A Design of Hybrid Automatic Repeat Request Scheme based on FlexRay used for Smart Hybrid Powerpack

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***Abstract*—FlexRay is an automotive communication protocol, which is developed by core members of the FlexRay consortium (BMW, Bosch, DaimlerChrysler, Freescale, GM, NXP Semiconductors and Volkswagen). Nowadays, it is set to become widely used in the automotive industry where it will replace traditional networking schemes such as Controller Area Network (CAN). However, in the FlexRay, it just uses the Cyclic Redundancy Check (CRC) code to detect the errors. In this paper, we design of a Hybrid Automatic Repeat Request (HARQ) scheme which combines the CRC code with Reed-Solomon (RS) code. Smart Hybrid Powerpack (SHPP) is an electro-hydraulic system, which is combined with advanced technology like fault tolerant, intelligent control, smart phone remote control and monitoring. This paper will apply the FlexRay into the SHPP system using the HARQ scheme. Simulation result shows good performance by using HARQ scheme comparing with CRC code only.**

Keywords-FlexRay; HARQ; SHPP

I. INTRODUCTION

FlexRay is a communication network for distributed automotive systems. It is an option for upgrading existing network systems using traditional CAN in the automotive industry as well as other industrial control applications. Because of the dual channels for fault tolerance which can communicate the same information and improve the fault tolerance ability, it could also be used for new applications in industrial automation, where safety and reliability in a work environment can be guaranteed [1].

The FlexRay protocol has been designed to carry information at a rate of 10Mbits/s by each channel, which means that an equivalent data rate of 20Mbits/s can be achieved. The FlexRay frame format consists of header segment (5 bytes), payload segment (0-254 bytes) and trailer segment (3 bytes). The frame trailer segment contains a 24-bits CRC code. FlexRay frame format is shown in Fig. 1, which is a standard [2].

Hydraulic systems have been widely used in industrial applications because of their durability, high power-to-weight ratio, reliability and large force and torque, etc. [3]. Two types of hydraulic transmission system are commonly used in industry, namely valve controlled and pump controlled hydraulic system [4]. Valve control hydraulic system has the main fault of the low energy efficiency. The loss of energy is due to the leakage from the pump bypass valves or transfer of energy into heat via throttle losses at the control valves.

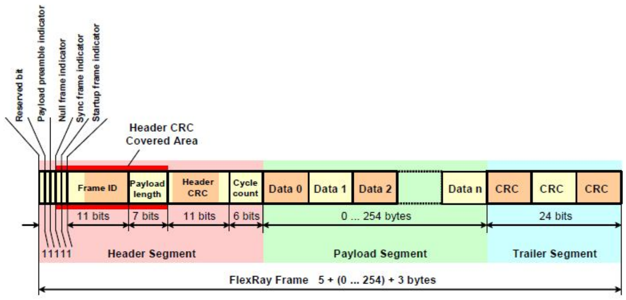

Figure 1. FlexRay frame format

At the range of pump controlled hydraulic systems, the concept of Electro Hydraulic Actuator (EHA) has been popular because that the EHA acts as a Power-Shift which shifts the power from high-speed electric motor to the high-force of hydraulic cylinder by bi-directional piston pump. Thus, the EHA creates a sleeker, cleaner way to produce hydraulic power with higher energy efficiency [3].

SHPP is an electro-hydraulic system which combines the EHA system with advanced technology like fault tolerance, intelligent control, smart phone remote control and monitoring. The whole structure of SHPP system is shown in Fig. 2.

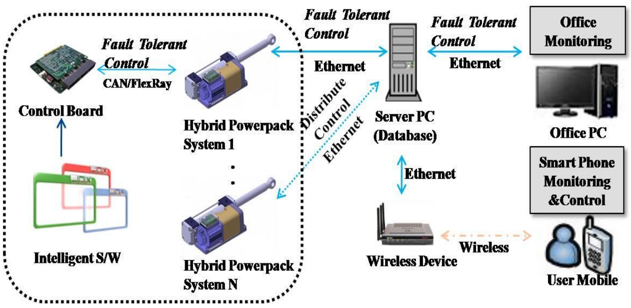

Figure 2. SHPP system structure

In the SHPP, for sensor part, some sensor fault tolerant technology will be done. The sensors include position sensor, pressure sensor and temperature sensor. For network part, FlexRay error control coding will be made in this SHPP system. Some intelligent control methods like fuzzy control, adaptive fuzzy control will be tried in the SHPP. These control methods are smart technology recovering from faults like noises, disturbances and so on. The most advanced technology is that smart phone will act a good role in the system, including monitoring and control by the smart phone. All these advanced technology will make the SHPP system smart, intelligent, safe and accurate.

In this paper, we suggest using the FlexRay in the SHPP and the system can be more reliable and safe. Furthermore, based on the FlexRay protocol we design of a HARQ scheme as the fault tolerant logic to improve the error correction ability. The rest of this paper is organized as follows: Section 2 will introduce proposed HARQ scheme for SHPP system. Section 3 will show the MATLAB simulation result. Conclusions of this paper will be represented in the last section.

II. DESIGN OF HARQ SCHEME FOR SHPP

A. CRC Code and RS Code

In the HARQ scheme, CRC code and R-S code are used to design the fault tolerant logic. CRC code is used to detect errors after R-S decoding. In this paper, we use the CRC-24 code as the error detecting code. The generator polynomial g(x) is written as (1) shows to us [2].

$$g(x) = x^{24} + x^{22} + x^{19} + x^{18} + x^{16} + x^{14} + x^{13} + x^{11} + x^{10} + x^{8} + x^{7} + x^{6} + x^{3} + x + 1 \quad (1)$$

R-S code is one of the error correcting codes. It can efficiently correct not only random errors but also burst errors. R-S code is a non-binary cyclic code with symbols made up of m-bit sequences, where m is any positive integer having a value greater than 2. R-S (n, k) codes on m-bit symbols exist for all n and k for the following relation as (2) [5].

$$0 < k < n < 2^m + 2 \quad (2)$$

In (2), k is the number of data symbols being encoded, and n is the total number of code symbols in the encoded block. The relation between n and k can be given as (3) [5].

$$(n, k) = (2^m - 1, 2^m - 1 - 2t) \quad (3)$$

In (3), t is the symbol-error correcting capability of the code. It means that the code is capable of correcting any combination of t or fewer errors and t can be expressed as (4) [5].

$$t = (n - k)/2 \quad (4)$$

In this paper, we use RS (15, 9) code with 4-bit in each symbol; so, the error probability of this R-S code is 3 symbols, which means it can correct 3 symbol errors or fewer symbol errors successfully.

B. Proposed HARQ Scheme

The algorithm of the proposed HARQ scheme is shown as seen in Fig. 3. First, the signal from main controller will be changed to data. In the receiver, the R-S code will decode the coded data and then do CRC decoding. By using the R-S (15, 9) code, 3 symbols errors or less than 3 symbols errors will be corrected perfectly. Then, the CRC codes will check whether the R-S codes corrected all the errors successfully. If there is no error detected by CRC codes, the signals will be sent to the SHPP.

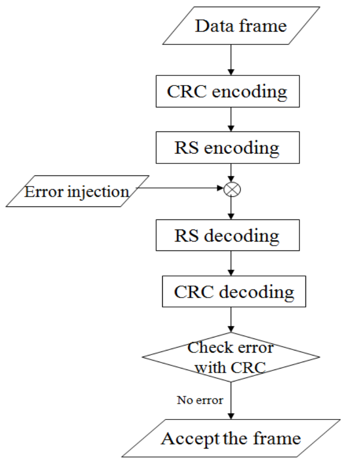

Figure 3. Proposed HARQ scheme

C. System Modeling of Brushless DC Motor Drive System

In this paper, we only use the brushless DC Motor (BLDCM) drive modeling. After that, we will adapt to EHA system based on this paper result. First step is to make the BLDCM drive modeling for error control coding between Main controllers and Motor drive. The BLDCM system model is developed considering armature voltage and load torque as two inputs, angular velocity and Motor position as two outputs. In order to simplify the model, all the stator phase windings are assumed to have equal resistance per phase and constant self and mutual inductances, iron loss is negligible, motor flux is unsaturated and power semiconductor devices are ideal. The line to line voltage equation in the motor can be represented as, [6]

$$V(t) = I(t)R + L\frac{dI(t)}{dt} + e_b(t) \quad (5)$$

where V(t) is input voltage of phase, I(t) is armature current of phase, $e_b(t)$ is back-emf of phase, R is armature resistance of phase, L is armature inductance of phase. The BLDCM generates three phase voltages by the line to line voltage

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equation. The phase currents, phase voltages and phase back-emfs are assumed to be equal. The total resistance opposing the phase current will be twice the resistance per phase.

For linear analysis, we assume that the torque developed by the motor is proportional to the current the armature current and the air-gap flux. Thus, the motor torque equation can be expressed as, [6]

$$T_M(t) = K_T I(t) \tag{6}$$

where T_M (t) is the motor torque in N-m, K_T is the torque constant in N-m/A, I(t) is the armature current in A.

Since the sum of all the opposing torques due to mechanical elements of motor and load torque is equal to the torque developed by the motor, the cause-and-effect equations for the motor circuit can be written as, [6]

$$T_M(t) = T_L(t) + J_M \frac{dw(t)}{dt} + B_M w(t) \tag{7}$$

$$e_b(t) = K_b w(t) \tag{8}$$

where T_M (t) and T_L (t) are torque developed by motor and load torque, w(t) is the rotor angular velocity in rad/s, K_b is back-emf constant in N-m/A, e_b(t) is the back-emf in N-m/A.

III. RESULTS

In this paper, motor control method is a PID control in the BLDCM drive system and we assume that speed control system is designed without load conditions because we focused on the network system between Main controller and BLDCM drive system. The PID controllers are most suited for control systems with fixed system dynamics and no parameter variations during the operating conditions. The PID controller can be easily implemented for the BLDCM drive system to improve its performance. The simulink model using PID controller is shown in Fig. 4.

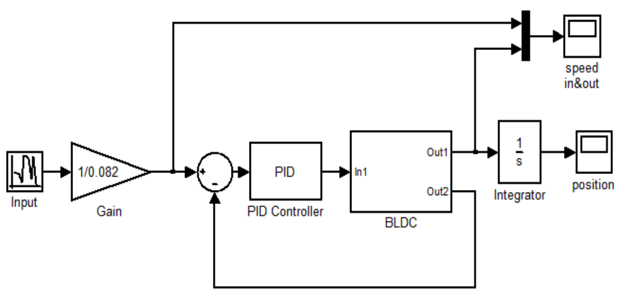

Figure 4. Simulink model using PID controller

To make the BLDCM drive system using PID control method, we decide parameters of the BLDCM. Parameters of the BLDCM are shown in Table I [6].

TABLE I. PARAMETERS OF THE BLDCM

Parameters	***Values***
Stator resister, R(Ω)	0.57
Stator inductance, L(m-H)	1.5
Inertia, J_M(kg-㎡)	0.000023
Torque constant, K_T(N-m/A)	0.082
Back-emf constant, K_b(N-m/A)	0.082

The gain parameters of PID controller are determined using the Ziegler Nichols Tuning method [7] and found to be K_p=0.2051, K_i=29.52 and K_d=0.00053326. The simulation of BLDCM drive control system is carried out using MATLAB software. We determine that the reference rotor speed is 414.63rad/s. The response of the BLDCM speed control system with PID controller is shown in Fig. 5.

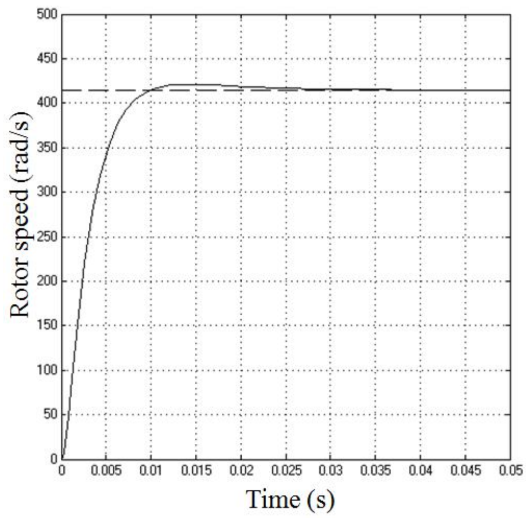

Figure 5. Response of the BLDCM control system with PID controller

For error control coding between the Main controller and the Motor drive system, we convert the rotor speed to the rotor speed voltage as (8) and we calculate the rotor voltage is 34V.

Fig. 6 shows the input voltage of the Speed controller, when the error is 3 symbols with CRC code only. The voltage is always 50V but the desired voltage is 34V. In the simulation, we assume the noise is forever existed and the error pattern is sure, which means even retransmission is made, the errors never change. When errors happen, CRC code can just detect the errors and retransmit the signal. It costs time and the errors could not be processed well forever.

Because of the shortage in the CRC code, when some errors are always existed in the channel, the retransmission is needed all the time. If the system is critical, it will have big problem. So we need some other methods to cover the CRC shortage. In the below, we add the RS code in the channel, which means HARQ scheme is used.

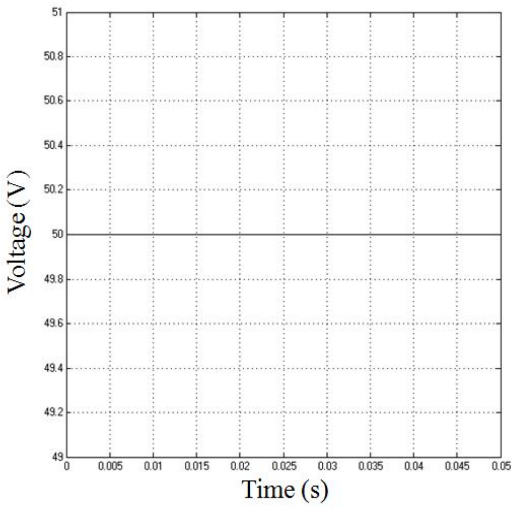

Figure 6. The input voltage of Speed controller (Error is 3 symbols with CRC code only)

Fig. 7 shows the simulink model of error control coding with HARQ scheme. The error control coding consists of mainly three parts that are Encoder, Channel and Decoder. Display 1 shows the corrected error symbols by RS code. Display 2 shows the CRC decoding result: "0" means no error and "1" means have errors.

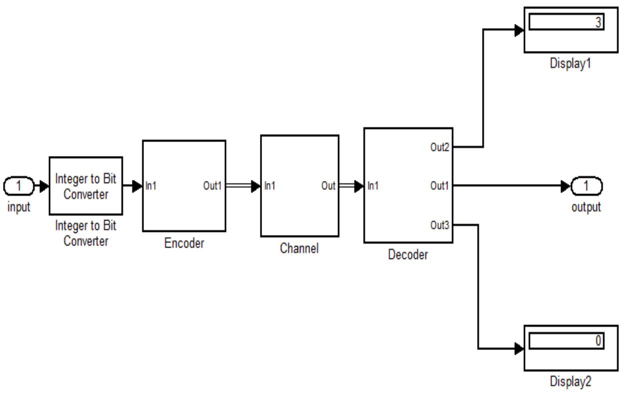

Figure 7. Simulink model of error control coding with HARQ scheme

Fig. 8 shows the input voltage of Speed controller, when the error is 3 symbols with HARQ scheme. The voltage is always 34V. In the simulation, we assume the error pattern is same with CRC code only case. Because the use of RS (15, 9) code, 3 symbol errors are corrected well and it doesn't need retransmission anymore.

Comparing Fig. 6 with Fig. 8, we know that HARQ scheme shows better performance than CRC code only. The error signal 50V is covered to 34V, which means the small error pattern is processed well by HARQ scheme. Furthermore, it does not need retransmission and can save time for the system.

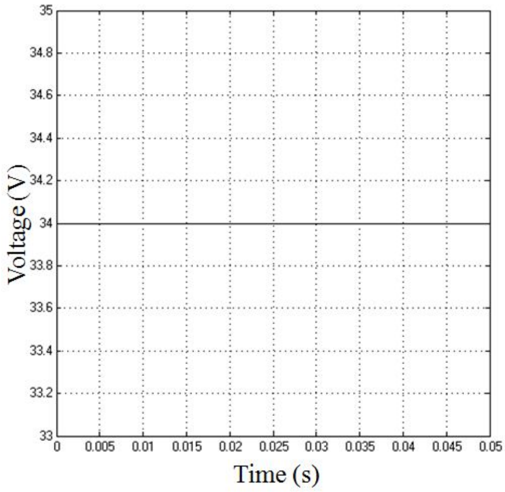

Figure 8. The input voltage of Speed controller (Error is 3 symbols with HARQ scheme)

IV. CONCLUSIONS

In this paper, we applied the HARQ scheme based on FlexRay used for SHPP system. In the system modeling part, BLDCM control system with PID controller is done. In the error control coding part, HARQ scheme performs well in the system fault tolerance. With the RS code, some burst error or small bits error can be corrected well. When errors are bigger than the ability which RS code can correct, we will use other methods like retransmission or second channel to cover the errors. Our final goal is to make the real SHPP system based on fault tolerant and use adaptive fuzzy control.

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