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Research Article

# Design and Development of Electrical Energy Management System for Vehicle

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## Abstract

*Increasing trend of vehicle population and the challenge of meeting the stringent emission norms, it is required to improve fuel economy and help develop environmentally-friendly vehicles. On the other hand, new technologies in automotive domain contribute to a substantial increase in the electrical power consumption in vehicles. This research article deals with the design and development of Vehicle Electrical Energy Management System (VEEMS) which dynamically controls the charging voltage of the alternator and cuts off the accessory electrical loads. The challenge of maintaining the system energy in balance is met by optimal use of the battery energy based on the drive conditions and its temperature & state of charge. The VEEMS control strategy is designed identifying the deficiency zones in the typical drive cycle of the vehicle with conventional charging system. The system components were selected and modeled and the designed control strategy is implemented in MATLAB Simulink. The MATLAB Simulink models are integrated with the vehicle simulation model built using AVL ADVISOR. The vehicle model is simulated for the NEDC, FTP and DUDC drive cycles, with and without VEEMS. The results obtained from simulation indicate that the VEEMS has a potential to improve the fuel economy to the tune of 1.5-5 % in the drive cycles tested. The pay back analysis showed that the system is cost effective for the increase in fuel price. The pay back analysis showed that the system is cost effective for the increase in fuel price.*

***Keywords:*** *Vehicle, Energy management, Fuel economy, Charging control, Drive cycle*

## 1. Introduction

An ever-increasing range of leading-edge technologies emerging into the automotive market makes this one of the most exciting and dynamic manufacturing sectors in the world. The amount of electronics being designed into the modern car has grown tremendously over the years. Currently, around 90% of innovation in new cars is electronic based, with global industry analysts forecasting that by 2015 electronic content will account for 40% of the cost of a typical mid-sized car. In the domains like Power train, Chassis, Body, Infotainment & Telematics, Active & passive safety Electronics systems are used in the vehicles. To meet these value added functions the vehicle should have a good on board electrical energy generation system on board energy generator i.e. alternator should be capable of taking additional load and it should also ensures the battery charging in a good condition. The alternator in the Engine system is a continuous load on the engine. To cater the board net requirement either the size of the alternator to be increased, but increasing

The increasing the capacity is the easy way, but there are limitations like

- More parasitic loss leads to increase in fuel consumption and leads to increase in emission.
- Design of alternator becomes bulky and packaging in engine is complex.
- Thermal loss of the electrical machine increases, hence it calls for separate cooling system.

Hence electrical energy management in gaining momentum in modern automotives to cater the increasing load demand also to reduce the fuel consumption hence by meeting the stringent emission norms. In this work the electrical energy management is mainly done by optimizing the utilization of alternator and electrical accessory loads.

### *1.1 Literature Survey*

A number of researchers have studied on the energy management in vehicle and vehicle system loses and explained the concept of fuel saving by reducing the load on the engine and energy management. The European OEM's are obliged to EG443(2009) and has to ensure that the new car released by them will be the 130gm / km of $CO_2$ emission by 2015 and the same will be reduced to 95gm/ km by 2020. In terms of fuel consumption the 2015 target is approximately equivalent to 5.6 liters per 100km of gasoline and 4.9l/100 km or diesel. The 2020 target

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equates approximately to 4.1l/100 km of gasoline and 3.6l/100 km of diesel. The legislation is also for vans, but for this vehicle the limit varies i.e. the new vans should produce 175gm/km by 2017 with the target phased in from 2014 and 147 gm/km by 2020. In terms of fuel consumption is 7.5l/100 km of gasoline or 6.6 l/100 km of diesel for 2017 target. The 2020 target equates to 6.3 l/100 km of gasoline or 5.5 L/ 100 km of diesel.

Tadatoshi and Syunichi (2009) addressed the problem of reducing emission by improving fuel economy. The importance of charging management system for improving fuel economy is done by method of detecting vehicle motion and SOC of the battery. The system defined in his paper is a simple system which can be retrofitted in any vehicle. This system gives more emphasis on the regeneration technique, where the vehicle kinetic energy is converted into electrical energy and stored in battery for later use only while applying brake or decelerating the vehicle. This reduces need of extra fuel to generate electricity, thereby improving fuel economy. Moreover the technique stated by him where the battery charging while re-generation is controlled based on SOC. Since this solution provided is a stand-alone system hence the method of vehicle movement is alternatively sensed by the alternator speed which is a cost effective solution. With this technique around of fuel economy improvement of around 0.85% and the results projected around 1% for increase of load by 10A.

Meissner and Richter (2003) have provided technique for battery management, by monitoring the battery SOC and SOH. The data of battery in past and present are acquired and processed. Based on the data processed the energy available for the future is predicted which can be utilized for the energy management system to utilize battery to maximum possible extent and also considering the degradation of battery due to its use and life factor.

The battery temperature, SOC, SOH and its reserve SOC parameters are considered and algorithm is designed in such a way that the future loads are predicted and battery provides healthy cranking even after several days of use. If the actual SOC is higher than minimum SOC threshold then energy management system can utilize the stored energy. If the actual SOC is less than the minimum threshold then the system to should activate the immediate means to increase the SOC of the battery to maintain future load and cranking capability

Pickering (2004) has provided a new idea for managing electrical loads in vehicle. This invention for the user activated loads by monitoring the status of the load and the status of the source which deliver the electrical current. This system monitors the ability of source and impairs the load in order to limit the current utilized. The electrical current limitation is done based on the priority of the use of the consumer units. Then the priorities of loads are reversed once the current limitation is not observed.

The literature review reveals improving fuel economy will help in reducing the emission. Electrical energy management is one of the techniques adopted to improve fuel economy and reduce $CO_2$ emission. The technique like dynamic charge control, with regeneration, battery management and accessory load cut off are used and the gaps in these methods are identified, the system will be designed and developed to address the gaps in these methods.

## 2. Design Methodology

To design and develop Electrical energy management system for the vehicle, which will optimally manage energy and improves fuel economy of the vehicle by dynamic charge control and load cut off methods. VEEM System general architecture is designed and system components and specifications are identified. Vehicle electrical charging system components like alternator, battery and electrical loads are modeled in MATLAB Simulink. SUV vehicle model is created using AVL ADVISOR software and electrical charging system model is connected to software and tested and deficiency of the existing system and areas for improvement in the existing system are identified. Based on the identified areas of improvement, VEEMS control strategy is designed and it is modeled in MATLAB Simulink. The VEEMS control strategy model is connected to AVL ADVISOR software, the vehicle system is tested for fuel economy improvement and energy balance in simulation for NEDC, FTP and developed urban drive cycle with and without VEEMS. The controller with implemented control strategy is tested vehicle for fuel economy improvement and energy balance vehicle and the results are compared analyzed with simulated values.

## 3. System Architecture Design

To realize the electrical energy management system, the system architecture to be designed with the suitable vehicle system components as shown in figure1. The system components perform the required functions to achieve the full functional VEEMS. The system has set of input signals i.e. various vehicle parameters which are taken through sensors and switches present in vehicle system, the controller controls the electrical output of the vehicle system and electrical load on the system. In vehicles there will not be any constant energy supply, the energy is utilized for starting the engine and also for keeping the consumer electrical loads even in the engine off condition. Hence battery in the system serves a storage device and also as a buffer. Similar way the alternator is generates the output based on the change in the engine speed and load demand.

Hence to understand the system the system components are modeled and its behavior in a vehicle drive cycle can be easily studied. This will accelerate the development process and it provides a convenient way in understanding the electrical system distribution of power to the consumer loads, battery charge level and energy utilized. The system architecture designed for the SUV consists of inputs from the basic sensor and switches in the vehicle, which are interfaced to an electronic control unit which in turn will control the charging system and the accessory loads accordingly to reduce the load on the engine system and by hence the fuel consumption of the engine is reduced. The major system components for the electrical energy management are battery sensor, engine speed, vehicle speed sensor, accelerator pedal position sensor, brake pedal position sensor, ECU, alternator and accessory load cut off relay.

The selected SUV electrical and electronics architecture, APPS, BPPS, VSS and engine speed sensor are hardwired to the EMS ECU. The EMS ECU is also connected to vehicle LIN network.

The battery sensor, intelligent alternator and VEEM ECU are connected to EMS ECU via vehicle LIN network. The Battery sensors, intelligent alternator, VEEM ECU are defined as LIN slave nodes, where as the EMS ECU in the network acts as a master node in the vehicle network.

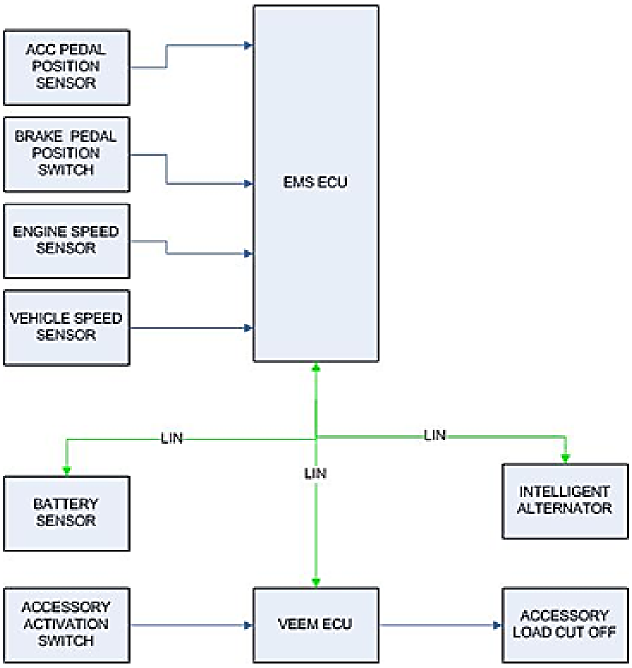

Figure 1- VEEM system architecture

Typical electrical power system of the vehicle considered is shown Figure 2. The major components of the power system are Engine, Drive train, Alternator, Battery and Electrical loads. For our study electrical system components like Alternator, Battery and Electrical loads are modeled. The power flow of the system starts from the engine, converting the fuel power to mechanical power, which is then transmitted to the clutch and transmitted to the transmission i.e. the drive train of the vehicle, based on the gear change by the driver the vehicle speed varies and power is transmitted to the wheel for the motion of the vehicle. The mechanical power comes out of the engine splits into two direction one part goes to mechanical drive train for the vehicle propulsion, whereas the other part goes to the alternator. The alternator provides electric power for the electric loads but also takes care of charging of the battery. The power flow of the battery can be positive as well as negative. When the power generated by the alternator is less than the power required by the other electrical loads, the battery supplies the shortage in the power to the loads. But alternator charges battery while normal condition driving and also the loads if the power requirement is met. The output of alternator varies with respect to the engine speed, but the engine speed changes based on the driver demand, Hence the output of the alternator changes.

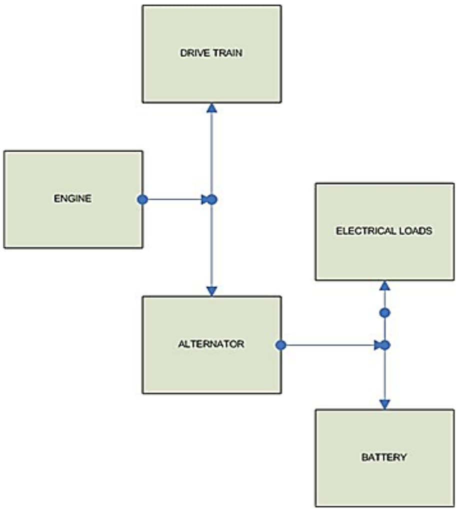

Figure 2- Vehicle system power flow

The output of the alternator varies due to change in rotor resistance. As the rotor resistance increases due to heat, then field current decreases. Hence the magnetic flux density decreases and the power generation current also decreases.

The alternator output characteristics of a typical 12V 140A alternator can be generated by

$$A(r) = 140\,(1 - e^{(-(r-800)/1000))}) \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

Torque of the machine varies with speed and load,

Torque of the machine can be determined by

$$T = (60/\,(2 * (22/7) * r)) * \eta \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

The mechanical input to the alternator is the torque needed by the alternator to overcome the magnetic pull of the rotor. The magnetic force varies with respect to the speed and the current output of the requirement of the machine. The model of the alternator is made with the concern specific type of operating scenario. The alternator model consists of two parts, the electrical machine and regulator to control the output current. Both the components are modeled as separate instances shown in figure3. The general architecture of the alternator model which is made based on the energy flow.

The voltage drop characteristics of alternator are due to the internal resistance of the machine, and variation in internal resistance of the machine due to temperature is feedback to develop the output of the machine. The output of the model can be used for the analysis of the vehicle electrical system. In the vehicle electrical system the battery acts as a chemical storage device for the electrical energy generated by the alternator. In the vehicle considered lead acid battery is used. Battery characteristics are determined by the internal chemical reactions, and these reactions are affected by the ambient temperature, the state of charge (SOC), the charge discharge rate, and charge –discharge history. Various modeling methods are used namely electrochemical model and electrical equivalent circuit model. The electrochemical model gives more accurate results, but it is very complex to model and it takes more time for simulation, therefore the electrical equivalent circuit model is adopted in this study and it is relatively accurate and efficient.

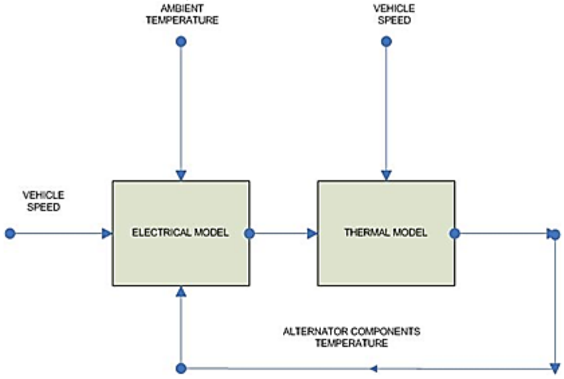

Figure 3- Alternator model

The electrical equivalent model of battery is shown in Figure 4. The open circuit voltage parameter E0 in the equivalent circuit is due to the chemical phenomenon. The R0 is the internal resistance of the battery. E0 is a function of the SOC and temperature, The OCV of the battery can be determined by the state of charge and ambient temperature

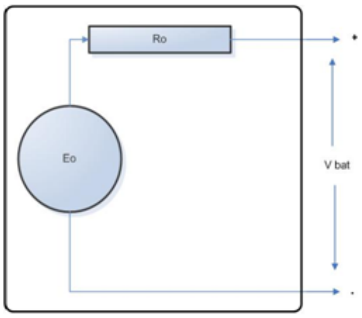

Figure 4- Battery Equivalent model

The internal resistance is highly dependent on the temperature of the battery, at low temperatures the internal resistances of battery will increases and at higher temperature the internal resistance of battery decreases. Hence internal resistance of battery is inversely proportional to the temperature of the battery. The SOC of the battery can be determined by the equation 3.

SOC = Remaining capacity / Full charged capacity……..3

SOC can also be calculated by equation 4.

$SOC = SOC_{ini} - 1/C \int [I_b\,dt]$ ……………………………4

The continuous monitoring of discharge current with respect to time the SOC of battery at any time can be easily determined by subtracting the initial SOC. Vehicle electrical consumers are the electrical loads in the vehicle, the electrical loads in the vehicles are classified based on the type of loads i.e. resistive loads, inductive loads and constant power sinks. The high power consumers in the vehicle are the resistive in nature such as heaters and lamps. The medium power consumers are the inductive loads such as motors, actuators and solenoids. The constant power sinks in the vehicle are ECU and other sensors which will draw minimum power during the drive. The electrical equivalent of the loads can be simplified into its internal equivalent resistance. The equivalent resistances of the each load are connected in parallel and final equivalent resistance is derived or actual power of the load can be fed to the load.

### *3.1Control Strategy Design and Development*

The vehicle system which consist of mechanical and electrical systems, any study on the vehicle to asses system function and performance it is a costly and time consuming exercise, hence the simulation tools are developed to assess the component and system performances in the complex system consisting of many systems. The developed system component model blocks are linked to the AVL ADVISOR software, where the SUV power train is modeled. The preliminary test of the existing system is conducted to assess the existing system components and their working nature.

The Figure 5 represents SUV drive train using components from ADVISOR. Note that most blocks have two inputs and two outputs. Each block passes and transforms a torque and speed request, and each block also passes an achievable or actual torque and speed. The top arrows, feeding left-to-right, are the torque and speed requests. The drive cycle requests or requires a given speed. Each block between the driving cycle and the torque provider, in this case the ICE then computes its required input given its required output. It does this by applying losses, speed reductions or multiplications, and its performance limits.

The “ACC “in between clutch and fuel converter is the Electrical and mechanical accessory in the ICE, The control strategy is fed to the ACC to run the Electrical accessory as per the derived logic. At the end of the line, the ‘ICE fuel converter’ uses its required torque output and speed to determine how much torque it can actually deliver and its maximum speed. Then passing information back to the left, each component determines its actual output given its actual input, using losses computed during the ‘input requirement’ pass described above. Finally, the vehicle block computes the vehicle's actual speed given the tractive force and speed Limit it receives, and uses this speed to compute acceleration for the next time step and so the cycle continues throughout the duration of the driving cycle.

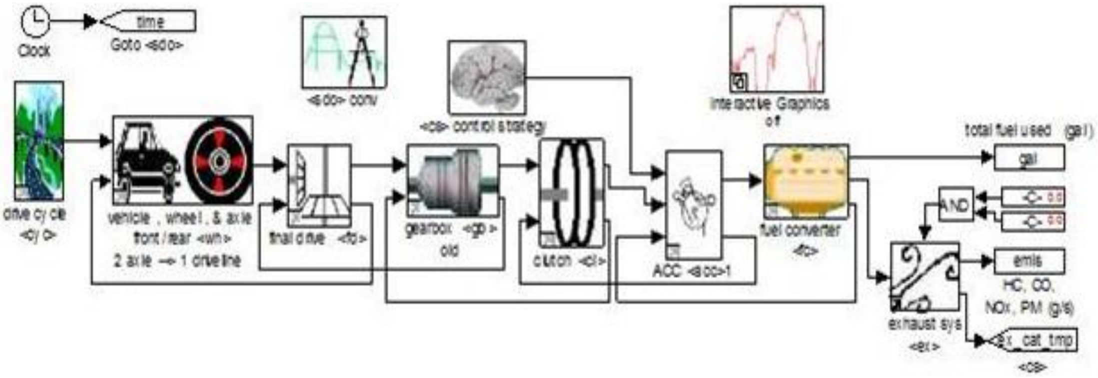

Figure 5- SUV simulation model

## 4. Conventional Charging system concept

The Electrical system in vehicle has conventional alternator, energy storage system device and electrical loads. When the vehicle is driven the alternator generates power to feed the loads L1, L2 & L3 if the switch S1, S2 & S3 are closed respectively. Then alternator charges the battery if the battery is in charged and discharged condition. If load L1 is connected then the battery charging current

$I\,b > I_{L1}$ ……………………………………………5
when battery SOC is low

$I\,b < I_{L1}$ ………………………………………………6

When battery SOC is high
Where I b & $I_{L1}$ battery charging current and load current respectively .But in both the conditions battery is charged by the alternator because the regulated voltage of the system will be always higher than the battery voltage.

$V_{reg} > V_{bat}$ ……………………………………………7

If the load L1, L2 & L3 are connected then the battery gets charged and discharged based on the alternator speed and its output. I.e. at low idling speeds of the engine

$Ig\ = (I_{L1} + I_{L2} + I_{L3}) - I_b$ ……………………………8
Where Ig is the alternator current output, in this case battery discharges at idling condition if the load is more than the generation the battery discharges. With this basic Understanding, for the given drive cycles the alternator output voltage and battery SOC is analyzed.

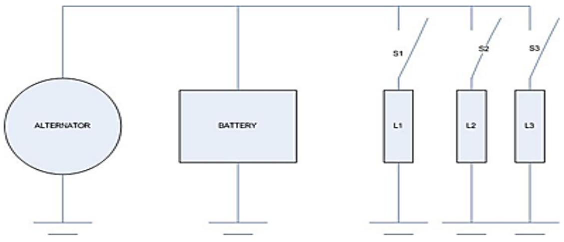

Figure 6 -Vehicle electrical system

The alternator, battery and electrical loads in the vehicle constitute the charging system in the vehicle. The component models designed and developed for the SUV is connected in the engine accessory window of the power train. Then the derived urban drive cycle is selected in the drive cycle selection menu and the vehicle is simulated to run in the derived drive cycle. As per the above convention system theory the battery charging characteristics for the given load condition and the alternator torque pattern are studied in details to identify the deficiency zones in the drive cycle obtained results are shown in figure 7.

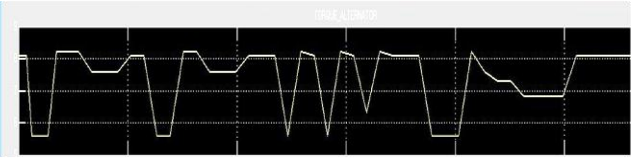

Figure 7 -Alternator Torque

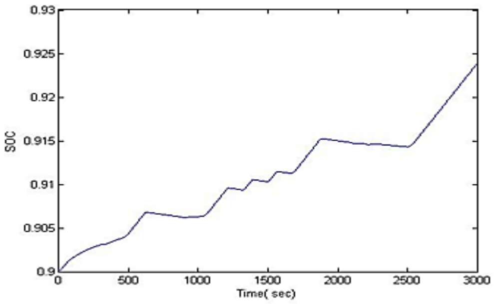

Figure 8- Battery SOC developments

### *6.1 Conventional charging system drawbacks*

The battery charging pattern shown in Figure 8, Charging of the system is irrespective of battery SOC and Battery temperature, hence continuous power consumption irrespective of the demand. Charging system consumes more power at engine low idling speeds with increase in loads the discharge will higher and no control on loads. While in acceleration phase the alternator provides sudden load on the engine. Continuous charging of the system in cruising. Mild discharging occurs during deceleration and

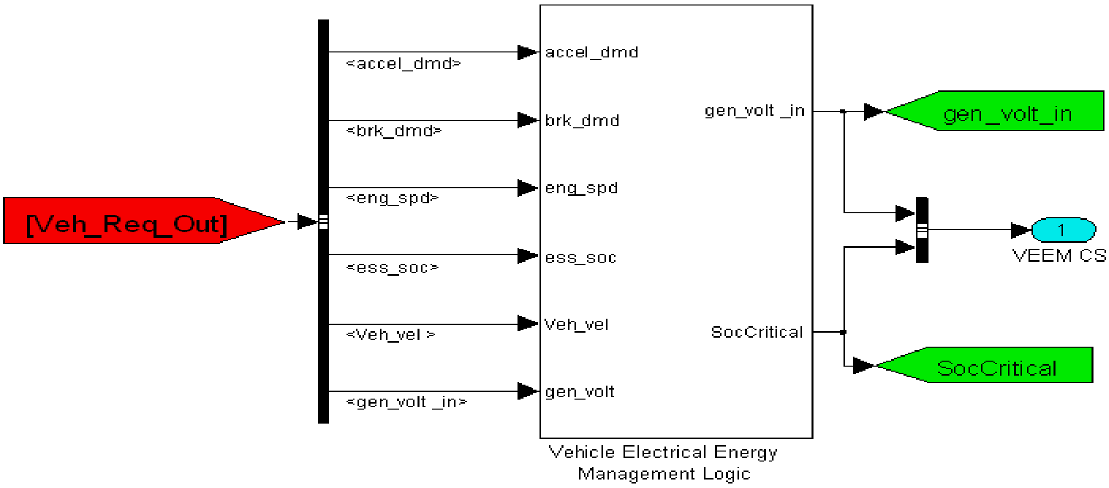

Figure 9 -VEEMS control strategy box

no value addition and power is lost in braking. Consumer loads are controlled by the user; hence the over utilization of the loads irrespective of time is high which causes load on the alternator at low and idling speeds. Charging system will always with high load in night mode of driving and very less load in the day driving hence battery is over charged. The consumer loads are not flexible with respect to charging and SOC of the battery

## 5. Control strategy design

The simulation run with the conventional charging system components shows deficiency of the system in idling, acceleration, cruise and deceleration phases, the battery charging is without any control which will lead to overcharging of battery and reduction in battery life. The load on the engine increases at low idle speeds, which will increase the fuel consumption and also the kinetic energy, is wasted in the deceleration phase. In acceleration phase sudden increase in load on engine needs more quantity of injection to produce instant boost. The system works independent of the temperature of the battery the control strategy is designed in such a way that the drawbacks found in the conventional system are properly addressed. The methods are also designed based on the reviewed literatures and specific technical methods which are not detailed in the technical papers and journals. Following control methods shown below are designed to solve the defined problem.

- Battery condition based charging
- Hot and Cold battery charging
- Speed ramp based charging
- Regeneration
- Load cut off

## 6. Alternator operating modes

To achieve the electrical energy management with dynamic charge control, it necessary to have different modes of operation of the alternator based on the battery SOC. The modes of operation of the alternator are defined based on the set voltage of the alternator. The set voltage

is the regulator setting voltage to switch on and switch of the field of the alternator to control the generation of the machine. Following modes are utilized to achieve the electrical energy management

- Generation mode
- Isolation mode
- No Generation mode
- Re-gen mode

### *6.2 Generation mode*

In generation mode of operation the alternator set point voltage is kept greater than the battery by 1.6 V, Then the alternator always keeps the system voltage 14V in order to maintain the battery charging and cater the connected loads.

### *6.3 Isolation mode*

Isolation mode of operation is the mode where the alternator is electrically isolated from the e electrical system. The set point voltage in this mode is made equal to the battery voltage; hence at this volt the alternator supplies the electrical load connected in the system. Since, at this voltage the battery will not get charged due to equi-potential of battery and alternator. Hence in this mode the charging current will be either zero or less than 0.5A. At this mode electrically battery is not connected in the charging system.

### *6.4 No-Gen mode*

No generation mode of alternator means the alternator is electrically disconnected from the charging system. The alternator is mechanically connected to the engine drive system, hence during cut-off mode the alternator will not generate power and it loads the engine system will minimal load due to the mechanical coupling of the alternator rotor. The set point voltage at cut off mode is set to a minimum value as per specification. At this voltage the alternator cannot generate the load current for the battery and connected loads, at this mode the vehicle electrical system is supported by the battery.

### *6.5 Re-gen mode*

Re-gen mode is high potential difference charging mode, where the charging current of battery increases enormously. The set point voltage of the alternator is set to maximum. Since the potential difference is more than 3V the charging current of the battery increases. At this output the torque of the machine also increases. Hence this mode to be selected during the deceleration phase, the similar type of technique is also used in hybrid vehicles.

### *6.6 Control strategy model*

The control strategy designed with different operating modes of the alternator with respect to battery SOC and the drive cycle phases. To realize the control algorithm designed it needs to be modeled to verify the effectiveness of the designed system. The control strategy is modeled in MATLAB SIMULINK shown in figure 9.

## 7. Simulation & Testing

The VEEM controller modeled in MATLAB Simulink, to be tested for its functionality in the simulation environment. The model is tested in the SUV simulated using AVL ADVISOR. The vehicle system is with and without VEEM

logic to be tested in different drive cycles like NEDC, FTP and derived urban drive cycle and the results are analyzed and discussed

### *7.1 Test conditions*

To test the system a standard drive cycles are defined and following parameters are used for evaluation. The initial parameters for the test conditions are kept constant i.e. the vehicle load fixed as 500W and Battery initial SOC as 90%. Charge balance or Energy balance of the system shown in Figure 10.

### *7.2 Fuel rate consumption*

The SUV Power train model was run in NEDC, FTP and Derived urban drive cycles shown in Figure 13.

### *7.3 Without Electrical Energy management*

The vehicle simulation is done with conventional system i.e. without electrical energy management where the battery charge balance and fuel rate consumption are recorded. The % SOC improvement in the battery the 2% increase as shown in Figure11.

Fuel consumption rate with conventional alternator without Electrical energy management.

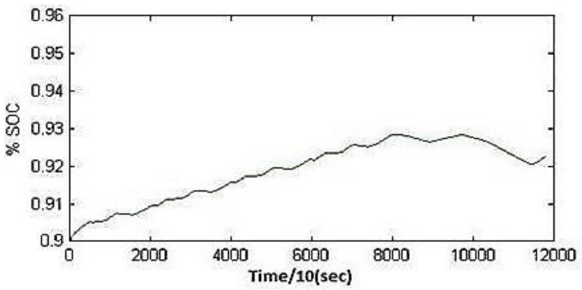

Figure 10 -SOC graph without electrical energy management-NEDC

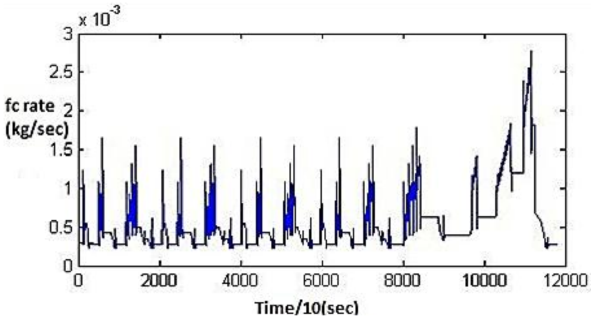

Figure 11 - fc Rate without electrical energy management-NEDC

### 7.4 With Electrical Energy Management

The battery system discharges since the control algorithm allows the system to run in the cut off mode. Hence the %SOC of the battery decreases by 0.04 shown in Figure 12.

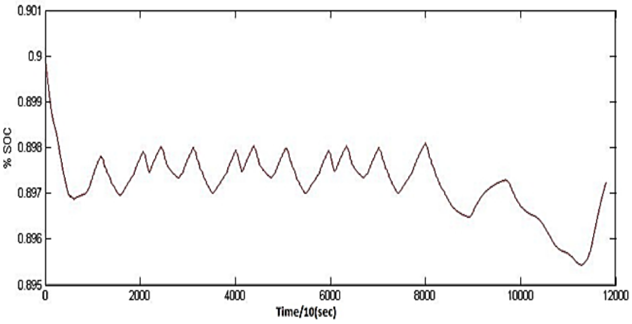

Figure 12 -SOC graph with electrical energy management-NEDC

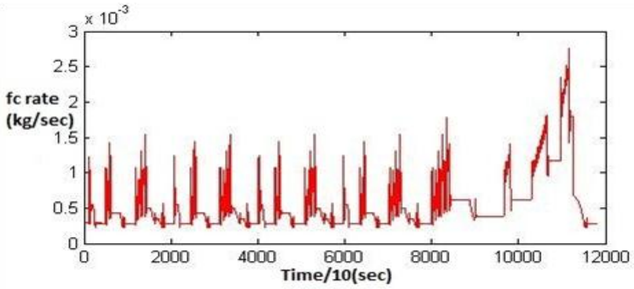

Figure 12- fc rate graph with electrical energy management-NEDC

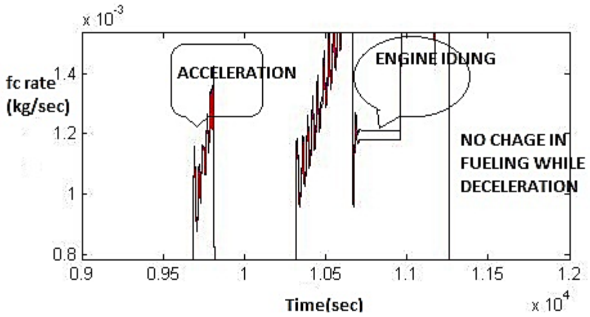

Figure 13 -fc rate comparison graph-NEDC

## 8. Result summary & Discussions

The summary of fuel economy results and Charge balance as obtained through simulation without EEM and with EEM are tabulated in Table 1 and the % fuel economy comparison of the simulated drive cycles are shown in Figure 14.

There is definite improvement in fuel economy and a minor reduction in the SOC battery, but the result varies with respect to different drive cycles. The result shows that the derived urban drive cycles provides maximum of 5.42%.

Table 1 Result Summary

| S. No. | Vehicle - control | Cycle | Mileage (km/L) | Fuel Economy (l/100km) | % SOC |
|---|---|---|---|---|---|
| 1. | Without EEM | NEDC | 9.79 | 10.21 | + 1.82 |
| 2. | | FTP | 9.29 | 10.76 | + 2.49 |
| 3. | | DUDC | 10.32 | 9.69 | + 4.24 |
| 4. | With EEM | NEDC | 10.18 | 9.82 | - 0.04 |
| 5. | | FTP | 9.48 | 10.54 | - 2.28 |
| 6. | | DUDC | 10.88 | 9.19 | - 8.02 |

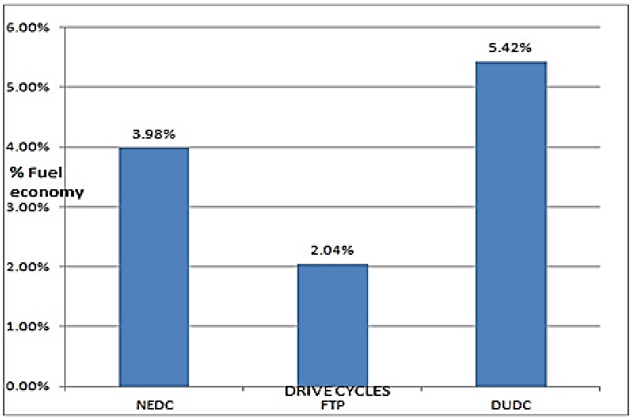

Figure 14 - %Fuel economy comparison

In NEDC, base vehicle distance covered per liter of fuel is 9.79km, the same vehicle with electrical energy management the mileage is 10.18km. There is definite mileage improvement of 3.9% with the effect of electrical energy management technology. The extrapolation of the data, base vehicle fuel consumption for 100km of drive in the similar drive pattern consumes 10.21 liters of fuel, whereas the same vehicle with electrical energy management system consumes 9.82 liters of fuel as per the simulation.

The SUV used for creating the model for simulation and testing of the VEEM system, in the same vehicle derived control strategy with the developed LIN communication table is ported in a Body Control Module (BCM). The BCM of the SUV performs the function of VEEMS. The SUV fitted with the VEEM control logic ported BCM is tested in Chassis dynamometer for the % fuel economy and charge balance. The vehicle testing is lab is performed for the NEDC. The initial conditions of the vehicle are set as per the initial conditions of the simulations. The vehicle is fitted with 90% of battery before start of test and the vehicle is loaded to 500W of electrical equivalent load. Making the initial conditions and test parameters same ensures easy co-relation of the simulation results with the actual one. The results obtained in the lab environment are analyzed and compared with the simulation results. The results obtained shows the % Fuel economy improvement with and without Electrical energy management is 1.48% and a reduction of 0.93 from the initial SOC of the battery shown in Figure 15.

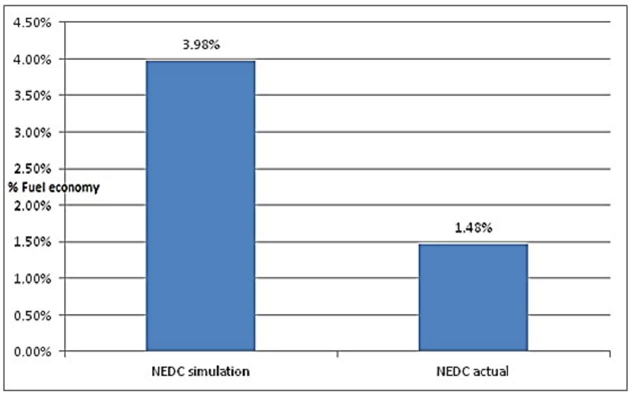

Figure 15 - % Fuel economy comparison

The benefits are realized in both the simulation and actual test, the difference between the simulation result and actual test is 2.5 for the % fuel economy and 0.89 for the % SOC reduction. This shows that the simulation models are to be tuned further in line with actual system to achieve the accurate results. But fin the actual vehicle driving conditions in road % fuel economy will be better due to drive cycle pattern which depends on city or high way and also the drive during day and night time for the change in load conditions, Hence the combination of drive pattern and load conditions will improve % fuel economy and the results will be better than the lab results.

## Conclusion

While it's imperative that hybrids and alternative fuel solutions are aggressively pursued worldwide to address the energy security and emission topics, low cost electrical energy management system solution presents a highly penetrative, realistic and effective means of controlling the urban pollution which is a challenge especially in the developing countries. Dynamic charge control and load cut off based electrical management system is easier to integrate in the vehicle than the other low voltage hybrid systems. The Electrical energy management system reduces $CO_2$ release to the atmosphere by 11.8gm/ km considering simulated values. This reduction in $CO_2$ will improve the air-quality leading to better quality of life particularly for children and future generation.

The system has to be thoroughly validated and necessary components are to be reinforced/modified (if required) before deploying the vehicles, Even though resilient challenges are to be overcome before integrating electrical energy management, it is worth to overcome those challenging considering the benefits of the system realized at a very low cost. It is possible to model the Electrical energy management system in MATLAB Simulink and run in the AVL ADVISOR and simulate the model for NEDC, FTP and Derived urban drive cycles with reasonable accuracy. The difference of simulated to actual was only 2.5, models can be further fine-tuned to achieve the same. It is possible to simulate the system with good levels of accuracy and correlate with real-world usage results. The payback period of the system is 8 months ~ 1.72 years and depends upon the usage of the vehicle in all traffic situations. Additional to the fuel economy improvement, the system offers following tangible benefits Reduction in Oil Dependency for India, Savings in Foreign Exchange, Cleaner Atmosphere

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