

CHAPTER 4 METHODOLOGY AND SYSTEM DESIGN

The chapter applies mathematical model based simulation modeling concepts from system design of automotive power window 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.

4.1 DC Motor Model

In automobile permanent magnet direct current (PMDC) motor are used for multiple low power application. In power window system, PMDC motor armature winding in electromagnet whereas field winding is a permanent magnet. Multiple advantages make PMDC motor as the first choice in motor selection criteria like smaller size, comparatively cheaper and excitation voltage is not required[85, 86]. The objective for the development of the mathematical model is related shaft power of the motor with input power to the motor in terms of voltage, current, angular speed and torque. The equivalent circuit diagram is illustrated in Figure 4-1.

To understand free running condition and stall condition of PMDC motor which is an important component of power window system, two equations can be derived to understand electrical characteristics[86, 87] and mechanical characteristics.

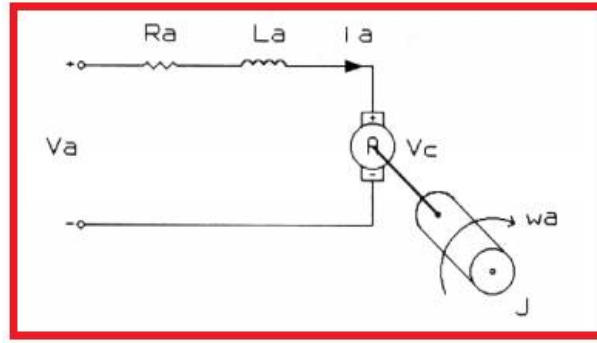


Figure 4-1 Electrical circuit of PMDC motor

The equation for electrical characteristics is represented by equation (4-1) whereas a mechanical characteristic is represented in equation (4-2).

$$V_a - i_a R_a - L_a \frac{di_a}{dt} - K_v \omega_a = 0 \quad (4-1)$$

Where V_a = Source voltage across armature coil, i_a = Armature coil current, R_a = Armature Resistance, L_a = Inductance of armature coil, K_v = Velocity constant and ω_a = Rotational Velocity,

$$K_t i_a - J \frac{d\omega_a}{dt} - B\omega_a - T_L = 0 \quad (4-2)$$

Where K_t = Torque constant, J = Motor moment of inertia, B = Damping coefficient and T_L = Mechanical load torque.

4. 1. 1 Free Running Condition (No Load)

The free running condition of DC motor also called No mechanical load current required by armature coil to overcome friction loss of motor shaft[88], aerodynamic drag by rotor shaft. In this condition, no-load current is required to run the rotor shaft without load.

$$P_{elec} = P_{Mech} + P_{Loss} \quad (4-3)$$

Where P_{Mech} = Mechanical Power or Shaft power, P_{elec} = Electrical power and P_{Loss} = Power loss (iron loss, hysteresis loss, and copper Loss),

$$P_{rot} = M \times \omega \quad (4-4)$$

P_{rot} = rotational mechanical power, ω = angular velocity and M = Torque.

In power window DC motor if no load is acting on the motor shaft i.e. $M = 0$ then motor runs in free running condition and this case armature current is very small called free running current (I_f). Drag force required to run motor freely and to overcome drag force analogs power is required by the motor and this achieved by the free running current.

4. 1. 2 Stall Condition (Full Load)

When load acting on the motor shaft, armature current requirement changes and accordingly motor torque changes. The stall condition is also known as full load condition which is defined as maximum torque is generated by the motor before it is coming to halt state illustrated in Figure 4-2. From equation (4-2) and (4-3) maximum current [89] in armature coil generates the highest torque by power window DC motor. In DC motor when a heavy load is applied field flux decreases due to armature reaction which is neglected due to a small magnitude. So torque is directly proportional to armature current. For all class of DC motor specific characteristics curve is represented in Figure 4-2.

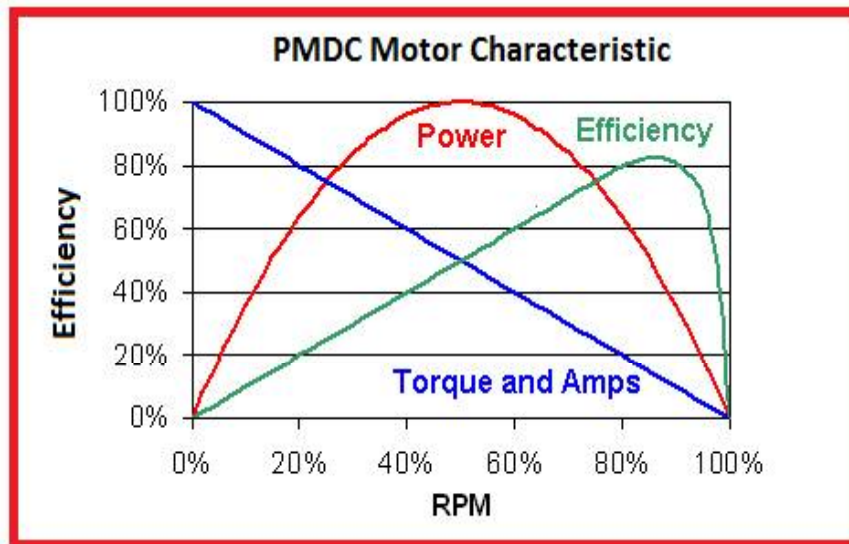


Figure 4-2 PMDC Motor Characteristics curve

4.2 MATLAB/Simulink Model

The simulation model using MATLAB/Simulink describes the motor-driven power window system. The parameter specification and description of power window DC motor used in Simulink model are listed in Table 3-1. The electromechanical model presents the DC motor coupled power window system. The power window mechanism is driven through the DC motor with a self-locking mechanism having ring and pinion gear with gear ration of 1: 50. Lead screw having pitch length of 3 mm is coupled with ring gear to generate linear movement of power window system. The mechanism used in electromechanical power window system required pulley for driving arrangement called as driving pulley “DP” followed by four supportive rollers RL1, RL2, RL3 and RL4 which is integral comments of cross arm mechanism, apart from that system have two additional glass claps represented as GCL1 and GCL2.

When DC motor rotates in clockwise or counter clockwise direction then accordingly glass clamps move upward or downward and subsequently power window moves inappropriate direction. In cross arm mechanism glass clamps GCL1 and GCL2 rotates which is further attached through rope arrangement and accordingly both clamps GCL 1nad GCL2 rotates at identical speed maintaining a level of glass window movement symmetrical. During development of simulation model using MATLAB/Simulink, rope drum block, supporting rollers and belt drive pulley block form the electromechanical [90] power window system. The driving pulley is simulated with Simulink using the Rope Drum block, while the supporting rollers (RL1, RL2, RL3, and RL4) are modeled with Belt Drive Pulley blocks (DP). Description and specification of the various mechanical components used in the development of plat model using Simulink are captured in Table 3-1.

The controller must decide the behavioral characteristics for power window development based on various information esteems and indicated framework necessities. With help of various input like driver upward, passenger upward, driver downward and passenger downward switch, similarly sensory data like

current sensor, flexi force sensor, and temperature sensor are used as controller input through which upward and downward movement of power window system achieved.

Driver upward, passenger upward, driver downward and passenger downward are digital I/O switch whereas current sensor, flexi force sensor, and temperature sensor are an analog sensor which is configured with ADC port. With help of adequate input to the controller, then modify the controlling techniques and accordingly computed the real-time load current and load voltage by appropriate power window dynamics equation[91]. The simulation system model was constructed using Matlab/Simulink which is represented Figure 4-3.

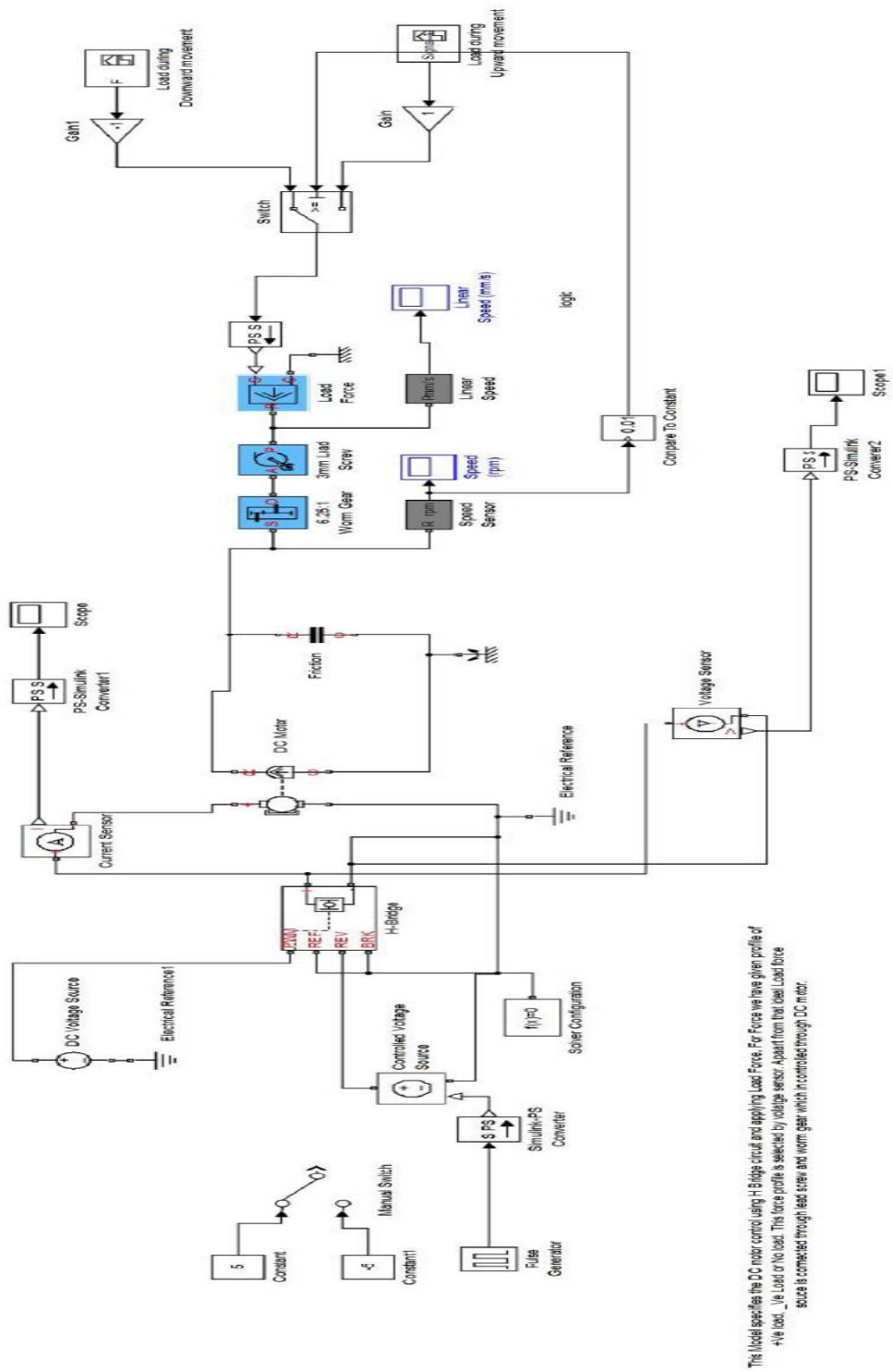


Figure 4-3 Simulation model of power window system using MATLAB/Simulink

4.3 Software in Loop Testing

The term ‘software-in-loop testing’, is popularly known as SIL testing, used to define an examination procedure where executable code of simulation model or algorithms or entire control system, typically transcribed for a power window system which is a typical electromechanical system[92], is tested in Matlab/Simulink environment which is typically a modeling platform through which test the software. Testing the system behavior during the early stage of design require SIL testing and simulation technique.

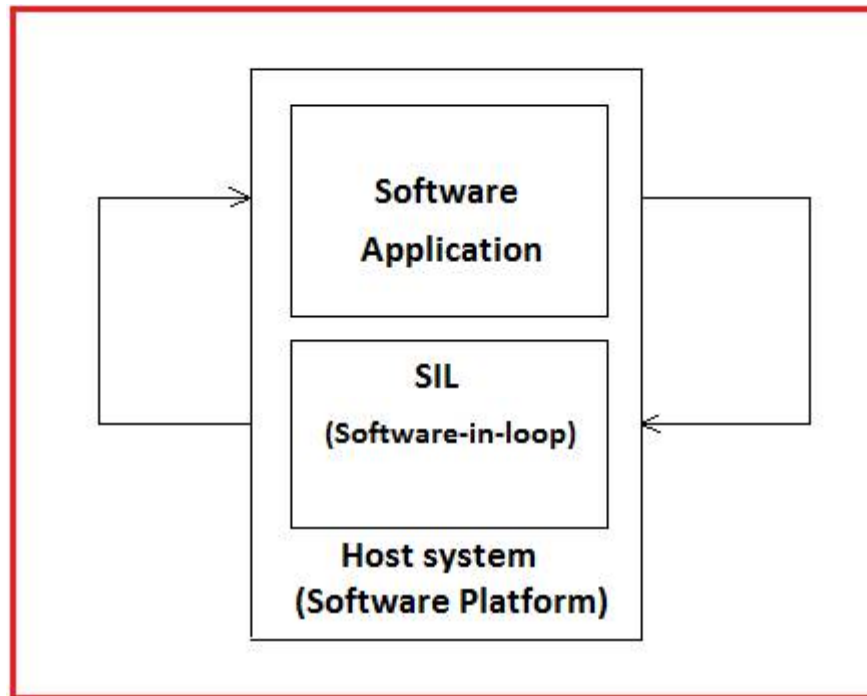


Figure 4-4 Software in loop testing

In power window system which is a typical mechatronics system requires possession of the original software and hardware. At the beginning of the research, no one has the hardware to implement and validate so all you need is plant model simulation to make sure that you will create real conditions for your software-hardware package. As per project development cycle, hardware comes later in the project development phases. Your algorithm and control code has to be tested in software environments only and the process followed for testing known as software-in-the-loop simulation or testing[63]. This is an

earlier stage in the testing procedure where researcher tests its algorithm but not the entire power window system. From Figure 4-4 it is clear that software algorithm[93] and the model are running on the same machine, usually a host system which is typically a computer.

4.4 Sensor Calibration Model

In the research work, current sensor and flexi force sensor are used. Current Sensor is used to calculate the amount of DC current flowing in the load circuit which is connected in series with DC motor, control power window system. The current sensor ACS712 has an analog output and if DC motor moves clockwise or counterclockwise accordingly voltage varies and changes its polarity. Exact amount of power being drawn by the device is confirmed by the sensor. Flexi force sensor i.e. SEN-09375 is used to measure the force acting on the window frame, with this valid and invalid force identification is achieved for obstacle detection [52, 94] algorithm.

4.4.3 Current Sensor Calibration

The current sensor IC, measurer's different current associate with load circuit. Internally different level of magnetic field is created when known amount of current is flowing in the coil leads to generation of voltage with help of hall effect principle.

$$P = V * I$$

Where P is proportional to V (voltage) and I (current)

To perform full calibration procedure connect external ammeter with at least 15A range in series with motor and battery, to properly measure current drawn from a battery source.

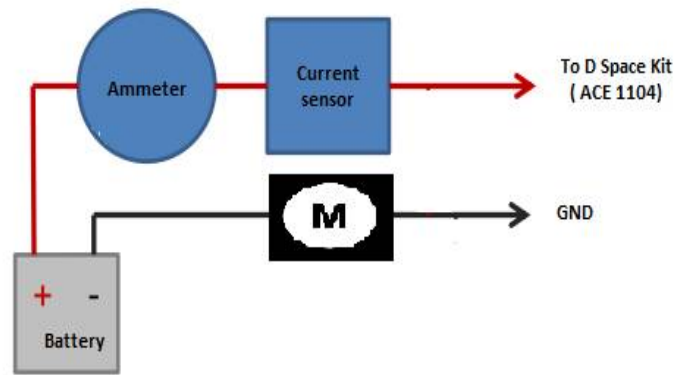


Figure 4-5 Experimental setup for current measurement

4. 4. 3. 1 Zero Offset

Due to technology, some sensor may produce output voltage even though no current is flown through the sensor. The system must know this offset value in order to properly calculate actual current flowing in the circuit. The typical offset value for current sensor is zero or a small value close to zero but current sensor principle is Hall Effect principle which has significant offset value and proper calibration must be performed before use. To calibrate sensor's zero offset set to throttle down (cut engine) to minimize current consumption. Set proper ammeter range to get a reliable measurement. Current drawn from the battery in this step must not be greater than 2A.

4. 4. 3. 2 Setup Description

For current measurement in load circuit uses current sensor i.e. ACS 712 series to the Load circuit i.e. power window motor circuit shown in Figure 4-7. The current sensor circuit is capable of identifying load current during clockwise as well as counterclockwise movements. For current sensor i.e. ACS 712 Connect V_{IN} and GND to +5V and 0V respectively from dSPACE ACE 1104 Kit. The output of current sensor finally, attached to ADC port of D space kit and voltmeter is connected to observe the V_{OUT} generated by the current sensor, second pin sensor is connected GND of dSPACE simulator kit. Even though the motor is not working then also small voltage is observed. This small voltage is nothing but the noise in the circuit generated through amplification and other process circuit.

Low voltage generated by the circuit represents which is typically a zero current level of the sensor called noise. When the user presses upward switch motor rotates in clockwise direction and accordingly load current changes from 0A to 9.8A similarly whenever the user presses downward switch load current changes from 0A to 8.2A respectively. With addition of different load[95] i.e. small level (0N to 60N), medium level load (60N to 120N) and High-level load (120N to 300N), such that observation gives you an actual reading. The flow chart of the power window system implementation, software development procedure and validation is represented in

Figure 4-6. In the flow chart various condition are identified and accordingly control is taking place which further drive the DC motor.

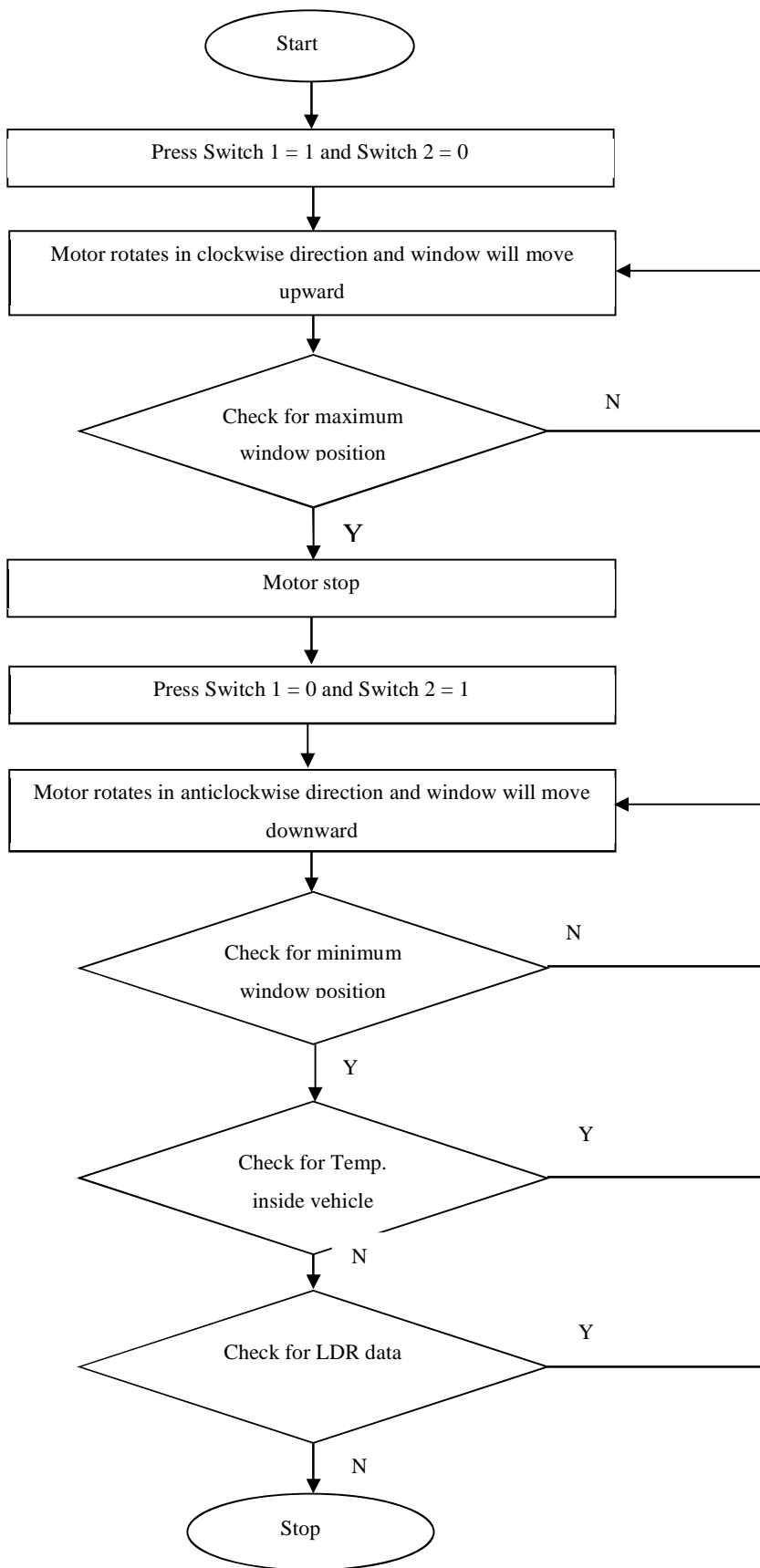


Figure 4-6 Functional module flow diagram

Considering a situation where the voltage doesn't increase/decrease with respect to the change in load. To solve this, sensor circuit connections as well as power supply unit has to be verified. Rotation of the motor is achieved with help of Figure 4-7 and appropriate manual input leads to the voltage changes as the current [96] changes in the load circuit. Installation angle of current sensor is also vital calibration parameters because of its Hall Effect operating principle. For proper installation perhaps need to set the sensor angle to its most touchy edge (most elevated voltage) such that sensor is capable to identify little changes in current.

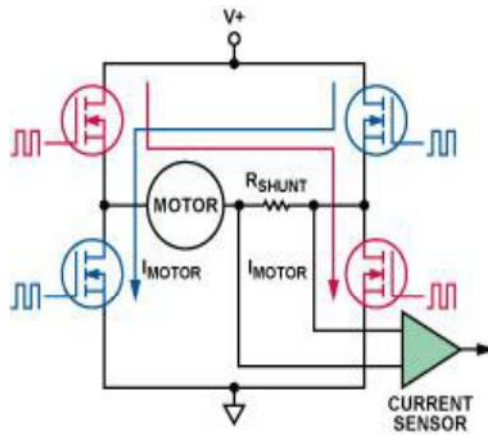


Figure 4-7 Current sensing circuit for power window DC motor

In the current research activity the focused load range is nothing but the detecting little to medium load range of 0 N to 120 N acting on power window frame then accordingly set the desired pressure in the pneumatic circuit. Such that a smaller change in current is also capture through high sensitive sensors. For sensing larger load i.e. 120N to 300N, higher sensor rating is required, corresponding to adequate voltage rating so that sensor will not saturate before it reaches the maximum desired load current to sense. For the calculation of force, power, current and torque following equations are used.

$$Power = \frac{Force \times Linear_Distance}{Time} \quad (4-1)$$

$$Power = \frac{Torque}{Radius} \times \frac{(Radius \times Angular_speed \times Time)}{Time} \quad (4-2)$$

$$Power = \frac{\frac{Torque}{r} \times (r \times Angular_speed \times t)}{t} \quad (4-3)$$

$$Power = Torque \times Angular_Speed \quad (4-4)$$

$$Power = Torque \times 2\Pi \times Angular_Speed \quad (4-5)$$

$$Torque(Nm) = Force(N) \times Distance(cm) \quad (4-6)$$

4.5 Flexi force Sensor Calibration Model

Flexi force sensor i.e. SEN-09375 is used to measure the force acting on the window frame, with this valid and invalid force identification is achieved for obstacle detection algorithm[52, 94]. Calibration of flexi force sensor is divided into two components one is signal conditioning unit and another one is calibration of static forces.

Signal conditioning unit consists of FSR and operational amplifier IC this is required for the initial procedure to test working condition of the Flexi Force sensors. However, sensor calibration is required before using the physical model. To calibrate the flexi force sensor following procedural steps are required and Figure 4-8 is recommended circuit for testing and calibrating flexi force sensor. It is recommended that signal conditioning is also required for sensor usage in plant model. Detailed flexi force configuration is represented in Figure 4-9. The procedure will "soften up" the sensor and ought to be done before adjustment and before using in a physical model for best outcomes. For the duration of three seconds add maximum rated load to the sensor that is if a maximum rated load of flexi force sensor is 300N then add 10% extra load i.e. 330N. Remove the load and repeat the steps for three four times.

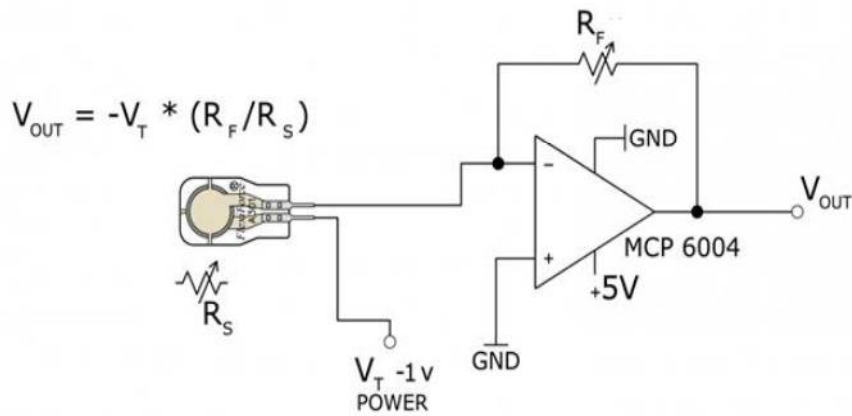


Figure 4-8 Circuit diagram of flexi force sensor

In the second step i.e. calibration of static forces below following steps required:

Step 1: On the sensor apply 1/3 of the test load (Force). Leave the Force on the sensor a similar measure of time (before recording the output). This limits the drift error of flexi force sensor. Record the yield, and after that dismiss the Force from the sensor.

Step 2: Abode 2/3 of the test load (Force) on the sensor, again holding up for the estimated amount of time. Record the yield. Record the yield, and after that dismiss the Force from the sensor.

Step 3: On the flexi force sensor apply full test load (Force). Hold the force for appropriate once output gets captured. Eject the Force from flexi force sensor. Multiple sets of reading are sufficient to adequately analyze the system behavior and plot the set reading with respect to time.

Step 4: Accumulate each arrangement of information (Sensor Output versus Force applied) and plot the information on the chart. With help of calibration circuit gather set of data and using modern tools like MATLAB plot the best fit graph between force and voltage.

Step 5: Utilizing different condition for gathering sensory data to plot best-fit line characteristics to determine force for unidentified load during experimental analysis.

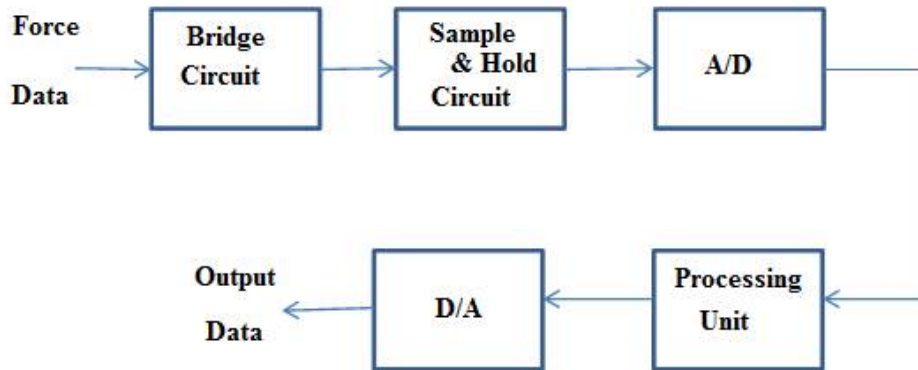


Figure 4-9 Detailed Flexi force sensor configuration

4.6 Algorithm For Obstacle Detection

In power window, obstacle detection is very crucial with respect to safety. In this process, various techniques are followed using current sensors[97], different algorithms and computer programming for object detection in power window system when glass frame [98] is in upward motion.

4.6.4 Decision Tree Classifier Algorithm

A Decision Tree classifier algorithm is a tree-like diagram dependent on two sensor reading: current and flexi force data, which is tested for a property and branches thereby indicating the result of the test. Accordingly, power window continuous operation decision or halt decision action is taken as shown in Figure 4-10. The characterization rules are also shaped by the sensor data of power window system[62, 99]. To partition both information first the current sensor data has to capture in the load circuit and then physical force acting on the power window frame is picked as it is the most noticeable credit to isolate

the information. The tree is developed by recognizing characteristics and their related branches which are utilized to dissect the information at middle of the tree. After the tree is framed, it can anticipate the decision about halting the power window system or moving continuous discarding smallest current and force data. A flowchart of decision tree algorithm development procedure and operation is illustrated in Figure 4-11.

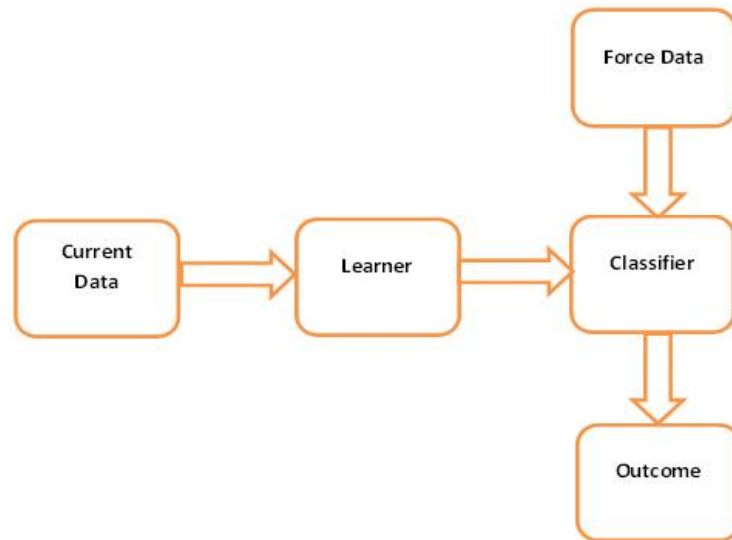


Figure 4-10 Block diagram of decision tree algorithm

DT algorithm analyzes, data and recognizes significant characteristics with respect to current and force data and accordingly takes a decision about the valid operation or malicious operation. This algorithm adds value to power window system by analyzing a large set of current and force data which is associated with system. This further helps to identify interruption data[56]. It recognizes different trends and patterns to detect obstacle, which promote investigation and development of smart power window system which takes a decision on the basis of the algorithm[55, 100]. The fundamental favorable position of utilizing decision trees algorithm rather than other strategies is that they provide a larger set of training and testing rule and can be easily incorporated into real-time system i.e. ACE 1104.

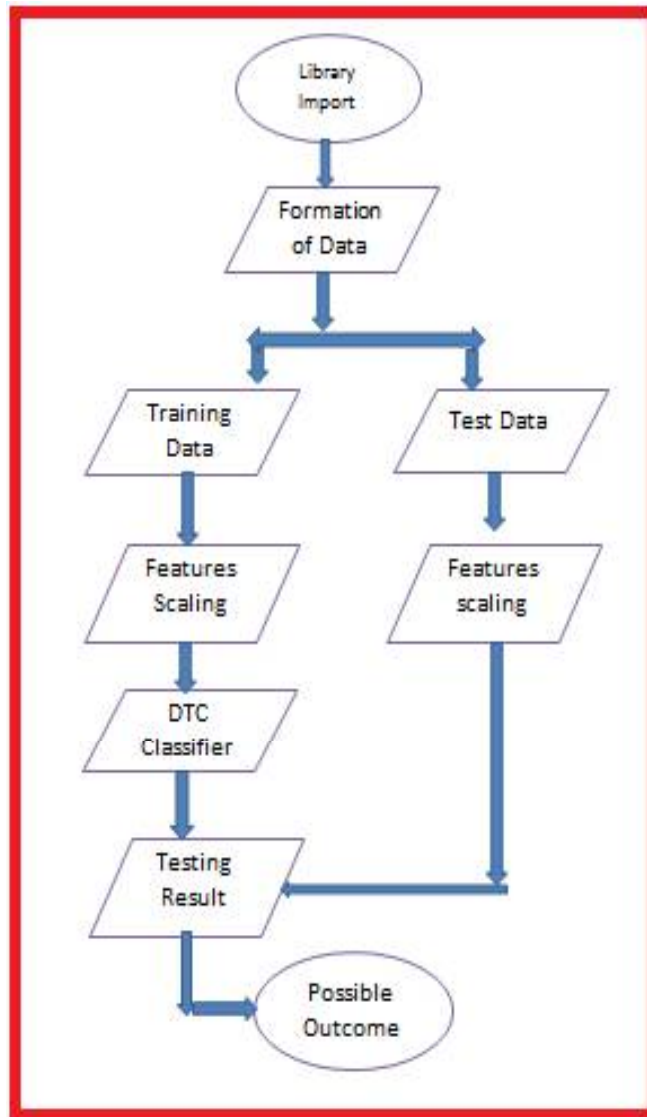


Figure 4-11 Decision tree classifier algorithm flow chart

The chapter concludes, DC motor model with stall condition and free running condition, Matlab/Simulink model of power window system, software in loop testing, current & flexi force calibration model and selection of decision tree classifier algorithm. The next, result and discussion chapter explain various system results.