Modeling and Simulation of Linear Electro Mechanical actuator for Missile Application with high redundancy

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Abstract. The military, defense missiles are self propelled systems with high security, reliability, and accuracy in targeting the obstacle. The firing of missiles is considered as milestones in growth of research areas. In such field, Electro Mechanical Actuator (EMA) helps to maintain the altitude of missile path, which is predefined path. Moreover, As EMA is exposed to environmental aspects, the altitude of missile may get altered. So on replicating the critical components i.e., BLDC drive and power inverter in EMA based control systems, the accuracy in monitoring the altitude is improved without any interruptions and with high reliability. This paper proposes dual redundant power inverter system to run BLDC motor with redundancy management and logic, fault tolerant and fault diagnosis by using MATLAB/SIMULINK with the results.

Keywords: Missile, Electromechanical actuator (EMA), Dual redundant, Inverter, BLDC drive, Fault diagnosis.

1 Introduction

Military defense systems [1] involve updated technology in firing, detection, tracking, attacking of against missiles. Military missiles can be surface to air missiles, surface to water missiles, air to air missiles to protect India and in advancement in technology aspect. In such defense applications, an expertise, and mastered, highly equipped control architectures are required. In such control surfaces, EMA plays a key role and it should be capable to act according to the desired conditions. A subsystem of an EMA includes power electronic circuitry, intelligent controller, an BLDC drive, ball screw mechanism for position detection, and its associated components. In order to decrease the complexity, the replication of building block is enough to meet the criteria. As the fundamental structural blocks in EMA are power converters and BLDC drive, designing of these components became a challenge. In some of the missiles, EMA is installed in two stages each for some amount of distance and it is triggered through battery. The concept of missiles are completely different as in aircraft. A simple fault occurrence in any subsystem of electromechanical actuator leads to whole outage in the system and investment would be in risk. So, missile applications also require safety and accessibility, So 'Redundancy management' is necessary.

Dual redundant[3] logic is a combination of two modules, each module is having three phase power inverter stage and BLDC motor windings as shown in the below Fig.1.

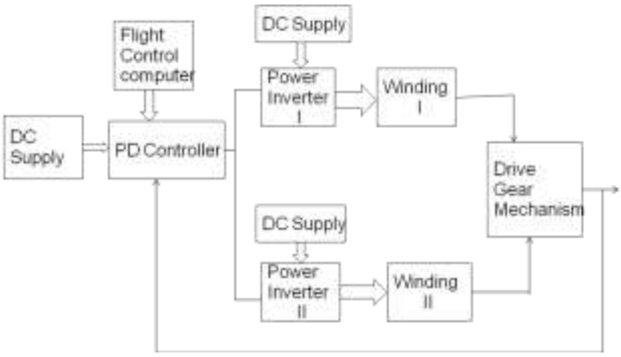

Fig.1 ElectroMechanical Actuator Block Diagram

2.Dual Redundant Logic:

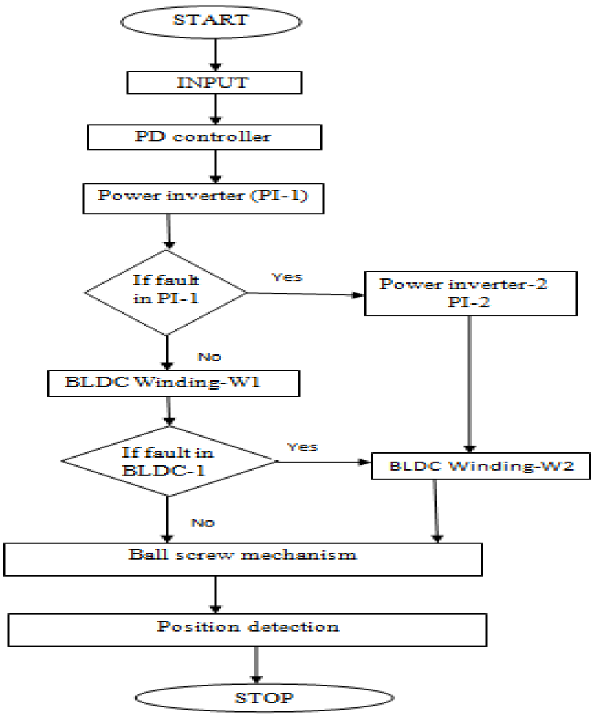

Fig.2 Flow chart representation

3. Redundancy Management:

The redundancy logic [4][5] to this system is limited for only one fault in each module, and the same concept was also depicted in the flowchart above fig.2. In fig.3, Primary chain is always in operation under normal conditions. If any fault occurs, then only redundant chain takes the service. If there is a fault in PI-1, the system can run without interruption either through PI-2, W2 and PI-2,W1 . Of course the latter is preferred because if second fault occurred in W2, then the whole system will be out of redundancy.

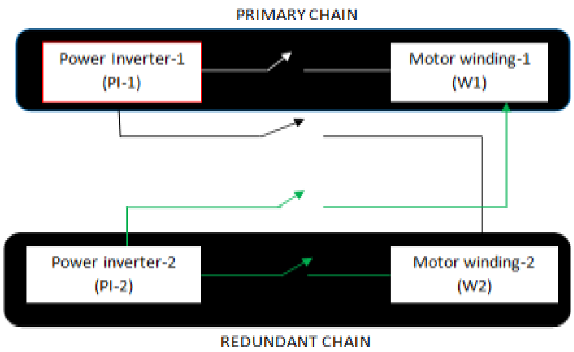

Fig.3 Redundancy Management

4. Mathematical Modeling of BLDC motor:

The BLDC motor can be modeled in the same way as conventional dc motor. The detailed approximated equations d-q transform is discussed in paper [5]The equivalent electrical circuit is shown in the figure below.
Equivalent of the motor armature coil is indicated by an inductance (L_a) which is in series with armature resistance (R_a) along with a induced voltage (V_a) which is opposing the voltage source.
Mathematically, the differential equation for the motor equivalent circuit can be designed by using basic Kirchoff's voltage law in the electrical loop.

$$V_a = I_a R_a + L_a di/dt + e_b$$

On applying laplace transformation for the equation above,

$$I(s) = (I_a(s) - e_b(s))/(Ls + R_a)$$

The generated electromagnetic torque in machine is directly proportional to the armature current and can be written as

$$Te = K_t I_a \text{and } T_e = Jdw/dt + B\omega \text{ ;}$$

$$\text{Where, , } \omega = d\theta/dt$$

On Laplace transform $\omega(s) = Te/(Js+B)$
Where, K_t is Torque constant and J is inertia of motor

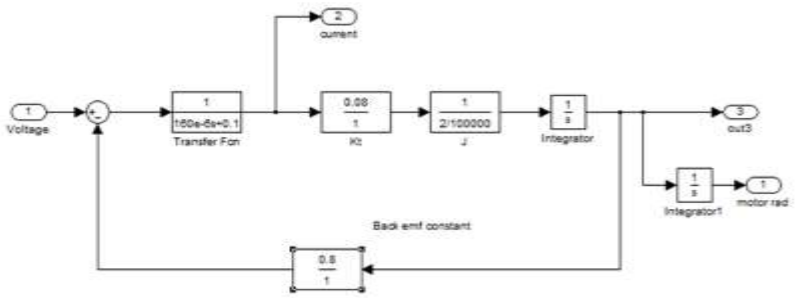

Fig.3 Mathematical model of BLDC motor

3.1 Selection of Power Inverter Configuration:

A various number of inverter topologies with the fault diagnosis and fault treatment has been presented in the previous papers[6].On comparison and analysis, by designing in

MATLAB, two three phase standard six switch power inverters are used for this specific type of application. Each inverter configuration is analyzed under different types of faults such as single switch failure, multiple switch failures, one leg open circuit, etc.,

4. Fault diagnosis and Fault management:

With the intention to improve the reliability of the system, dual redundancy logic is implemented to EMA with Power inverters and brushless dc motor [7] is designed. Fault diagnosis and fault treatment is discussed in previous research papers [8] by various techniques. In this paper, the probability to occur faults in various available subsections are presented in the below table in different cases.

Table.1 Possible switching cases

Healthy/section	Faulty section	Recommended path
PI-1→ W1	If Fault at W1	PI-1 → W2
PI-1→ W2	If fault at PI-1	PI-2→ W2
PI-1→ W1	If Fault at PI-1	PI-2 → W1

5. SIMULINK DIAGRAM:

The whole actuation system with the redundancy is shown in the Fig.4. It consists of primary chain and redundant chain, an LC filter to get smoother current waveform, and a mechanical transmission system where the electrical motor output is converted into mechanical system with parameters as position and the same is taken back as feedback signal.

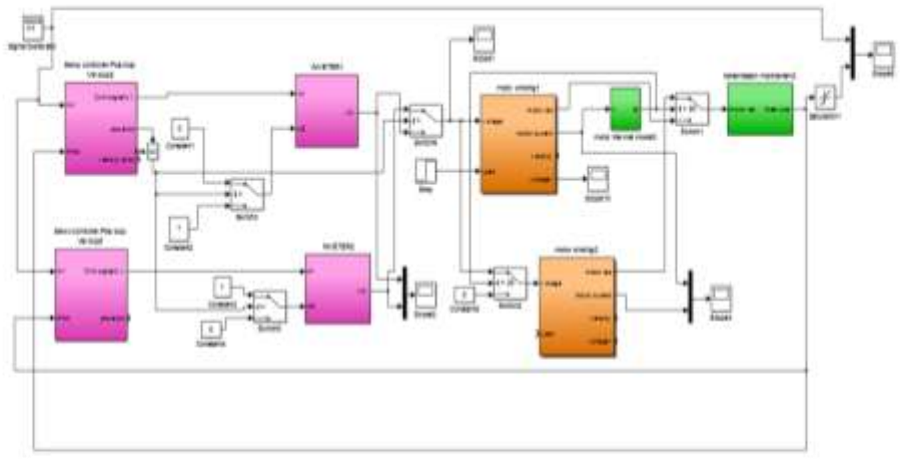

Fig.4 Simulation diagram of EMA with dual redundancy logic

The chosen parameters which are used in the simulation of this paper have been presented in the following tabular column.

Table.2 Simulation parameters

Rating of BLDC motor	10Kw
Voltage	100volts
Current	50Amp
Inductance	160μH
Armature Resistance	0.1ohms
Torque Constant	0.08
Torque	8 Nm
Inertia J	2x 10^{-5} kg-m^2

5.1 Simulation Results:

In Fig.5, the output of the actuator position follows the input signal. Due to improper tuning in velocity feedback loop, the phase delay occurs between the input commands and output produced. So tuning is important for smooth operation. When an overload fault occurs in motor winding1, due to high rise in current, the motor could not drive the load and deviates from the output and comes out of scope which is shown in Fig.6. and the respective fault currents and the power inverter voltages switching are shown in Fig.7 an Fig.8respectively. And the affected position and recovery system are shown in Fig.9 and Fig.10.

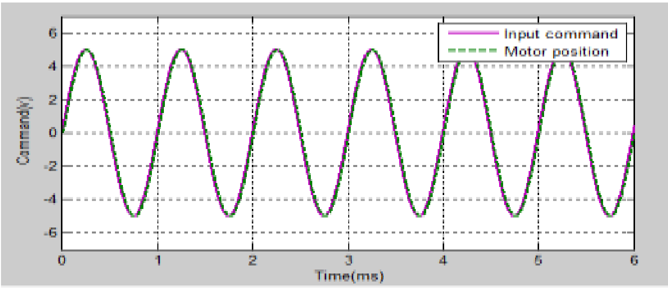

Fig.5 Electromechanical actuator position under normal condition

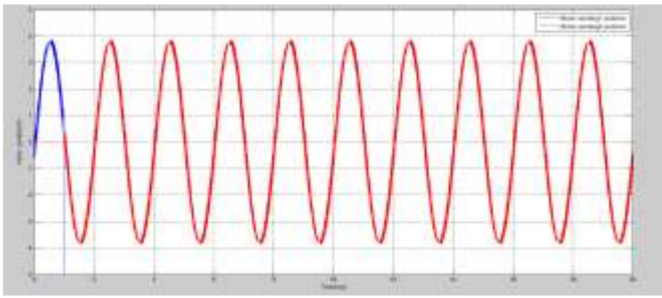

Fig.6 When fault occurs in Winding1 due to overload

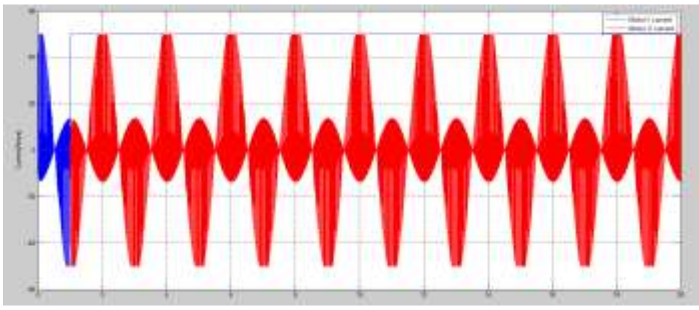

Fig.7 Motor currents when W1 is fails

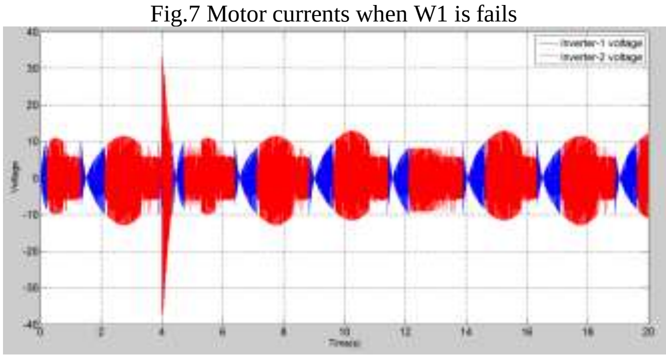

Fig.8 Inverter voltage with one leg open

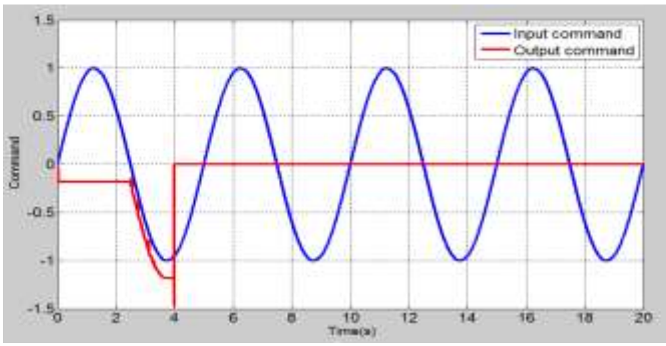

Fig.9 Power Inverter voltages.

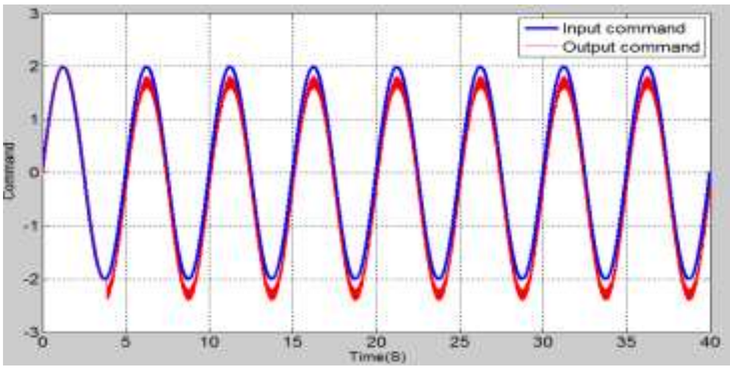

Fig.10 After fault recovery

5.2 Conclusion:

On simulating Electro Mechanical Actuator (EMA) model with the implementation of dual redundancy logic, the different possibilities are mentioned and it is simulated for each case and with different faults. Moreover, as Missile is a prestigious, milestone of country, or defense area, the high accuracy and reliability is needed for smooth operation for all the conditions and with no interruptions. It has been analyzed with different types of varying parameters and fault recovery process in very less time.

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