

Failure Modes Investigation and Analysis of Electric Power Steering System with PMSM Drives

Chinchul Choi and Wootaik Lee
Changwon National University

Jiyeol Kim and Seongjoo Kim
MANDO Corp.

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ABSTRACT

This paper presents a method to investigate the failure modes of an electric power steering system and to analyze the faults effects systematically by use of an accurate simulation model. EPS is one of safety critical systems which should be designed to be fault-tolerant. In order to make a system fault-tolerant, some special design and analysis methods are indispensable. To analyze the effects of these faults the intuitive system model is developed using MATLAB/Simulink and the major failure modes of system are investigated. The developed model provides useful environments to inject and remove the various faults. The proposed model and method can be used to analyze faulty system dynamically, and it will be a great help to make a system more reliable.

INTRODUCTION

There is a trend in the automotive industry towards an increasing number of safety-related electronic systems that directly contribute to active vehicle operation [1]. Particularly, electric drives can replace traditional mechanical actuators to achieve advantages such as higher efficiency and improved dynamical performance. Due to factors such as high power density and efficiency, maintenance and extremely wide operating speed range, permanent magnet synchronous motors (PMSM) are the subject of development for traction drive applications [2].

For electric drives used for propulsion, power assisted steering and braking, faults can be critical since an uncontrolled output torque may have an adverse impact on the vehicle stability, which ultimately can risk the passenger safety [3].

With the increasing complexity of modern automotive systems, system modeling and simulation techniques are gaining increased significance to address a variety of system development issues including design robustness, safety and reliability [4].

There are many simulations and modeling studies for abnormal behaviors of PMSM drives [5], [6], [7], [8]. But those are only dealt with one specific issue of faults, not system level behaviors. Those are interested in only transitions from normal to abnormal state, not vice versa. In order to confirm the fault-tolerant attributes of a control algorithm, the transient state must be considered when both injecting and removing faults intermittently.

This paper investigates the failure modes of electrical components for the EPS with the PMSM drive system. Abnormal behaviors of each component are modeled modularly in an object oriented manner and then modules are integrated into the system level model in the MATLAB/Simulink environment. Injecting and removing the single or multiple faults can be simulated easily. As an example, some electrical fault cases are simulated by use of these component models, and these effects are investigation.

The proposed model and analysis results are very useful for development of fault-diagnostic and fault-tolerant algorithm throughout the whole development process of the system.

INVESTIGATION OF FAULTS

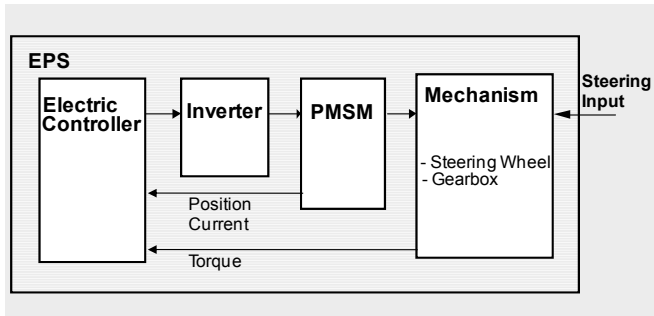


Figure 1. Block diagram of EPS

Figure 1 describes the components of EPS and their interface as a block diagram. The various types of electrical faults, which can be developed in EPS, are investigated. Refer to the appendix for the detailed list.

MODELING

The abnormal behaviors of components are modeled in consideration of interfacing with normal models which are introduced in our previous studies [9], [10]. Using the fault injection techniques, it is easy to switch the state of system from normal to abnormal and vice versa. The single or multiple faults can be injected or removed at any time and state of simulation. This feature is implemented using the step input block of Simulink and then faults can be injected by using the command language of MATLAB.

The following key faults are considered for our study which presents the usefulness of the system analysis.

FAULTS OF MOTOR POSITION SENSOR

This system uses an encoder with specific number of pulses per revolution (PPR) for estimation of the motor position and speed.

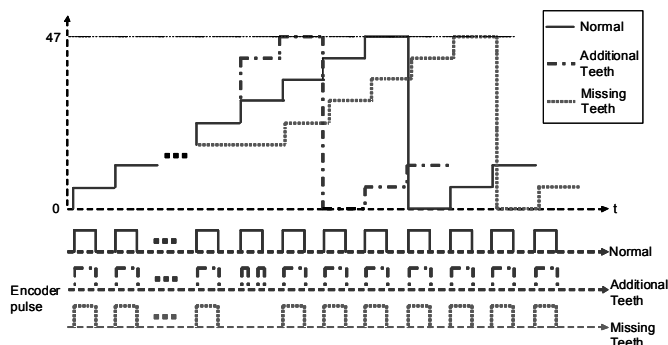


Figure 2. Abnormal behaviors of a motor position sensor

- Missing teeth : $\theta_{e_step} = (cnt - Teeth_{miss}) \times \frac{2\pi}{PPR}$
- Additional teeth : $\theta_{e_step} = (cnt + Teeth_{add}) \times \frac{2\pi}{PPR}$

θ_{e_step} represents the estimated position as described in Figure 2. cnt can have the integer value from 0 to (PPR-1) according to rotate the rotor and encoder. If the controller misses the pulse, the estimated position decreases as amount of $Teeth_{miss}$ which represents the missed pulses. In the opposite case, the estimated position increases as amount of $Teeth_{add}$. Using this principle, the motor position sensor is modeled simply.

OPEN-SWITCH OF INVERTER

By use of circuit-domain representation, the voltage source inverter (VSI) is easily modeled. The possible faults of VSI circuitry are described in Figure 3.

- F1 : DC link capacitor short-circuit
- F2 : Open-switch
- F3 : Short-switch
- F4 : Open-gate

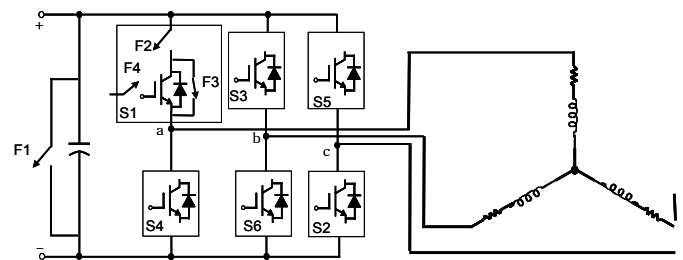


Figure 3. Faulted circuit of a 3-phase VSI

From Figure 3, VSI model is easily completed using switch device components as Figure 4.

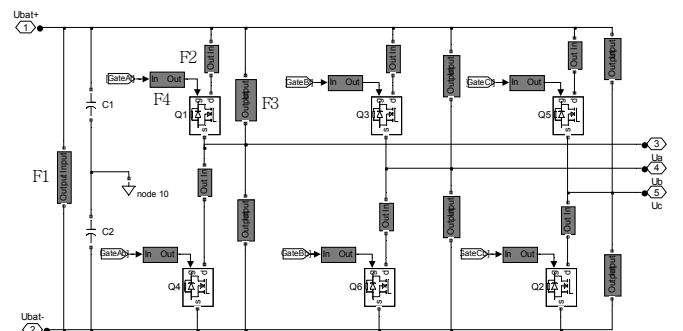


Figure 4. Implementation of VSI model