CHAPTER 1 INTRODUCTION

The chapter describes the introduction of power window system, its development from mechanical system to electronic based system and electronic control unit. Different ECU classification and devolvement process is discussed. The research motivation and system requirement of power window system is also discussed.

1. 1 Introduction to Power Window System

The fundamental of automotive electronics lies in the implementation of electronic systems in the automobile. Application of automotive electronics caters every subsystem of the vehicle[1] either it is injection system, ignition system, variable valve timing, automatic wiper control, electronic seat adjustment, radio communication, telematics, in-vehicle networking, infotainment systems and many others. Number of electronic systems increases with respect to time and add significant cost to automobile. From Society of automotive manufactures (SIAM) 2015 early report says electronic system cost in the automobile is only around 1% in the year 1950, around 30% in 2010 and by 2020 it is expected to reach 40%.

In the year 1974 when microprocessor is available easily in the market made economically feasible option to implement electronics in the vehicle and concept of automotive electronics became popular. In 1978, microprocessor series 6802 was introduced by company called Cadillac Seville introduced a "trip computer" which is mini ECU for the vehicle.

Dawn the line, in the year 1970's itself automotive electronics[2] evolved on the vehicle. During that time the only electronics devices used in the vehicle are radio, alternator which has inbuilt rectifier circuit with help of diodes and voltage regulator which stabilize output voltage of the alternator. From last

three decades, because of advancement in semiconductor technology and software development for the vehicle subsystem rapid technological invocation happen in this domain. In the 1970's era, introduction of electronics for vehicle engine controls i.e. replacement of carburetor based system to electronic injection system.

One of the goals of the electromechanical system is to deliver a quality product in terms of accuracy, lesser development cycle and product cost which satisfy functional safety of the system and is an integral part of basic safety regulation such as DIN 19250 or IEC 61508. Numerous fatal accidents have been reported where passenger's body parts such as neck get trapped in power window during window movement, leading to suffocation and severe harm. After increasing number of mishappenings, safety of the power window system became an important part of the safety regulation system.

Modern automobile engine has electronic injection and ignition controlled mechanism, permit the original equipment manufacturers (OEM) to achieve lower emission and higher fuel economy to satisfy stringent emission norms imposed by regulating agencies. These engines also enhanced the usage convenience for the drivers. Considering the concept of anti-lock braking system, it was first conceptualized and introduced in 1980's era. In the 1990's era rapid electronics development happens either because of stringent emission norms, or stiff competitive market introduced air bag system, speedy development in body electronics such as electronic seat motors, automatic door lock, instrument cluster panel light, lighting system, and keyless entry[2]. In early 2000's infotainment system capable of handling audio and video, signals sent via satellite (OnStar System), GPS, satellite radio and mapping capabilities was developed. In the late 2000's drive by wire which consists of throttle by wire, steer-by-wire and brake by wire system and wireless connectivity became popular option. By 2020 connected cars and autonomous vehicles is the future.

A window regulator is a mechanical assembly which is accountable for upward and downward movement in predefined set track. Mechanical

assembly lies behind the door panel. The basic window system was first introduced in the vehicle before 100 years which was typically operated by hand crank mechanism. The location of the hand crank was such that a person sitting next to a window[3] would easily turn the glass frame upward or downward. The lever for hand crank is coupled through either scissor arm or cable type mechanism which supports the glass frame to raise the window or lower down the window into the desired position. But with the passage of time, electrical and electronics accessories became an integral part of the vehicle at large and in power window system also. Power window systems uses DC electric motor for window motion.

After year 2000, power window system gained the public attention and widely used by the different vehicle classes such as sedan, hatchback, SUV etc. This new innovation further fueled the development of smarter power window system utilizing numerous switches, sensors, algorithm, and control system. Power window system consists of small electric DC motor which transfers its torque to ring gear through worm gear arrangement which is represented in Figure 1-1. The gear arrangement is used to generate sufficient torque to continuously do the work with help of small electric DC motor. Worm gear has a self-locking mechanism such that during halt position no one can open the window externally.

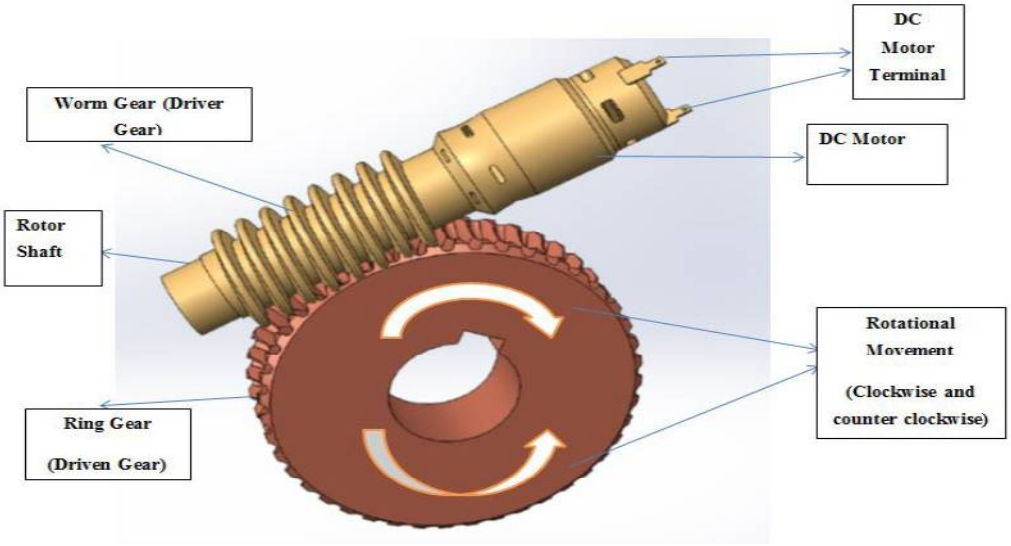

Figure 1-1 Insight view power window DC Motor

Power window is also known as smart electric window used in a vehicle to move the glass window frame upward or downward by pressing an appropriate driver or passenger switch with the help of different smart sensors. Power window system is improved version of mechanical hand-turned crank handle mechanisms[3] based system. The power window framework comprises of DC motor that provides clockwise and counterclockwise movement of the power window which is responsible for its rising up and lowering down and is controlled by a variety of switches. The upward and downward movements of the power window are controlled through the drive circuit. The input to the drive circuit is controlled by different switches, sensors and algorithm based signal which activates the drive circuit and accordingly current is flowing in the load[4] circuit. Most of the system in an automobile is currently migrating from conventional mechanical system to modern mechatronics based system.

For installation in a vehicle, the window must qualify safety standard in terms of functional and operational safety. For the development of power window, operational safety is defined by fatal accidents corresponding to passenger body trapped during upward movement of power window system leading to suffocation and physical damage. Similarly, placement of power window switch on the hand rest of the vehicle leads to trigger when a child wants to climb to keep his/her head outside of the vehicle causing failure of safety standard. To overcome this problem, several automobiles mount a driver-controlled locking system to prevent back seat travelers from unintentionally activating the switch. The lifting mechanism is a device that plays a noteworthy character in automotive[5] power window. In the power window system, glass window lifting mechanism is divided into two types: first is cross arm mechanism and second is cable drum mechanism as shown in Figure 1-2.

With the significant development in electronics sector, the automotive industry gives more emphasis on design and development of power window. Earlier, automotive window was used manually for a longer time. The user generally opened and closed the window of the door by turning a crank handle

clockwise for upward movement and counter clockwise for downward movements. Thereafter, as other manually-controlled systems [6, 7], manual operation is supplemented with the programmed working approach. Power Window systems with electronic controllers are fueled with electric DC motor thus windows are raised and brought down naturally.

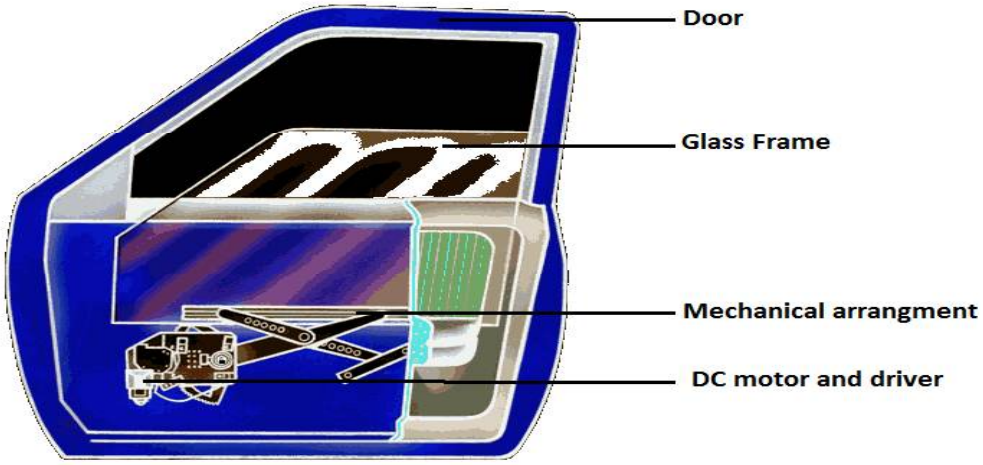

Figure 1-2 Automotive power window

A gear reduction ratio of 1:50 is maintained in power window system, where a DC electric motor rotor shaft is joined to a worm gear. Few other pinion gear mechanism provides larger gear reduction. This is associated with a lead screw which provides sufficient shaft power to start the power window system. A self-locking feature of worm gear helps to protect the contact linkage of pinion and worm gear arrangement presented in Figure 1-2. In order to adjust the different load to help move mechanical arrangement upward/downward direction, a control signal is required, generated either by switching actions like driver/passenger side upward, downward or by different sensory data such as current, temperature, and flexi force. These all factors are required as an input to the automotive window system making a control system which is represented in Figure 1-3.

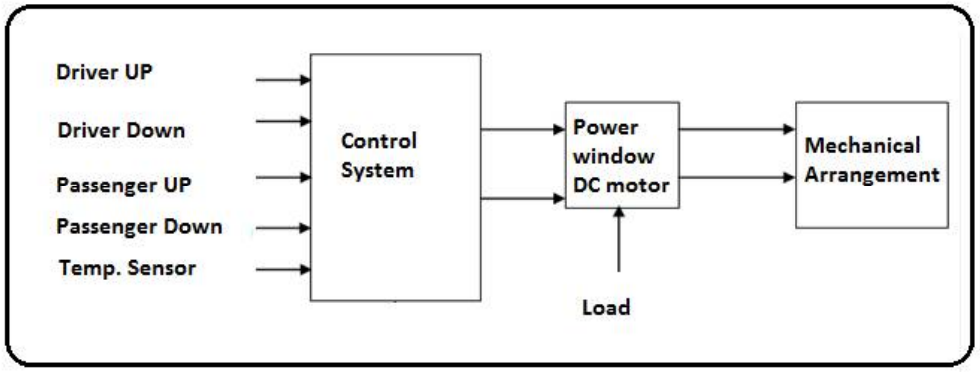

Figure 1-3 The power window system structure

Four types of electrical drive system for power window are available. These drive circuits are further categorized as relay driver circuit, H- Bridge circuit, BLDC (Brushless DC motor) and PMDC (permanent magnet DC motor). The ECU (Electronic Control Unit) board contains various switches through which upward and downward movement of glass frame takes place. When upward switch is pressed, glass frame which is coupled with DC motor moves upward direction and vice versa for downward[8] switch.

The power window control system framework comprises of power electronics[9], and DC motor based drive circuit, which further comprises of MOSFET based H Bridge circuit[10], accordingly shown in Figure 1-2. To make the system more precise, two proximity sensors are installed in car window: One at the top side of the glass window frame and other at the lower side of the frame. This assists in identifying the start and end position[11] of the frame. In this mechanism, different sensors are used to measure current, flexi force and temperature. Current and flexi force sensor are deployed in such a way that if there is an obstacle, the power window travels downwards to a predefined level. Whenever vehicle cabin temperature exceeds a threshold limit, certain action has to be taken for the downward movement of the glass frame as represented in Figure 1-4. The lifting instrument at specific location utilizes a linkage to lift the window glass frame upward and downward while maintaining a constant level.

The rotor shaft of the DC motor is coupled with a worm gear arrangement and number of other spur gear arrangement forms larger gear reduction

mechanism. This provides large torque to lift the power window upward and downward. The linkage comprises of the long arm appended to an iron bar which holds the base of the window frame as shown in Figure 1-2. One end of the arm moves freely in the space as the window rises upward or downward. On the other side of the iron bar, there is an extensive plate that has different gear arrangement coupled with DC motor rotor gear arrangement thereby running the power window system[3, 9]. This is the normal linkage utilized on a different segment of an automobile with manual windows. However, the difference between the manual and power window is the crank handle based mechanism in former and motion by DC motor in latter. This is represented in Figure 1-2

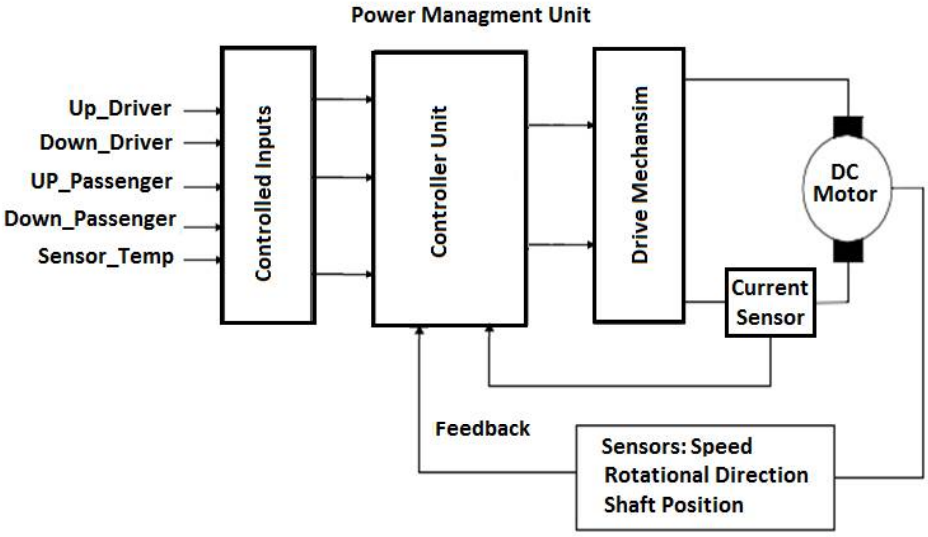

Figure 1-4 Block diagram representation of power window system

1. 2 Electronic Control Unit

In automotive electronics, ECU (Electronic Control Unit) is a popularly known terminology used for system or subsystems in a motor vehicle embedded system that controls different electrical systems. Considering any vehicle in today's era electronic control unit is a key component. Considering the case of modern engine[12] the embedded computers in this case totally controls the engine settings and its supporting functions (ignition system, injectors system, turbocharger and many others). The ability to tune a modern car has been taken away from automotive mechanics and now sits with

electronic software engineers, embedded engineers, and dedicated vehicle experts which are clearly represented in Figure 1-5.

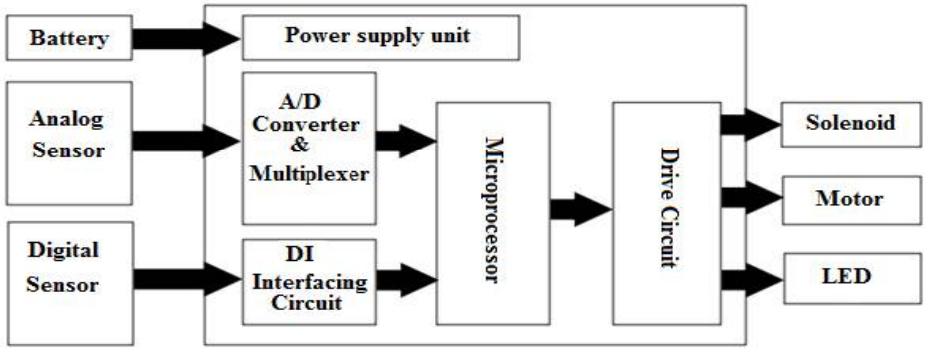

Figure 1-5 Block diagram of Engine Control Unit (ECU)

1. 3 Functions and ECUs Per Vehicle

Considering the electronics development in some of the modern vehicles have up to 80 ECUs onboard. Embedded software development with respect to ECUs continues to increase with respect to total number of lines of code, its architectural complexity and difficulty with hardware interfacing. The challenges for the original equipment manufacturers to handle the rise in embedded system complexity and total count of onboard ECUs. The Figure 1-6 illustrates the number of function per vehicle, Number of ECU per vehicle and function per ECU with respect to time.

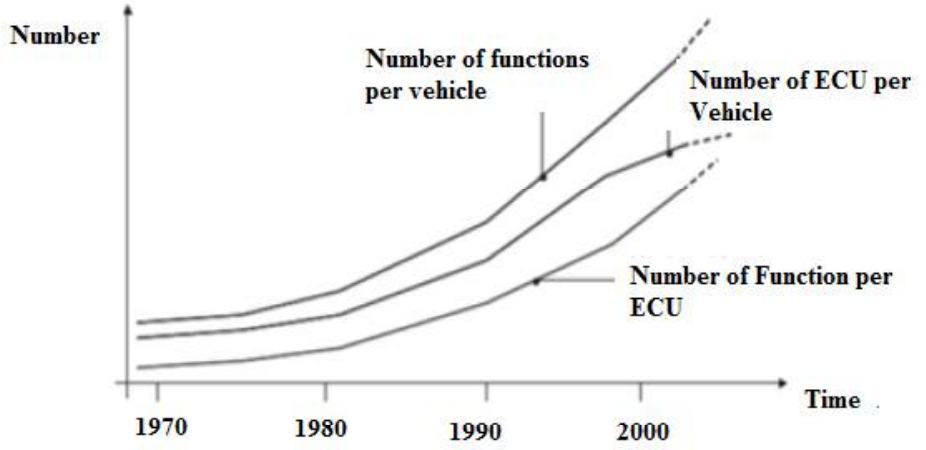

Figure 1-6 Number of ECU per vehicle and its function per ECU with respect to time

1. 4 Types of ECU

The classification of an ECU involves understanding of both software as well as hardware to do desired task of the subsystem. Vehicle electronic can be further categorized into four subsystems:

1) Powertrain drive system
2) Safety systems
3) Comfort body systems
4) Communication systems

Powertrain drive system containing Engine Control module called ECM, automatic transmission control system called ATC, Electronic injection system and Electronic ignition system. Similarly safety systems consists of brake control module like Antilock Brake Systems (ABS), Electronic Stability Program (ESP), airbag control unit, Tire Pressure Monitoring System (TPMS), anti–theft, suspension control module and steer by wire system. Third category is Comfort body systems[13] also known as body electronics consist of automatic Air conditioner, Electronic seat adjustment, HMI based dashboard displays system, Power window, wiper control etc. Last classification is called Communication systems which includes In vehicle networking protocol such as Controller area network (CAN), Flexray, Local interconnect network (LIN) and Media oriented system transport (MOST) apart from that it covers Global positioning system, radio Communication system and various on road/off road information systems which include web based and web enabled system For efficient performance above all subsystem requires Electronic Control Unit (ECU).

1. 5 ECU Design Concept

The ECU design and development requires hardware as well as software understanding to perform certain action in the vehicle subsystem. The increasing number of functions in a given vehicle is rising. In vehicle networking, high and continuously rising requirements in terms of safety, availability and reliability together leads to high level of system complexity that can barely be succeeded without a defined development process. Figure

1-7 represents ECU design and development classification which covers PCB design, Memory management and firmware management.

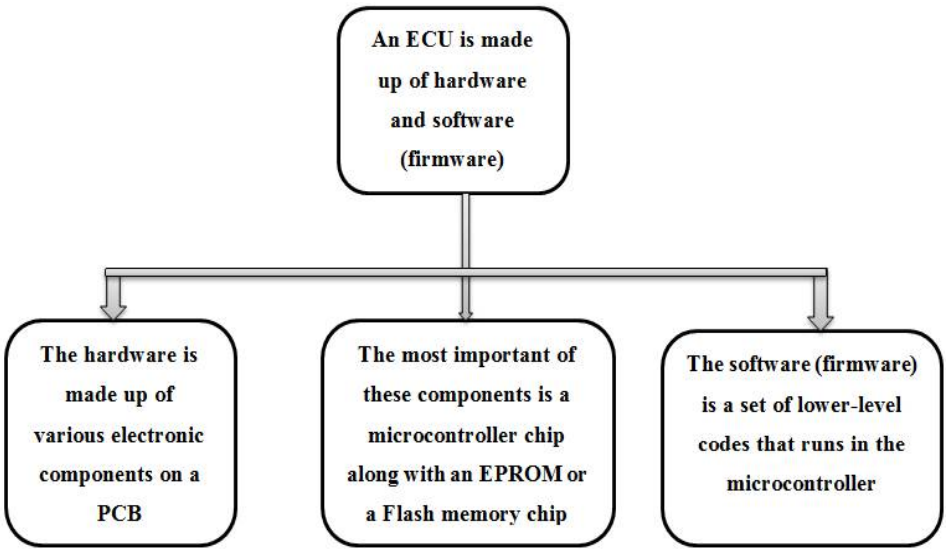

Figure 1-7 ECU design and development classification

1. 6 Research Motivation

It is discussed in the previous section that there is a distinct performance improvement in the system if model-based design approaches with different modern tools are used to solve the power window design problem. Following advantages are presented as motivating factors for this research.

In the vehicle, various electromechanical systems are used and one of the important and complex systems is Power window. Model-based design is a mathematical tool to address complex power windows control system. This cultivates knowledge into how this approach is beneficial for broad electro-mechanical framework system. The above methodology can be generalized to various automotive subsystems like drive train, power steering, Electronics ignition system etc.

1. Different factors affect automotive power window systems are a deviation in static and dynamic switch response time, sensory data, and interference with other system makes design and analysis complicated. Software in a

loop using Matlab/Simulink and Hardware in a loop using dSPACE control desk are used for the development of power window system with an aim to resolve such difficulties resourcefully.

2. To design power window system namely called object detection techniques during upward movement of power window glass frame. The mathematical model of DC motor with gear reduction and power window mechanism with roller and glass clamps has a large number of variables and constraints. This analysis finally validated on dSPACE control desk tool. With this study different problem got identified and various model-based approaches are the best fit technique for automotive power window system.

3. Mathematical Model-based design approach delivers a collective design environment, which assists universal communication techniques, algorithm design and implementation use different data analysis, and system validation and verification between numerous hardware tools. In power window system, identification and error correction is at system design level itself by using the software in loop methods. Offline simulation, as well as real-time simulation, is possible during design step.

1. 7 System Requirement

The requirements for power window system performance [5, 14, 15] are listed as follows. Different system requirement for enhanced performance needs different control system design to achieve operational safety. Consider obstacle detection algorithm which is used to protect any object get trapped in the upward movement of glass window frame, similarly upward and downward movement of power window need to design control system.

i. Time taken to travel glass frame from the lower position to higher and higher to the lower position is 5sec.

ii. To provide operational safety to the device DC Motor and its drive circuit, the maximum operational time defined to make it ON/OFF is 5 Second duration.

iii. The System has to move within 0.2 Second of time once the command is issued from the control system.

iv. The power window essentially stops when it reaches to a completely opened or completely closed level.

v. In the event that the upward or downward signal is generated in the span of 0.2 Seconds to 1 Second, the power window movement must be completely opened or closes, unless hindered by another control signal. This prerequisite speaks to the automatic upward and downward movement of the system.

vi. The system should have the capability to recognize an obstacle with a force under 100 Newton[15].

vii. The system must be brought down by roughly 10 centimeters provided an impediment is identified.

viii. Priority for the obstacle detection always higher over passenger control or driver control signal.

ix. Priority has to be provided to driver side controls system over passenger side controls system.

1. 8 Thesis Outline

In this thesis, automotive power window systems are introduced and various design processes are discussed. The following chapters are structured to demonstrate power window process and research work.

Chapter 1: The chapter describes the introduction of power window system, its development from mechanical system to electronic based system and electronic control unit. Different ECU classification and devolvement process is discussed. The research motivation and system requirement of power window system is also discussed.

Chapter 2: This chapter discusses a number of literature review related to automotive power window in the field of mathematical modeling, simulation,

hardware development, control system, algorithm development, Software in the loop testing and Hardware in the loop testing techniques.

Chapter 3: The chapter explains system design which covers power window system, Linear motor model, gear train model, controls system for motor and power window, hardware in loop simulation with dSPACE simulator, test bench setup of power window system with ACE 1104 hardware kit.

Chapter 4: This chapter applies mathematical model based simulation modeling concepts from chapter 2 to develop software and hardware for the automotive power window. The following section covers DC motor model with gear train arrangement in Simulink platform, software in loop testing, calibration model for the sensor, decision tree classifier algorithm for obstacle detection and hardware in loop testing.

Chapter 5: This chapter illustrates result and discussion of different methodology addressed in chapter 4 for current and flexi force calibration model, mathematical modeling of power window system, its software in loop testing, results for decision tree classifier algorithm for obstacle detection, hardware in loop testing and experimental setup result analysis is discussed.

Chapter 6: This chapter explains conclusion and future work of research activity which is formally demonstrated the design, control and development of smart power window system using model-based development and validated on dSPACE ace 1104 simulator. This concluding chapter encapsulates various techniques used in design, control and development of power window system which is demonstrated in chapter 2, chapter 3 and chapter 4. The research work is applicable to different type of electromechanical system which is not only used in automotive industry but also used in mechatronics industry, avionics industry, and robotics and automation industry. Various systems like Injection system, anti-lock braking system (ABS), Electronic stability program (ESP) and wiper system may use technological tool for rapid prototyping and validation may be done using dSPACE simulator.