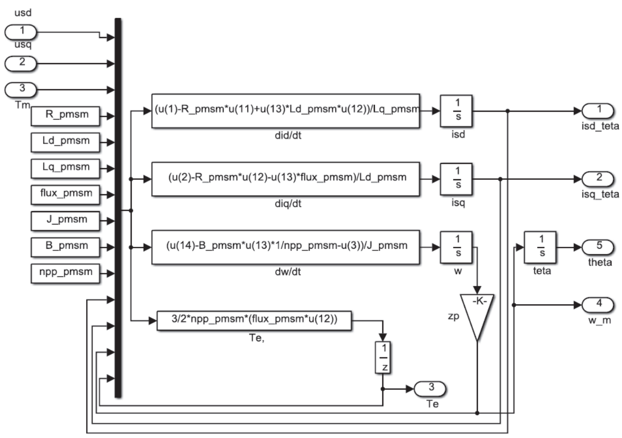

Fig. 2: PMSM Simulink model

TABLE II: PMSM Parameters

Parameter	Value	Units
DC-bus Voltage	13	[V]
Rated current I_{ph}	175	[A]
Number of poles	10	
Phase resistance R_s	0.02	[Ω]
Rated speed	1000	[rpm]
Rated torque T_N	24	[Nm]
DQ inductance L_{DQ}	150	[mH]
Permanent magnet flux λ_{PM}	0.0198	[Wb]
Inertia J	0.00048	[kg · m^2]
Friction coefficient B	0.0198	[Nm · rad^{-1}]

C. ECU Model

The ECU implemented logic consist of the torque input from the steering wheel and the vehicle speed. The function select a suitable torque for the assistance motor , the error between the feedback current from the motor and the current needed to develop the assistance torque is feed in the PI controller. The function implemented in ECU:

$$T_{\mathrm{M}} = \begin{cases} 0, & 0 \leq T_{\mathrm{d}} \leq T_{\mathrm{d0}} \\ trq(v), & T_{\mathrm{d0}} \leq T_{\mathrm{d}} \leq T_{\mathrm{dmax}} \\ T_{\mathrm{N}}, & T_{\mathrm{dmax}} \leq T_{\mathrm{d}} \end{cases} \tag{8}$$

$$trq(v) = (4 - 0.0606v + 0.0003v^2)(T_{\mathrm{d}} - T_{\mathrm{d0}}) \tag{9}$$

The threshold T_{d0} is set at 1Nm. If the steering wheel input torque is less than the threshold, the steering of the vehicle is not assisted and a good road feel is ensured. If the steering wheel torque is higher than the maximum threshold, 7 Nm, the assistance motor will deliver its rated torque, in this case 24 Nm. If the input torque is in between 1 and 7 Nm, depending on the vehicle speed, the assistance torque is calculated using the equation (8) and (9).

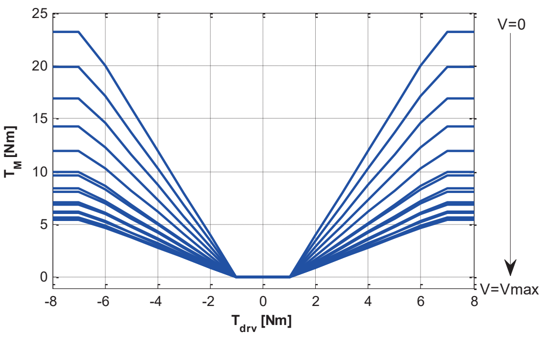

Fig. 3: EPS assist characteristics.

III. Implemented EPS Model

The architecture of the electric power steering system is presented in Fig.4. The mechanical system, ECU, torque control and the PMSM model are implemented in Matlab/Simulink. Some modifications have to be done in the Model Configuration Parameters in Simulink. The stop time in Simulation time must be infinite and the solver type must be in Fixed-step. In order to generate the Dynamic-link library (DLL) file in the Code Generation the System target file must be NIVeriStand.tlc. This file was loaded in NI VeriStand Simulation Models. The scenarios obtained from LMS Amesim are exported in Excel and those files are read in Stimulus Profile Editor . In the same editor the link between the driver torque signal from the scenario and the input in the Simulink is made. The model is running at 100 kHz, on the real-time processor of the Embedded Controller NI PXIe-8135, 2.3 GHz Quad-Core.

In EPS Mechanical System are implemented the dynamic equations (1),(2) and (3), the Simulink implementation can

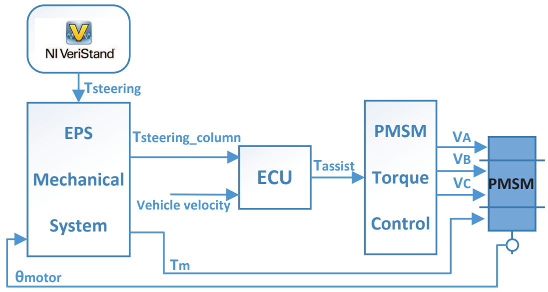

Fig. 4: EPS architecture.

be seen in Fig.5. The driver steering torque and the vehicle velocity are the inputs for the ECU. Based on the equations (8) and (9) the torque needed from the motor is calculated.

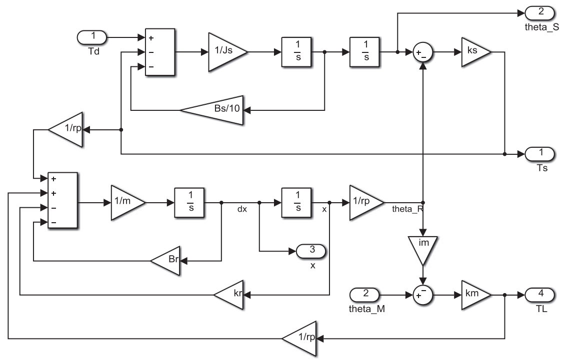

Fig. 5: EPS dynamic model.

The assistance torque calculated using the EPS dynamic model equations is the input of the torque control. From the input torque the reference q current is calculated. The current on the d axis is set to be zero. Two PI controllers are used to control the voltages on d and q axis.

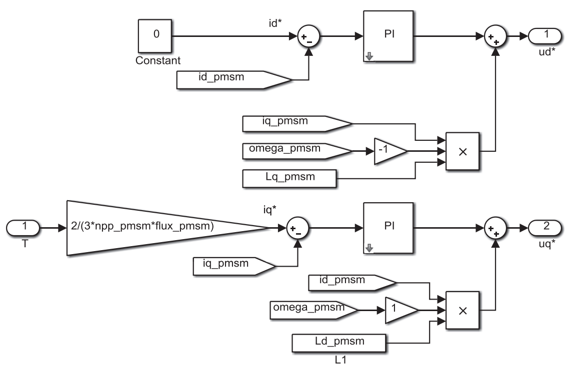

Fig. 6: Torque control.

IV. RESULTS OF THE SIMULATION

The simulations are performed on the real-time processor, based on imposing different steering torque inputs. In the first simulation a periodical sinusoidal variation of the steering torque was applied for a complete period of 6s. The amplitude of the sinusoidal wave is 8 Nm. Vehicle speed was varied, from 0 to 50 km/h (0, 10, 20, 35, 50 km/h). By varying the vehicle speed different assistance torque is needed to steer the vehicle, the results of this simulation are represented in Figure 7. The assistance torque is applied only if the input torque from the steering wheel is higher than 1Nm.

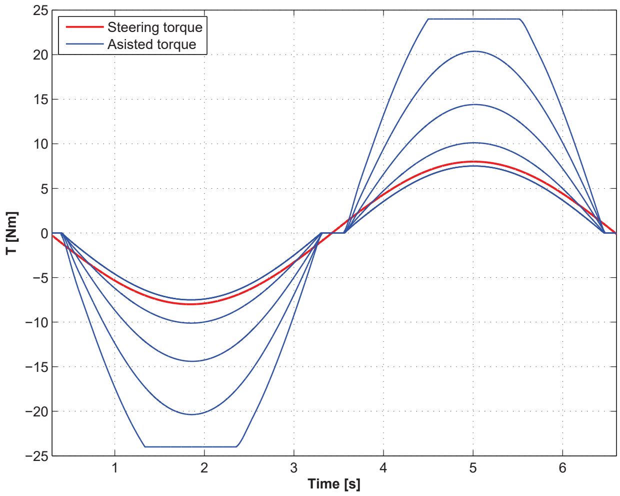

Fig. 7: Steering and assistance torque.

In Figure 7 it can be seen that at 7Nm input from the steering wheel the assistant torque from the PMSM is the rated torque, 24Nm. Another two scenarios from LMS Amesim are applied, the results are presented in Figure 8 and Figure 9.

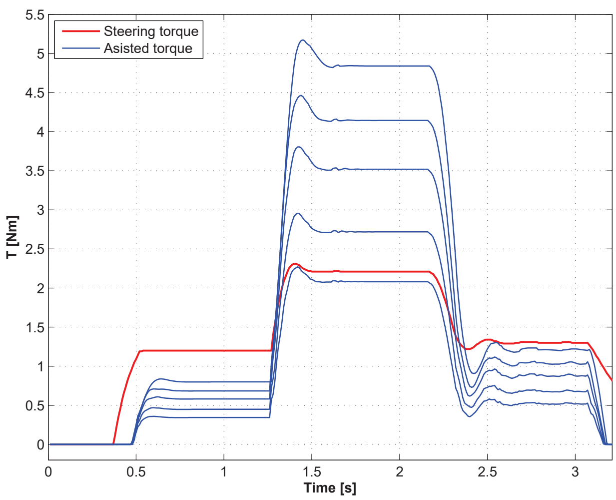

Fig. 8: First scenario from LMS Amesim.

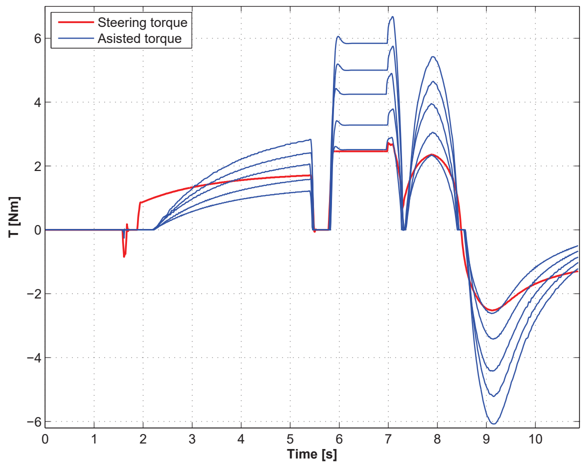

Fig. 9: Second scenario from LMS Amesim.

V. CONCLUSION

In this paper a complete electric power steering system was built in Matlab/Simulink and tested on the Embedded Controller NI PXI-e 8135 processor where different scenarios are applied using NI VeriStand. The assist motor used was a permanent magnet synchronous motor controlled using torque control. The mechanical system of the EPS was built based on the dynamical model. The results obtained in different scenarios applied in the simulation illustrate the effectiveness and the robustness of the EPS. Using this type of symulation and testing different motor sizes and types, applying different scenarious the suitable motor can be chosed for a better EPS performance.

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