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A NOVEL APPROACH TO DEVELOP ECU BASED AUTOMOBILE STARTING SYSTEM USING LAB VIEW FOR SAFE AND RELIABLE START

Murugesan V. M.[1], Chandramohan G.[2], Senthil Kumar M.[3], Rudramoorthy R.[4], Ashok Kumar L.[5], Suresh Kumar R.[1], Basha D.[1] and Vishnu Murthy K.[5]
[1]Department of Automobile Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India
[2] Karpagam College of Engineering, Coimbatore, Tamil Nadu, India
[3]Department of Mechanical Engineering, PSG College of Technology ,Coimbatore, Tamil Nadu, India
[4] PSG College of Technology, Coimbatore, Tamil Nadu, India
[5]Department of Electrical and Electronics Engineering PSG College of Technology, Coimbatore, Tamil Nadu, India
E-Mail: covaimurugesanvm@yahoo.com

ABSTRACT

Engine start is a very crucial phase in the operation of automotive engines and the starter motor plays a vital role in this short transient period. The quality of engine start influences emission and also the drivability of the vehicle. If a fault occurs with the starter motor, the engine cannot be run, especially in emergency vehicles like Ambulance, Fire engine etc. Starter motor faults cause some other faults. However, a complete exhaustive model of the combined engine starter system has not appeared to date in open literature. As a typical mechanical and electric device relating to efficiency, safety to passenger, car and starter reliability, starting system based on integrated control method by electronic control unit (ECU) and software based monitoring system is the right solution. This paper discusses MATLAB/SIMULINK R2007b based approach to develop an electronic control unit for starting system to reduce the internal resistance of the battery due to overloading, failure of mechanical components of starter motor and pitting of electrical contacts of solenoid switch and LabVIEW based condition monitoring of automobile starting system has been developed for implementation on the light duty vehicles. This technique is effective in detection of battery open circuit voltage, for reliable start and increased service life of both battery and starter motor, and also for safety of vehicle and passengers, conditions of seat belt and gear neutral positions are verified before cranking the engine. The ECU based starting system has potential to be used for real time condition monitoring and fault diagnosis of vehicles with the help of industrial computers.

Keywords: automobile starting system, medium duty vehicle, cranking, electronic control unit, labview, solenoid switch, DAQ.

1. INTRODUCTION

Starter is the key element of an automotive starting system which converts electrical energy of the battery into mechanical energy to start the engine. The quality of engine start influences emission and also the drivability of the vehicle. The starter motor plays a vital role in this short transient period. The main function of the starter system is to supply cranking torque to the crankshaft of the internal combustion engine until a sustainable RPM is achieved due to consecutive robust engine combustion events. The starter motor must at all times be ready to crank the engine, and during the course of its life must successfully complete thousands of starting operations. The torque generated by the starter motor is amplified through two or three stages of gear reduction so as to be capable of cranking the engine shaft from zero to around 200 RPM [1]. The cranking torque provided by the starter motor is a linear or quadratic function (depending on the stator winding configuration) of the current flowing through the rotor winding of the starter motor. In order to protect the starter system from damage due to high (transient) engine RPM, a roller one-way clutch (OWC) is introduced. In older or heavy-duty applications, a conventional gear reduction scheme may be adopted instead. As high density magnets are readily available today, the Permanent Magnet motor is more common. It makes the starter system compact with very high torque capability [1]. But in many cases, because of improper starter mounting, switching or lack of maintenance, etc., teeth of the two gears may not mesh properly and even impact each other. Improper mesh or violent impact can induce unstable, high transient forces and torques during starting, therefore, failures or troubles such as gear teeth flake off, meshing harness, tightly meshing, overrunning clutch failure, armature failure, drive end housing fracture, etc. are common in application after a certain period of service time. The drive end housing fracture which can be avoided by using power electronics and electronic controller unit.

Taking a passenger car which is mainly operated in town traffic, this can equate to about 2000 engine starts per year for an average annual mileage of 15,000 km (10,000 miles) [2-3]. The average starter motor has a service life, which is roughly the same as the engine to which it is mounted. The faults occurred on the starting system is not only the result of motor. The other elements and materials used in the starting system can be the reason of the faults [4]. The battery open circuit voltage, cranking speed are the main factors affecting the performance of the starting system and conditions like gear neutral position, seat belt locked position determines the safety of the vehicle and passengers at the time of cranking the engine.

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In this study, the state-of-charge of the battery of medium duty vehicle was measured by using battery tester and the value of peak current during cranking was measured with respect to state-of-charge of the battery. In addition, the conditions like gear neutral position, seat belt locked position are ensured for the safety of the vehicle and passengers at the time of cranking the engine. Based on the experimental results, a MATLAB simulation model of the starting system is developed and the results are compared. The simulated results are used for the development of electronic controlled unit for the medium duty vehicle.

Starter motor tests are conducted as per SAEJ 542 to measure electrical parameters and mechanical parameters of various starter engine combinations [5]. MATLAB/SIMULINK R2007b is used for modeling and simulation of starting system operation to design electronic control unit.

2. CONVENTIONAL STARTING SYSTEM

Automobile starter motor is a dc series electric motor or dc permanent magnet series motor. A drive mechanism couples the shaft through the pinion and flywheel ring gear to the engine crank shaft. Starter motor design, cranking ratios (pinion to ring gear ratios in which the ring gear has typically approximately 130 teeth (103 to 144 on passenger cars, 110 to 160 on commercial vehicles) and the starter pinion has typically 10 teeth (8 to 10 in passenger cars, 9 to 13 in commercial vehicles) [6] and battery performance are used to match the motor torque-speed characteristics to engine requirements. The advantage of using this motor, which has high starting torque (torque is proportional to square of current). Since it draws high current from the battery it influences the battery life.

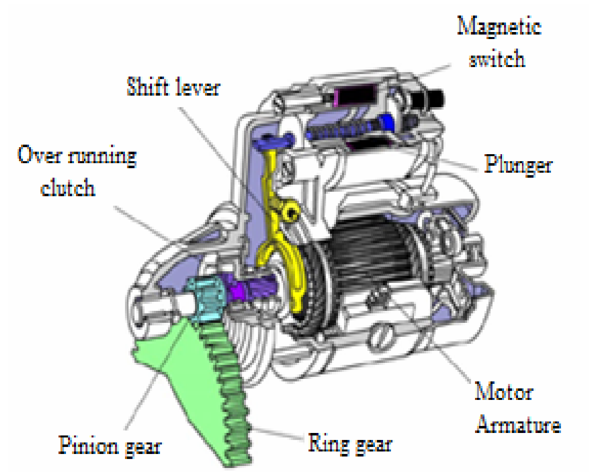

Figure-1. Automobile starter motor

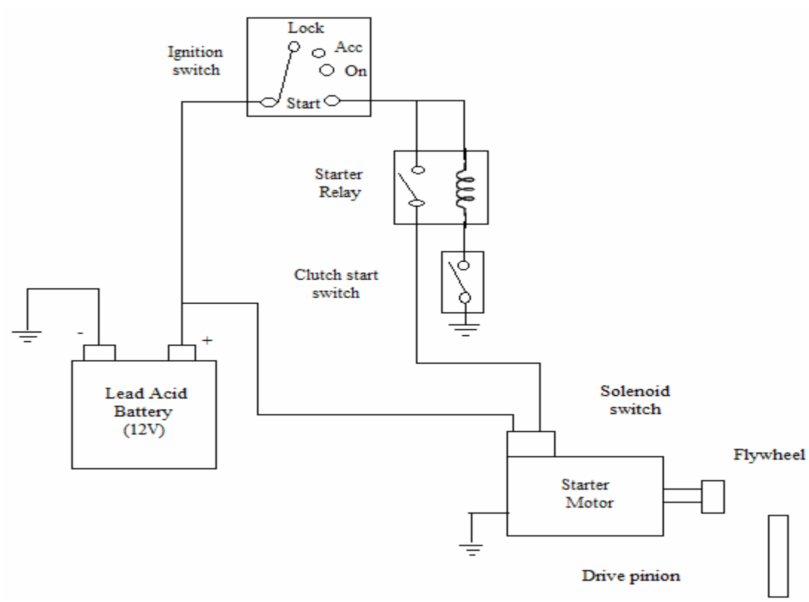

Figure-2. Automotive starting system.

The starter control circuit includes assistant control circuit and primary control circuit.

(a) Assistant control circuit

In starter solenoid switch, the magnetic field needed to start the sliding plunger moving is stronger than that needed to keep it engaged. If we had one coil for both jobs, the amount of current needed to generate sufficient magnetism to move the sliding plunger would be more than that is necessary to merely keep it in place. This would be a waste of energy, heat, and vital cranking amps that the battery is better spending on the starter motor itself. An improved solution would be to have a powerful electromagnet to get the sliding plunger moving, and then

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use a smaller electromagnet once the sliding plunger is in place (two coils of equal ampere-turns would also work). When starter relay is turned on, the exciter cable feeds both coils with battery voltage at the same time. To energize both circuits, the hold-in coil is grounded through the solenoid casing while the pull-in coil receives a ground path through starter motor windings. The combined force of both coils moves the sliding plunger in place; as the starter motor switch contacts close, the pull-in coil has done its job and can now be disconnected. It can be seen that once the contacts close, battery voltage is supplied not only to starter motor but also now to the ground side of pull-in coil. Since the pull-in coil is already being supplied with battery voltage from the starter relay, the potential difference across the coil drops to almost 0 V, which cancels any electric current and subsequently any electromagnetism the coil once had. On the other hand, the hold-in coil's operation is much simpler. Having a permanent connection to ground, from the moment a start command is given, the coil remains fully energized until the start command is released. This way the coil is always ready to hold the sliding plunger whenever the pull-in coil is disconnected. That's how it works. When ignition switch ST is turned off, starter relay will stop working and the starter motor switch contacts are disconnected with starter motor switch disk. Magnetism of pull-in coil and that of hold-in coil are counteracted with each other. Therefore, the starter circuit is shut off.

(b) Primary control circuit

When starter solenoid switch is turned on, the combining electromagnetic force of pull-in coil and hold-in coil switches on the primary control circuit of starter. Therefore, starter motor produces electromagnetic torque and starts engine [7].

3. PHASES OF STARTING

The torque delivered by the starter is highest when first switched from standstill and decreases continuously as speed increases. The surplus torque provided by the starter motor at the beginning of the starting sequence initially overcomes the static friction in the engine bearing surfaces (breakaway) and then accelerates the moving masses in the engine and ancillaries to the turnover speed. This is characterized by the intersection of the engine and starter torque curves at higher speeds, the starter-motor torque are no longer sufficient to continue driving the engine. The turnover speed must therefore be higher than minimum cranking speed for successful start.

4. STARTER MOTOR CHARACTERSTICS

The following set of curves shown in Figure-3 describe the performance of typical starter motor used. The torque-speed curve is governed by the volt-ampere charecteristic appearing at the motor terminals under load (i.e., the battery, cables, contacts and return circuit). Since it is a series motor, torque is proportional to motor current while speed is function of the voltage applied to the motor. According to the values of variables, the status of the motot is diagnosod by the help of the performance graph [8].

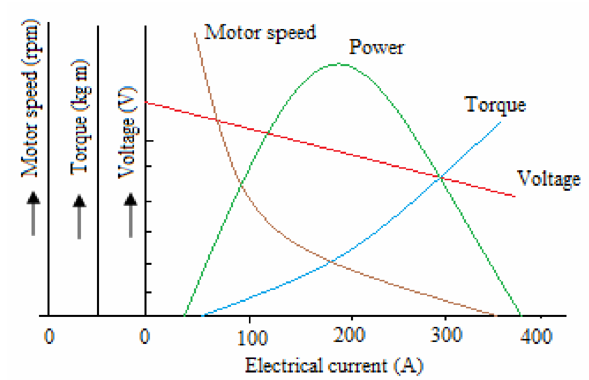

Figure-3. Starter motor: Torque- speed characteristics.

5. ENGAGEMENT RELAY SWITCH

Relays are used to switch a high current by means of relatively low control current. The starter current can be as high as 1500 A on light duty vehicles and as much as 2500 A on commercial vehicles. As contacts for current of this level are heavily loaded, the use of a power relay is an absolute requirement. The relay is actuated by a relatively low control current (relay current) of approximately 30 A for light vehicles and up to 80 A in commercial vehicles. A simple mechanical switch (ignition /starting switch, starter button) or a mini - relay operated by the engine control unit can then be used to switch the engine on [6].

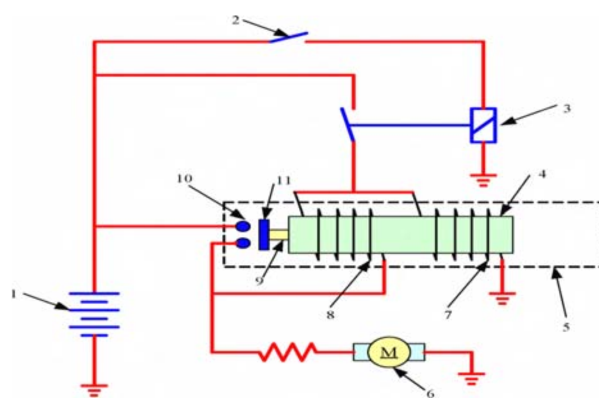

Figure-4. Traditional starter control structure.
1. Battery, 2. Ignition switch, 3. Starter relay, 4. Solenoid, 5. Starter solenoid switch, 6. Starter motor, 7. Hold-in coil, 8. Pull-in coil, 9. Sliding plunger, 10. Starter motor switch contact, 11. Starter motor switch disk.

The traditional vehicle starter control method is mechanical and electric control, i.e., ignition switch controls starter relay and the latter controls starter motor. As shown in Figure-4 the control components of starter include ignition switch, starter relay, and starter solenoid switch integrated with starter motor. The traditional starter

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control circuit includes assistant control circuit and primary control circuit [7].

6. PROBLEMS IN CONVENTIONAL STARTING SYSTEM

The mostly observed faults on starter motor and starting system are brush fault, open circuit fault (broken connection cables looses battery pole etc..) armature fault, field (excitation) and short circuit. The observed faults are as shown below (Figures 5, 6, 7, 8).

Figure-5. A. Solenoid contact arcing (pitting) fault.
B. Motor to solenoid connector warp
C. Field Winding fault.
D. Pinion teeth fault

Figure-6. Solder re-flows due to excessive heat.

Figure-7. Good solder on solenoid.

Figure-8. Damage caused by low system voltage.

7. ECU DEVELOPMENT PHASE

The detailed procedure followed to develop an electronic control unit (ECU) based starting system for safe and reliable start is given in the following flow diagram.

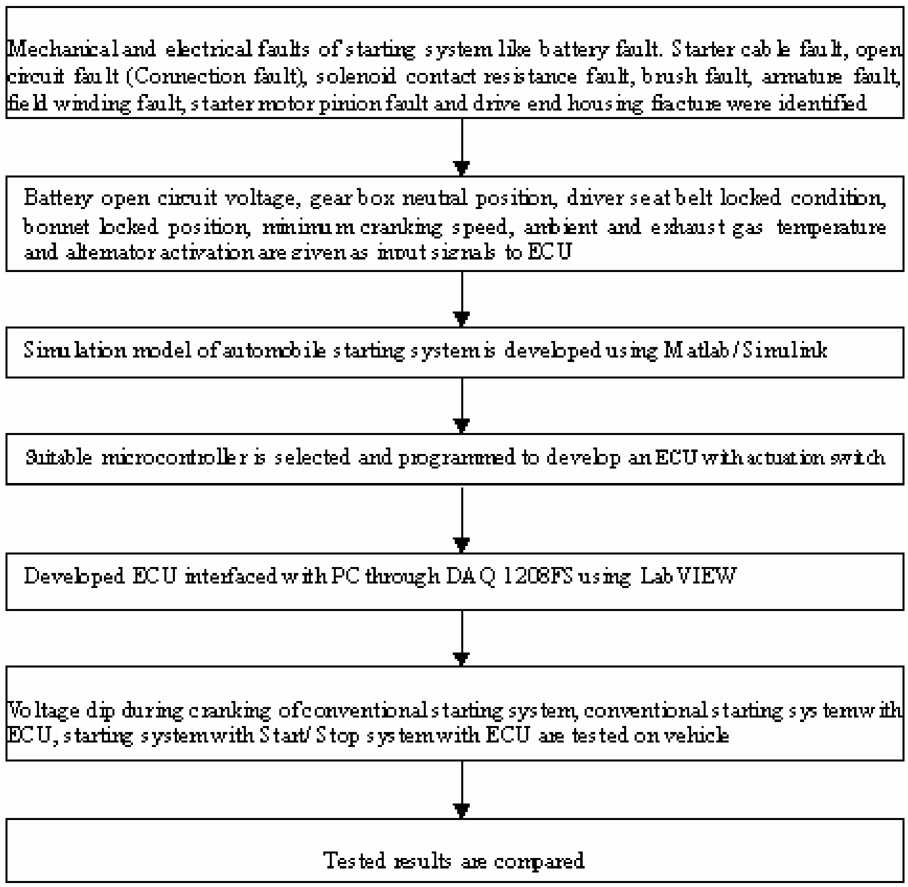

Figure-9. Flow diagram.

Based on Figure-9, the architecture of an electronic control unit based starting system for light duty vehicle is developed.

8. ARCHITECTURE OF ELECTRONIC CONTROL UNIT

The architecture of the proposed Electronic Control Unit is given below (Figure-10). The architecture consists of control unit and all the conditional parameters connected to the self motor.

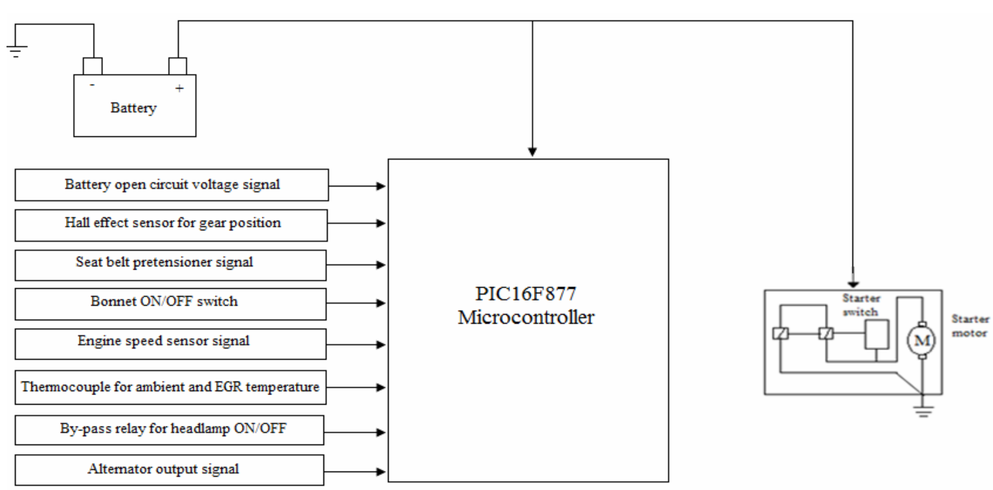

Figure-10. Architecture of electronic control unit for starting system.

To avoid overcranking (avoid meshing of strater pinion to flywheel ring gear while engine is running) alternator activation signal is considered, irrespective of driver starting behavior, cranking response should be same which reduces the pitting in hold in winding by incorporating minimum cranking time as 1s approximately [9]. Since starter motor should not run at no load condition which damages the armature, proper meshing of starter pinion gear and flywheel ring gear should be ensured. It is necessary to check the battery open circuit voltage and minimum cranking speed to reduce internal resistance of the battery. When driver locks the seat belt properly then only the ECU allow starting circuit to close the circuit and ready for cranking by verifying safety comditions like gear neutral position,bonnet locked condition,head lamp off condition to avoid overcranking.

9. ELECTRONIC CONTROL UNIT INTERFACING PHASE

The starter motor was energized by a 12-V battery, and the starter motor solenoid was controlled by an ECU. A commercially available data acquisition card (DAQ-USB 1208FS) and software (Labview) were used for sampling (Figure-11). Battery voltage were sampled and only motor current was used for analysis.

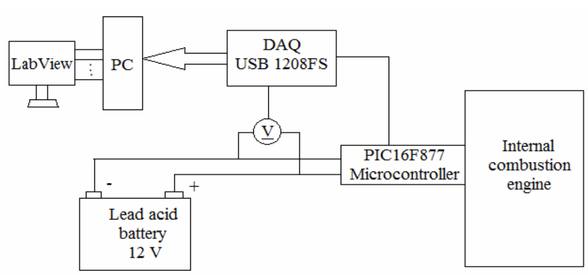

Figure-11. Block diagram of interfacing with PC.

The main components required to interface are lead acid battery, an internal combustion engine, PC installed with LabVIEW software, data acquisition card with installation software CD, Voltmeter to measure the voltage across the terminals of all monitoring conditions (battery open circuit voltage, minimum cranking speed, seat belt and gear neutral position) to ensure safe and reliable start and developed electronic control unit.

The measured voltages for interfacing with PC are given below in the table.

Table-1. Measured output voltages of individual parameters.

S. No.	Parameter	Voltage drop during cranking (V)
1	Battery voltage	12.0
2	Cranking speed	4.84
3	Gear neutral condition	4.79
4	Seat belt condition	4.82

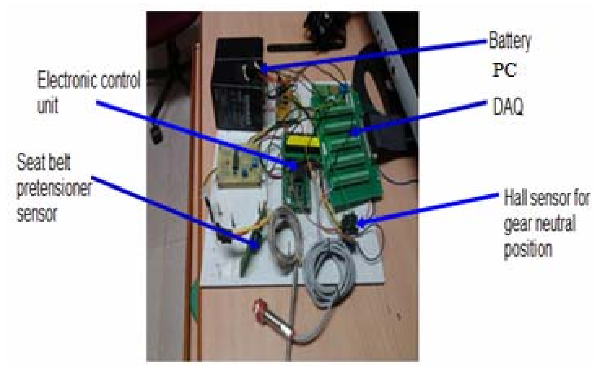

Figure-12. Experimental setup of interfacing ECU with PC.

Figure-12 is the experimental setup for interfacing hardware with PC by means of LabVIEW. As per the Block Diagram the output terminals of each parameter is connected to the DAQ USB-1208FS and is interfaced with the PC.

The output voltages of parameters like gear neutral position and seat belt locked condition were measured from ECU and the same were given as input to the DAQ which is being interfaced with PC through USB. The results obtained by simulations for LabVIEW monitoring system are shown below.

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Case-1: Gear neutral on and seat belt on.

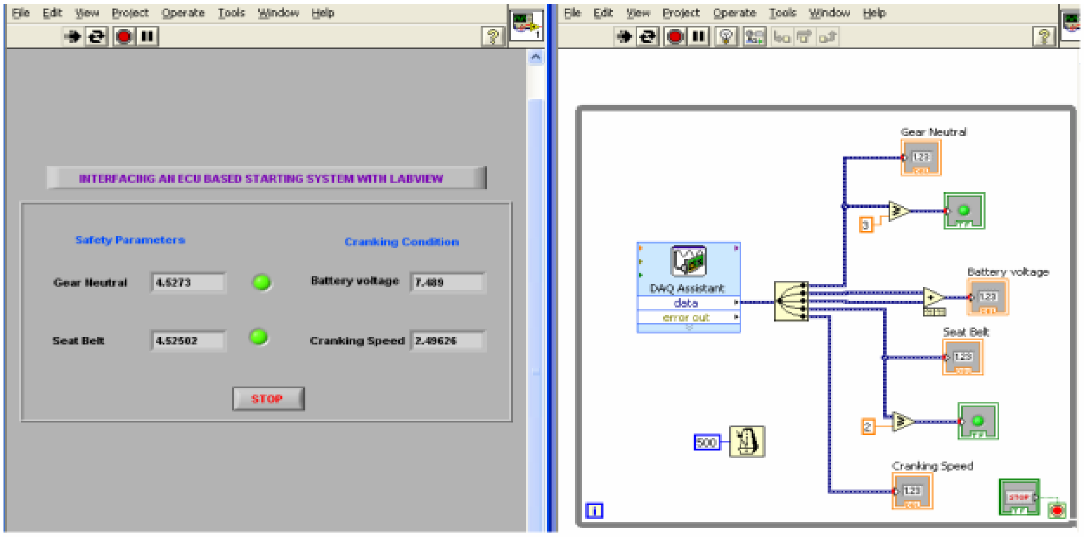

Figure-13. Gear neutral on and seat belt on.

It is found that (Figure-13) the voltage across the output terminal of gear neutral position displayed is 4.5273 V and is greater than the reference value 3 V. Hence LED is in ON position which means gear is in neutral position. Similarly, the voltage across the output terminal of seat belt displayed is 4.52502 V and is greater than the reference value 2 V. Hence LED is in ON position which means seat belt is locked. As the conditions are satisfied, ECU allows the current to flow through the starting circuit from battery.

Case-2: Gear neutral ON and seat belt OFF.

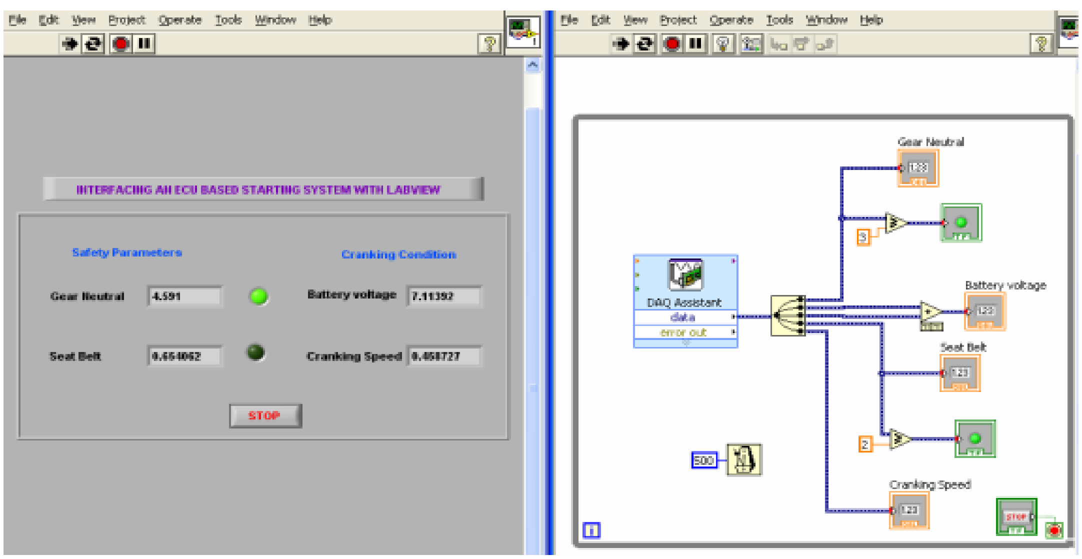

Figure-14. Gear neutral ON and seat belt OFF.

It is found that (Figure-14), the voltage across the output terminal of gear neutral position displayed is 4.591 V and is greater than the reference value 3 V. Hence LED is in ON position which means gear is in neutral position. Similarly, the voltage across the output terminal of seat belt displayed is 0.654052 V and is less than the reference value 2 V. Hence LED is in OFF position which means seat belt is unlocked. As the set conditions are not satisfied, ECU will not allow the battery to supply current to the starter motor by not closing the starting circuit.

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Case-3: Gear neutral OFF and seat belt ON.

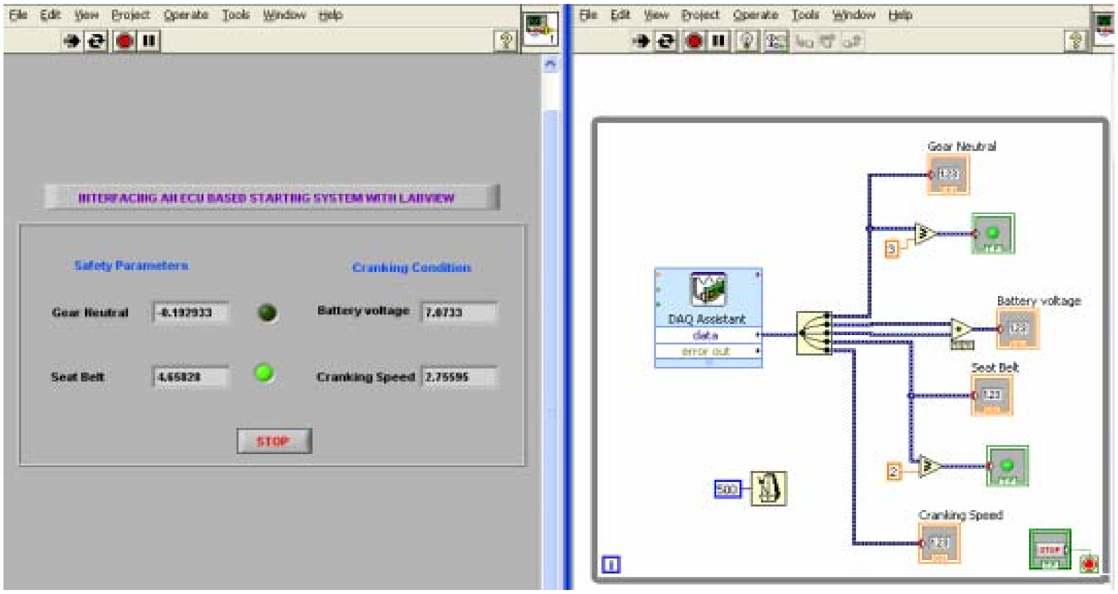

Figure-15. Gear neutral OFF and seat belt ON.

It is found that (Figure-15), the voltage across the output terminal of gear neutral position displayed is -0.192933 V and is less than the reference value 3 V. Hence LED is in OFF position which means gear is not in neutral position. Similarly, the voltage across the output terminal of seat belt displayed is 4.65828 V and is greater than the reference value 2 V. Hence LED is in ON position which means seat belt is locked. As the set conditions are not satisfied, ECU will not allow the battery to supply current to the starter motor by not closing the starting circuit.

10. EXPERIMENT CONDUCTED ON STARTING SYSTEM TO MEASURE VOLTAGE DROP

Test was conducted on TATA 407 medium duty commercial vehicle ELAK battery tester to measure voltage drop.

Table-2. Engine specifications.

Parameter type	Specification
Power	85ps@2200 rpm
Torque	95 Nm @ 1200 rpm
System voltage	12V
Fuel pump	Distributed type

Figure-16. Battery tester to measure voltage dip during cranking.

11. BOSCH FSA VEHICLE ANALYZER TEST

FSA 740 vehicle analyzer was used to measure the cranking current of medium duty vehicle at engine warm up condition. The analyzer shows the value as 347A @ 0.75 ms and reduced drastically as the back emf is generated.

12. VOLTAGE DROP DURING CRANKING

The vehicle was cranked five times with an interval of 30 s as per SAE J542 test method. No load voltage and cranking voltage of the battery were recorded.

Table-3. Measurement of voltage dips during cranking.

Number of Attempts	Battery open circuit voltage (V_{ocv})	Voltage drop during cranking (V_{dip})	Peak cranking current (A)
1	12.52	10.57	178
2	12.18	10.36	183
3	12.00	10.09	189
4	11.98	9.87	196
5	11.85	9.67	201

The Figure-17 below shows that battery voltage is decreasing during cranking and it will continue until the enegine is started. Drop in battery voltage in continuous attempt due to starting system problem will affect the life of the battery. So the designed electronic control unit will verify the starter motor pinion engagement, brush fault, open circuit fault (broken connection cables, looses battery pole etc.) armature fault, field (excitation) and short circuit then closes the battery-starter motor circuit to crank the engine, which increases the battery life as well as starter motor.

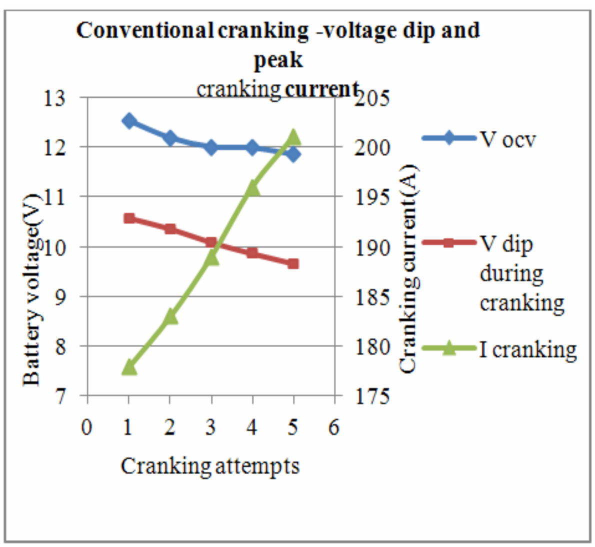

Figure-17. Voltage drop during cranking.

13. MEASUREMENT STARTER MOTOR INDUCTANCE AND RESISTANCE VALUES

Inductance and resistance of the starter motor were measured using LCR Bridge.

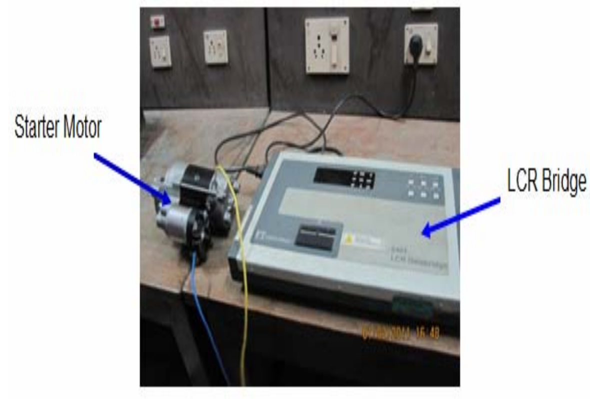

Figure-18. Measurement of inductance and resistance.

Table-4. LCR bridge test.

Vehicle	System voltage (V)	Inductance (H)	Resistance (Ω)
Force tempo traveller	12	55µ	0.04

The motor terminals without giving power supply to motor (no excitation) inductance and resistance were measured and tabulated.

14. SIMULATION OF AUTOMOBILE STARTING SYSTEM USING MATLAB/SIMULINK R2007B

Modeling and simulation of DC series motors and their applications are complex system that required a great deal of attention to the details and issues involved.

Table-5. Motor input.

Parameter type	Value
Resistance	0.04 Ω
Inductance	55 µH
Armature torque constant	7.67mNm/A
Motor inertia constant	3.92e-4 kg.m^2

The input supply of 12 V DC was given in Simulink model of ECU Based Automobile Starting System to measure armature current.

The relation between torque and current of a starter motor is given by:

$$Te = Kt\ Ia \quad (1)$$

Back Emf Equation for automotive starter motor is given by:

$$E = Ke\ \omega \quad (2)$$

The model is designed by using Matlab/ Simulink R2010a version. Input parameters of the starter motor are measured using LCR Bridge. The inductance and

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resistance were recorded. Now these parameters are assigned to the dc series motor model. The automotive starter motor model is shown in Figure-19.

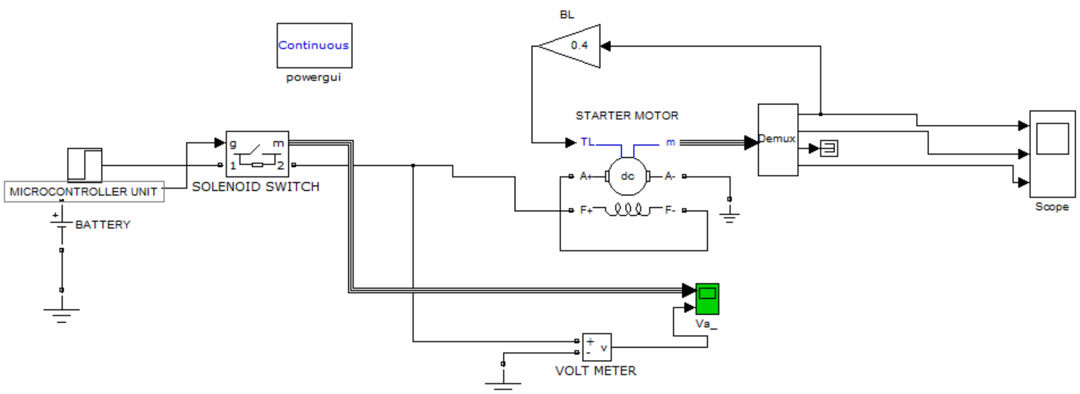
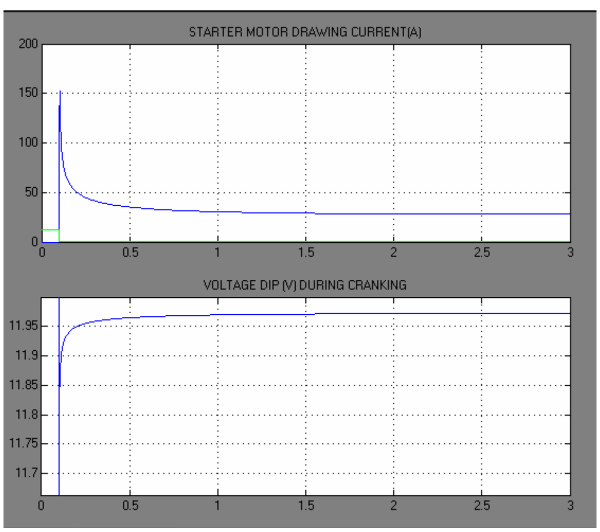
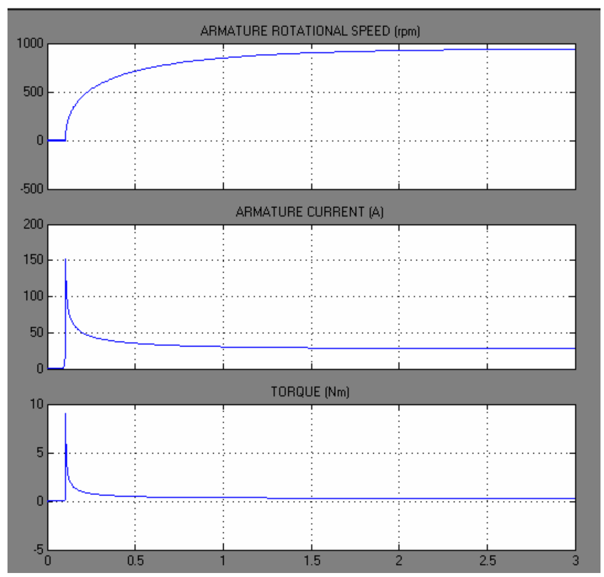


Figure-19. Simulink model of ECU based automobile starting system.

Positive terminal of battery is connected to the solenoid (ideal switch in Matlab /Simulink model) which is connected between battery and starter motor. Starter motor is a dc series motor hence field winding negative terminal F- is connected to armature positive A+ terminal. The negative terminal of armature winding A- is connected to the battery negative terminal. Continuous power guide tool box is used to run the Simulink model for Simpower systems. Step response of 3s is given by the microcontroller for ideal switch. Torque gain constant and motor inertia constant values for starter motor is given to dc motor model, these values are taken from the literature survey.



(a)



(b)

Figure-20. (a) and (b) starter motor simulation for maruthi 800 vehicle.

Simulation is run for 3s and the Simulink oscilloscope readings are plotted. Resistance and inductance are given to the motor model. Figure-20 shows the battery voltage dip from 12 V to 11.7 V at 10 ms while the armature speed increases exponentially from 0 to 800 rpm and the peak current is achieved at 100 ms which varies from 0 to 150 A and peak torque is 8 Nm at the same time.

15. MEASUREMENT OF VOLTAGE DIP AND PEAK CRANKING CURRENT WITH DEVELOPED ECU

The developed ECU was fitted in a vehicle; five consecutive cranking attempts were made to measure voltage dip and cranking current and tabulated as below.

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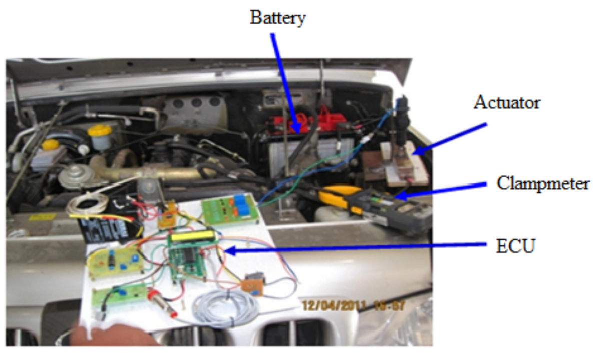

Figure-21. Cranking with ECU-measuring voltage dip and peak cranking current.

Table-6. Battery open circuit voltage, voltage dip and peak cranking current- using electronic control unit.

Cranking attempt	**Open circuit voltage** (V)	**Voltage dip while cranking** (V)	**Peak cranking current** (A)
1	13.0	10.5	222
2	12.7	10.2	236
3	12.1	9.9	241
4	11.9	9.5	320
5	11.7	9.2	340

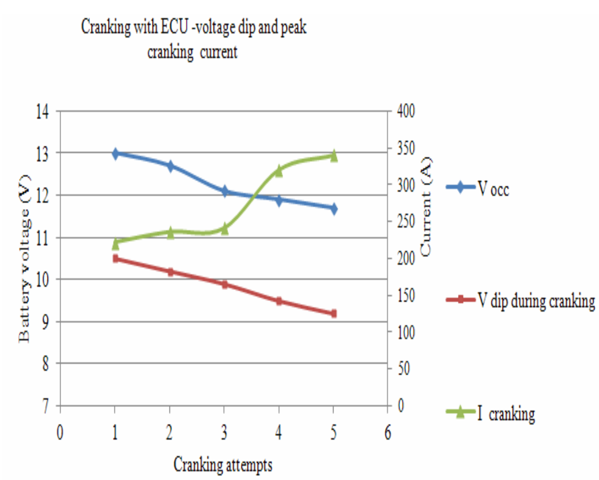

Figure-22. Cranking with ECU- voltage dip and peak current measurement plot.

This shows that during cranking, open circuit voltage of the battery drops (voltage dip) and peak cranking current is increased as like conventional starting system. Even though the driver behavior in holding the starter switch differs, this system will ensure the solenoid contact in closed condition for set time.

16. EXPERIMENTAL SET UP

The developed ECU was tested with a vehicle and the cranking current drawn by the starter motor at different attempts were recorded as below:

Table-7. Measurement of cranking current with ECU and without ECU during starting.

Number of Attempts	**Peak current during cranking** (A)	
	Without ECU	With ECU
1	176	222
2	205	236
3	230	241
4	300	320
5	317	340

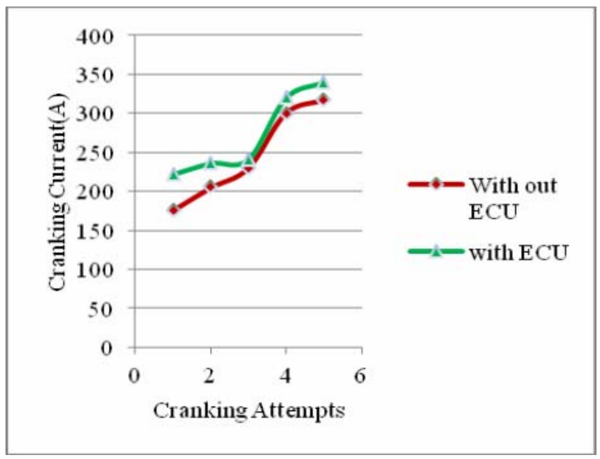

Figure-23. Cranking current during starting.

The Figure-23 shows that the current drawn by the starter motor is increased when ECU is connected in the starting circuit.

Hence the sufficient torque is developed by the starter motor by checking the. Battery voltage conditon, Gear box neutral position, Seat belt closed conditon, Bonnet closed/open condition, Proper meshing of engine flywheel ring gear and starter motor pinion, optimum cranking speed, ambient and exhaust gas temperature during cranking and alternator activation.

Since the cranking current during staring the engine with ECU is greater,the torque developed will be sufficient to start the engine without overloading the battery, therefore it improves the battery life by reducing its internal resistance.

17. CRANKING WITH START/ STOP SYSTEM - MEASURING VOLTAGE DIP AND PEAK CRANKING CURRENT

Hardware model is derived from the Mahindra Start/ Stop (Micro Hybrid) system. Similar to the

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conventional cranking, voltage dip and cranking current were measured on Mahindra Bolero Sle Micro Hybrid vehicle.

Conditions Checked By the Start/Stop System:

a) The gear selector rod is pushed to neutral position, bonnet switch is checked for its closing condition and the start stop switch position is moved to position '1'(actuated condition), then clutch pedal is pressed now the engine starts cranking.
b) Multimeter is connected across the battery positive and negative terminals.
c) Clamp meter is positioned around the starter cable and cranking current is measured.

The tests are conducted in such a way that theengine runs for 10s at idle condition then it will be stalled automatically. The same test was repeated five times.

Table-8. Battery open circuit voltage, voltage dip and peak cranking current- using electronic control unit.

Cranking attempt	**Open circuit voltage** (V)	**Voltage dip while cranking** (V)	**Peak cranking current** (A)
1	13.0	10.3	188
2	12.8	10.1	191
3	12.3	9.8	199
4	12.0	9.4	207
5	11.8	9.0	217

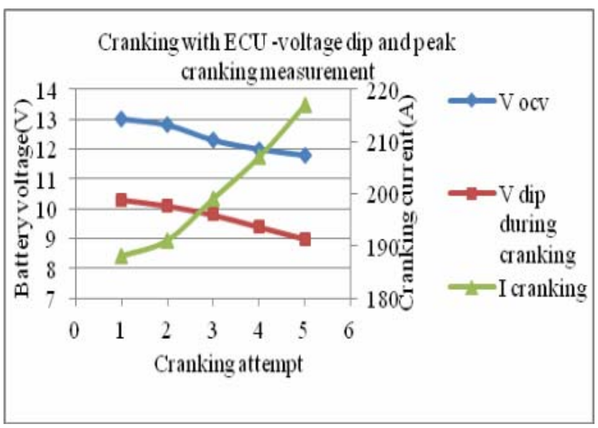

Figure-24. Cranking with start/ stop - voltage dip and peak current measurement plot.

Battery open circuit (V_{ocv}), voltage dip during cranking (V_{dip}) and peak cranking current ($I_{cranking}$) were plotted in Figure-24. This shows that during cranking, open circuit voltage of the battery drops (voltage dip) and peak cranking current is increased as like conventional cranking system. It checks gear neutral position, bonnet switch condition and dash board option switch in closed condition. The clutch pedal is pressed to start the engine. It doesn't allow the engine to run at idle speed beyond 10 seconds.

18. COMPARISON OF VOLTAGE DIP AND PEAK CRANKING CURRENT OF CONVENTIONAL STARTING SYSTEM AND CONVENTIONAL STARTING SYSTEM WITH ECU

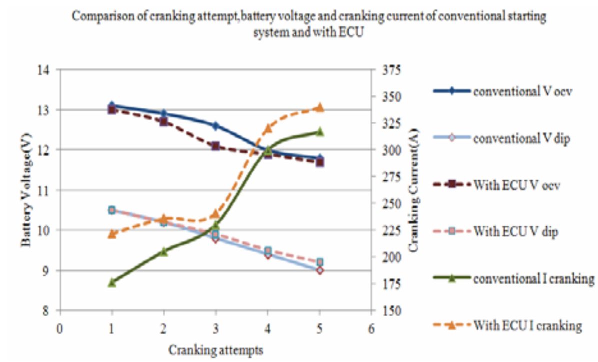

Figure-25. Comparison of cranking attempt, battery voltage and cranking current of conventional starting system and with ECU.

From the above graph it is found that peak cranking current of conventional starting system with electronic control unit (ECU) is slightly higher, since, battery power is effectively used in triggered time, the torque developed by the starter motor is higher.

19. RESULTS AND DISCUSSIONS

Starter motor failure components of Lucas TVS, Bosch, Visteon and Valeo brands have been collected for light duty, medium duty and heavy duty vehicles and reasons for various electrical failures were studied. It is found that the main cause for these failures due to uncontrolled current supply to the solenoid switch of the starter motor. The proposed electronic control unit will verify the conditions of the battery, meshing of the starter motor pinion and fly wheel ring gear, defined time interval between two consecutive starts to prevent high discharge of battery current to improve battery life and reducing cold starting emission by not allowing engine to crank at rich mixture if there is any problem with starting system. It also checks the gear neutral position, seat belt locked conditon for safety of the vehicle and passenger. The peak starting current of 327 A was measured expermentally using Bosch FSA vehicle analyzer. The inductance and resistance of the starter motor were measured using LCR bridge and the same were used to model starting system using MatlabSimulink R2007b. From the simulation it is found that the peak current of 300 A is almost matches with the experimental results. Based on this value the electronic controlled unit was developed and the same is tested on light and medium duty vehicle. The developed electronic controlled unit was tested on a medium duty vehicle with conventional starting system and a vehicle employed with Start/Stop system. From the experiment it is inferred that current drawn by the starter motor is increased when ECU is connected in the starting circuit. Hence the sufficient toruqe is developed by the starter motor thereby it reduces the internal resistance of the battery and improves its life. Since ECU verifies the gear neutral position and seat belt locked condition before starting the engine, it enhances safety to the vehicle and passenger. In future, the developed ECU will be tested on heavy duty vehicles. A graphical user interface (GUI) software for real time condition monitoring and fault diagnosis of serial wound starter motor can be developed. It makes possible to condition monitoring and diagnose the faults in starter motor before they will occur by keeping fault records of the past occurences. This system can be used in service shops and in test department of starter motor manufacturers and also it can be used for real time condition monitoring and fault diagnosis of vehicles with the help of industrial computers.

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