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A NOVEL LOAD SIMULATOR FOR PERMANENT MAGNET SYNCHRONOUS MOTOR

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ABSTRACT

This paper presented a new idea of using a DC generator as a permanent magnet synchronous motor (PMSM) load. Based on it, controlled the DC generator armature current to simulate typical PMSM load system has been proposed. The simulator controller is basically composed of by exciting current controller and armature current controller. In order to increase performance of the proposed device, an improved Composite control strategy for armature current was discussed. Meanwhile, build a base on TMS320LF2407DSP load simulator system has been developed, Very encouraging results are obtained.

Key words: *PMSM-DC generator unit, Composite control, Dynamic model load, Motor load simulation, DSP*

1. INTRODUCTION

High-capacity permanent magnet synchronous motor (PMSM) has been applied more and more extensively in ship electric propulsion due to nice performance. But Owing to the limitedness of the capacity of power system and the variety of drive motor load, modern submarines demand of higher power factor (PF) of electrical transmission, less harmonic pollution and power regeneration etc., therefore the realization that drive motors load simulation environments of different types become a research hot point of this field. PMSM load modeling is one of the most important factors for analyzing power system stability and designing dynamic controllers. [1]

In this paper, with the PMSM-DC generating unit as its research target, deeper and more general researches have been done on the design of simulation controller circuit, the theories, methods and fulfillments of the control of DC generator unit

armature current and exciting current.

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2. PMSM-DC GENERATOR UNIT

Generally, the Park model is used to model a Permanent Magnet Synchronous Motor. With PMSM, the voltage, stator flux linkage and

electromagnetic torque equation expressed in the rotor flux reference Frame (d-q coordinates), as in Fig.1.

When $L_d \neq L_q$

$$T = \frac{3p|\varphi_s|}{4L_d L_q}\left[2\varphi_f L_q \sin\delta - |\varphi_s|\left(L_q - L_d\right)\sin 2\delta\right] \tag{1}$$

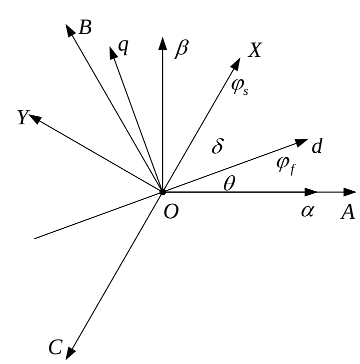

Figure 1 *the Reference Frames Used in DTC*

The PMSM-DC Driver System is shown in Fig.2, motion equations is

$$T - T_L = J\frac{d\Omega}{dt}$$

(2)

Where T_L is the load torque, J is the rotary inertia, Ω is the rotational speed.

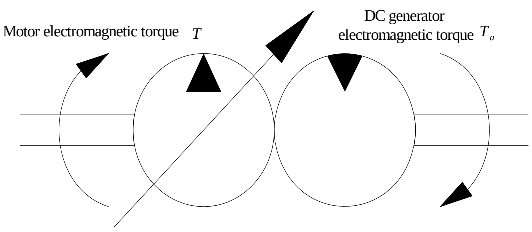

Figure 2 *the PMSM-DC Driver System*

Typical PMSM load torque/speed curves are shown in Fig.3. Usually, the PMSM load is described by shaft torque/speed. They give a strong indication of the variety of torque-speed Characteristics. Along such Curves the mechanical power required from the motor varies with speed. The base speed (unity speed in figure) corresponds to continuous duty rated torque (And power) and Rated (maximum) voltage from the PEC.

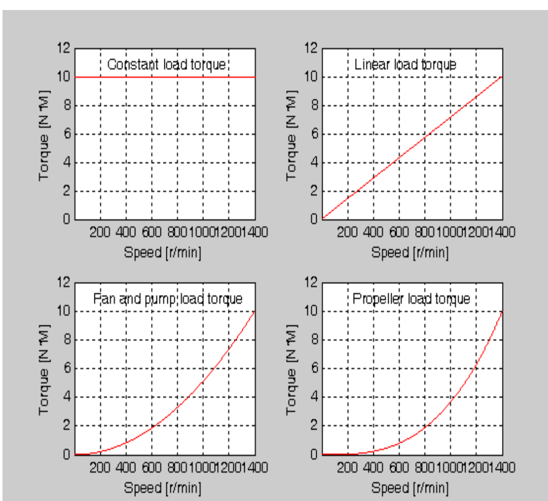

Figure 3 *Typical Load Torque/Speed Curves*

$$power = T_L * \Omega_r \quad (3)$$

To match the required speed/torque (and power) envelope, the motor and PEC should be carefully chosen or designed. However, the motor to mechanical load match should be provided not only for steady but also during transients such as drive acceleration, deceleration or short overload periods. The transients require higher-torques, in general below base speed, and both the motor and the PEC have to be able to withstand it. [2]

The T_L can be express as follows:

$$T_L = T_0 + K(n/n_e)^{\alpha} \quad (4)$$

Where T_L is the load torque, T_0 is the dry friction, n is the rotational speed, n_e is the rated revolution.

Where α is exponential.

1). Constant load torque characteristic; (α =0)

2). Linear load torque characteristic; (α =1)

3). Fan and pump load torque characteristic; (α =2)

4). Propeller load torque characteristic. (α =3)

In this paper we use a separately excited generator to as a load for PMSM. The separately excited generator is shown in Fig.4. In a separately excited DC generators are dc machines used as generators. As previously pointed out, there is no real difference between a generator and a motor except for the power flow. Fig.3 shows The PMSM-DC Driver System. Generator, the field flux is derived from a separate Power source independent of the generator itself. [3]

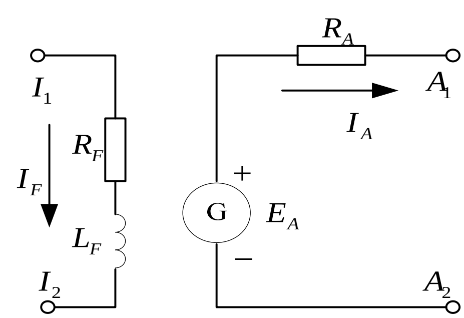

Figure 4 *the Separately Excited Generator*

The internal generated voltage in this machine is given by the equation

$$E_A = C_e \phi \omega n$$

(5)

Where C_e is electromotive force constant; ϕ is the magnetic flux magnetic flux; n is the rotational speed. $\varphi \propto I_F$, And the induced torque developed by the machine is given by

$$T_L = K\phi I_A$$

(6)

If Controlled the I_F as constant, then can control I_A to simulate the T_L.

Because $T_L \propto I_A$, the expression can be rewritten as

$$I_A = I_0 + K(n/n_e)^{\alpha}$$

(7)

Where the I_A is armature current, I_0 is the armature current initial value, K is the values of factor, n is the rotational speed, n_e is the rated Speed, α is the exponential, indicate the load type.

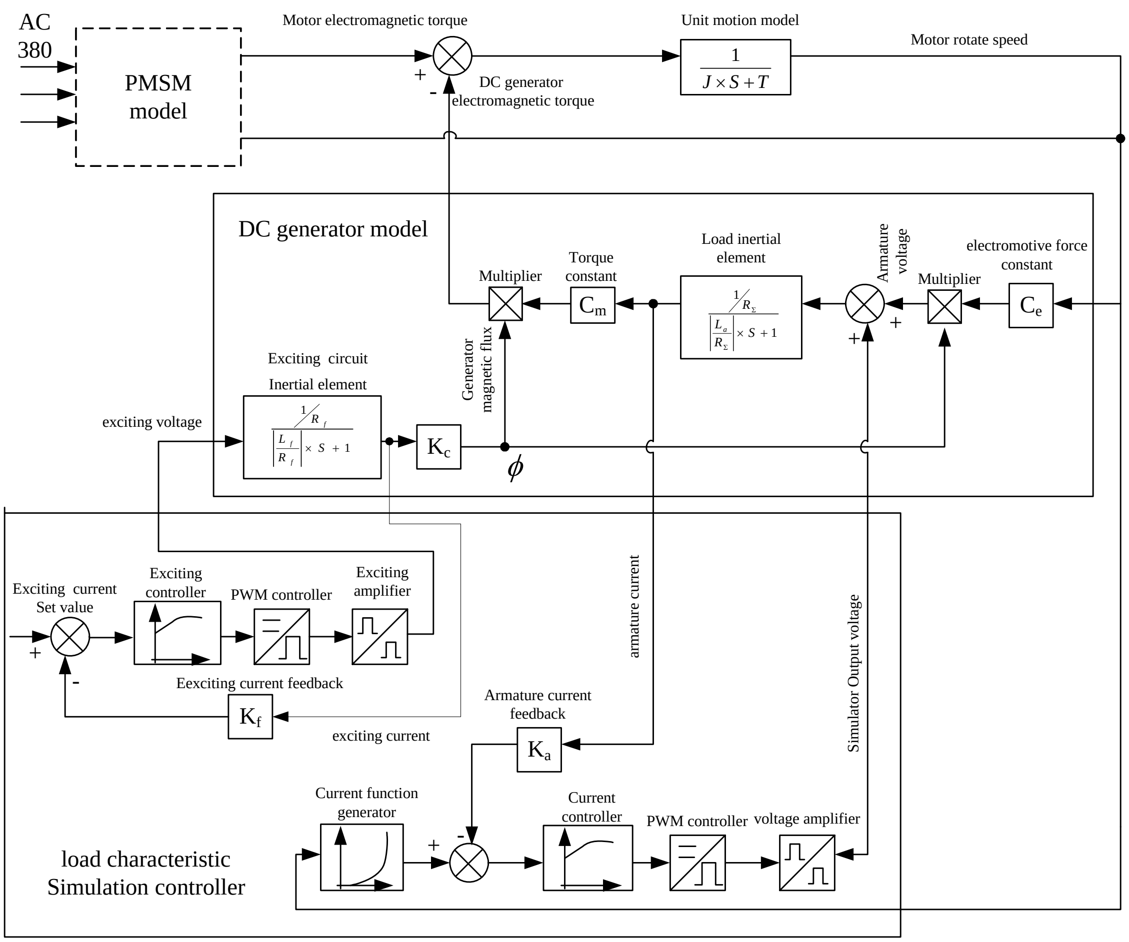

Figure 5 *the Block Diagram of Load Torque Simulator*

3. MODELS OF LOAD TORQUE SIMULATOR

Fig.5 is the total figure of the system configuration. The load torque simulator controller is composed of the exciting current controller and the main armature current controller.

3.1 EXCITING CURRENT CONTROLLER

The exciting current are adjusted by the digital PI law based on the bilinear transformation, which is formulated as

$$I_f[k] = P[k] + I[k]$$

(8)

Where the proportional term is

$$P[n] = K_p \cdot e_f[k]$$

(9)

And the integral term is

$$I_f[k] = I_f[n-1] + K_f \cdot (e_f[k] + e_f[k-1])$$

(10)

$e_f[k]$ Is the exciting current error input, and K_p, K_f are the proportional and integral gains, respectively. (4).

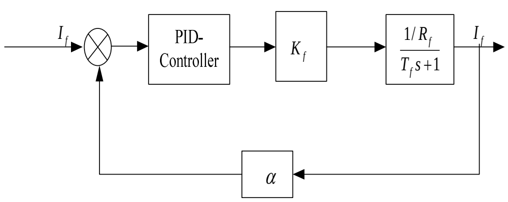

Figure 6 the Mathematic Model of Exciting Current Controller

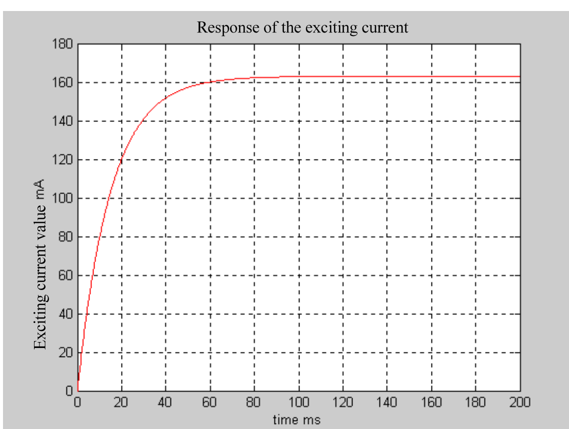

Figure 7 *Response of the Exciting Current for PI-Controller*

Computer simulation of this system has been carried out using MATLAB/SIMULINK software. Simulation results are presented in Fig.7.

3.2 ARMATURE CURRENT CONTROLLER

The architecture of composite controller we (8
developed is shown in Fig.8. The armature current is compared with its reference value and then, the obtained current error and the (9
change of error are used as the input of the composite inference system.

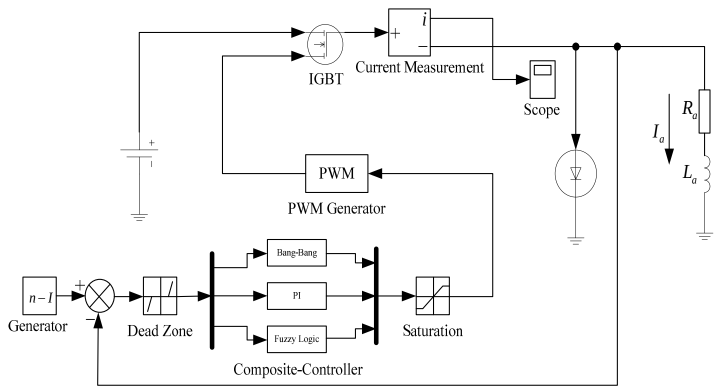

Figure8 *the Block Diagram of Composite-Controller for Armature current*

The Dead Zone block generates zero output within a specified region. The lower and upper limits of the dead zone are specified as the Start of dead zone and End of dead zone parameters. It can greatly reduce the armature current ripple.

The Saturation block imposes upper and lower bounds on a signal. When the input signal is within the range specified by the Lower limit and Upper limit parameters, the input signal passes through unchanged. When the input signal is outside these bounds, the signal is clipped to the upper or lower bound. This function can protect the MOSFET and the IGBT.

The control strategy is that:

1). When Constant load torque uses Bang-Bang controller. When the error signal exceeds the hysteretic band, the output of the Bang-Bang controller will transit from logic ‘0’ to logic ‘1’. The output μ_k is characterized by

$$\begin{cases} \mu_k = \mu_k & |e_a| \geq B \\ \mu_k = 0 & |e_a| < B \end{cases}$$

(11)

Where B is hysteretic band, e_a is the real-time error. [5]

2). When linear load torque uses PI

$$I_a[k] = I_a[k-1] + K_a \cdot (e_a[k] + e_a[k-1])$$

(12)

$e_a[k]$ Is the armature current error input, K_a are the integral gains, respectively.

3). When pump load torque uses PI and Fuzzy

Fuzzy Logic is a new control approach with a great potential for real-time application. Fuzzy logic controller is a rule based controller where a set of rules represents a control mechanism to correct the effect of certain causes coming from power system.

In fuzzy logic, the error (e) and error change rate (Δe) of the system output are two mainly input variables Used to the Fuzzy system. Its control rule is basically composed of by many IF-THEN statements shown as following.

$$if \quad e \ is \ A_i \ and \ \Delta e \ is \ B_j \quad then \quad u \ is \ u_{ij}$$

Where, i and j are the number indexes of control rules, u is the output of fuzzy controller. The rule base we used for this

(10

controller is shown in Table 1.

4). When Propeller load torque uses PI and Fuzzy. [6][7]

Table 1: The rule base e

e \ $\triangle e$	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
-6	6	5	6	5	6	6	6	3	3	1	0	0	0
-5	5	5	5	5	5	5	5	3	3	1	0	0	0
-4	6	5	6	5	6	6	6	3	3	1	0	0	0
-3	6	5	5	5	5	5	5	2	1	-1	-1	-1	-1
-2	3	3	3	4	3	3	3	1	1	1	-1	-1	-1
-1	3	3	3	4	3	3	1	1	1	1	-2	-1	-1
0	3	3	3	4	1	1	1	-1	-1	-1	-3	-3	-3
1	1	1	1	1	1	1	-1	-3	-3	-2	-3	-3	-3
2	1	1	1	1	-1	-2	-3	-3	-3	-2	-3	-3	-3
3	-1	-1	-1	-1	-1	-2	-2	-5	-5	-5	-5	-5	-5
4	-1	-1	-1	-1	-3	-3	-6	-6	-6	-5	-6	-5	-6
5	-1	-1	-1	-1	-3	-3	-5	-5	-5	-5	-5	-5	-5
6	-1	-1	-1	-1	-3	-3	-6	-6	-6	-5	-6	-5	-6

4. EXPERIMENTAL RESULTS

TMS320LF2407 is used to carry out the real-time algorithm. A MOSFET DC/DC Buck converter is used to adjusting exciting current. An IGBT DC/DC Buck converter is used to adjusting the DC generator armature current. With the help of RTI software, real-time control code can be generated automatically from the SIMULINK model. Fig.9 shows the Architecture of Load Simulator Controller .an incremental encoder is used to detect the rotor speed; a DC generator is used to load the PMSM machine. Sampling interval for current experimental result is 250us for both real-time controllers.

In the operation process, the control program samples rotate speed and armature current value in every other 2ms, and save the sampling value in out-chip RAM. There data are read into buffer with instruction from the host computer, and deal with by the software of the host computer. From Fig.10, it is seen that armature current has been greatly simulated the Typical load Torque/Speed characteristic.

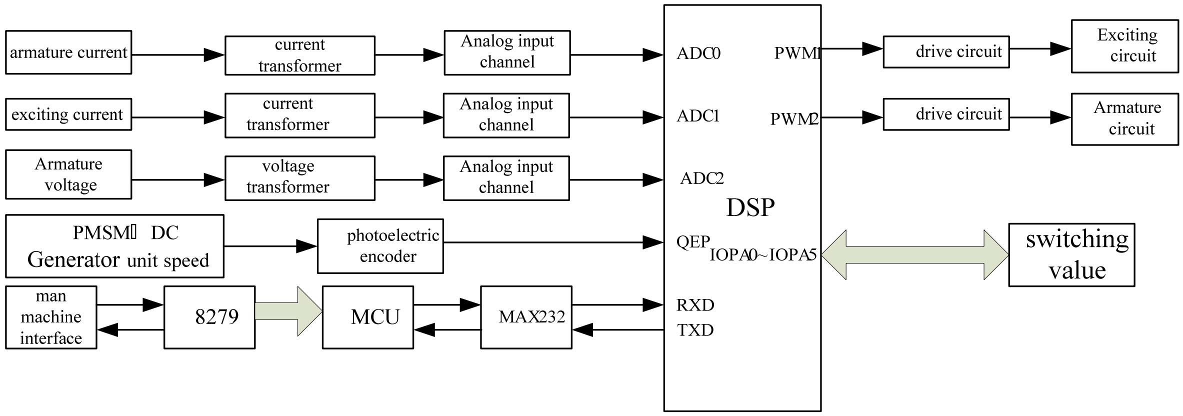

Figure9 *the Integrated Architecture of Load Simulator Controller*

5. CONCLUSIONS

In this paper, a PMSM-DC generator model for PMSM has been firstly proposed. Because the exciting current and armature current can be controlled easily and continuously, the developed method will be practical and accurate to be used for permanent magnet synchronous motor load modeling.

6. ACKNOWLEDGEMENT

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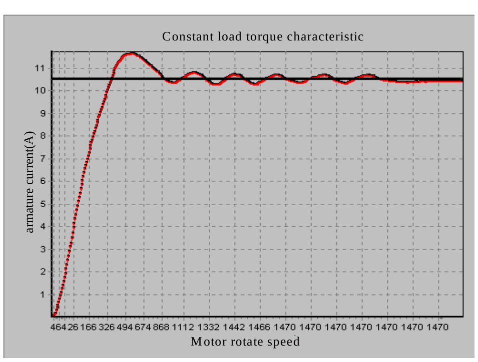
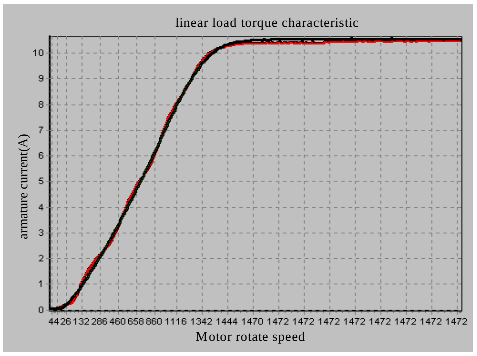
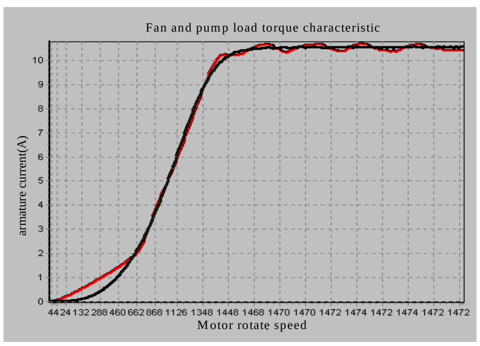


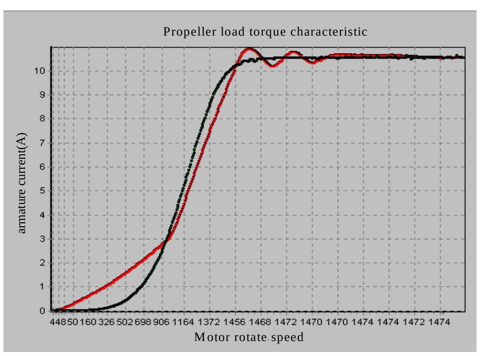
(a) Constant Load Torque Curve



(b) Linear Load Torque Curve



(c) Fan and Pump Load Torque Curve



(d) Propeller Load Torque Curve

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