FUEL ECONOMY IMPROVEMENT WITH USE OF BRUSHLESS DC MOTOR IN AUTOMOTIVE RADIATOR FAN ASSEMBLY

Satish N. Ghadage[1], Jayant B. Pawar[2], Sandeep N. Gade[3], Sandeep D. Nevase [4] & Prof. Parag V. Bute.

Department of Mechanical Engineering SRTTC Pune.

---***---

Abstract - The electrical power demand in automobiles is rising steadily. Especially in luxury vehicles, due to application of new electrical systems that enhance passenger comfort and safety.

Brushless DC motor (BLDC) remains an important and fast growing motor type with many performance advantages over brushed DC motor (BDC). BLDC motors are more efficient, high-powered, silent, deliver high torque, have longer lifetime and higher speed compared to BDC motors.

The project involves replacement of BDC fan motor of cooling module with a BLDC fan motor and evaluating improvement in performance, fuel efficiency and noise, vibration and harshness of vehicle. Component level durability of BLDC motor is also checked.

Key words: Brushed DC motor (BDC), Brushless DC motor (BLDC)Introduction.

1. INTRODUCTION

The radiator fan has an important job in the engine compartment. It can push air through the radiator core or pull it through. It must cool the antifreeze that circulates through the block and head passages and reduces the engine temperature. Fan designs have specific purposes for different sized vehicles and profiles. In old vehicle engine, mounted fans are used for radiator cooling. Engine mounted fans are less effective in traffic because they pull little air when the engine rpm is low. The use of electric motors and drives that run independent of the vehicle main engine increases the efficiency and effectiveness of engine cooling. Electric radiator cooling fan usually switch on when the engine coolant reaches a set temperature. Currently permanent magnet direct current motors (PMDC) power radiator fan. PMDC motor having brushes suffers from poor efficiency and friction problems and periodic maintenance of the brushes in order to avoid the appearance of sparks. The reason for their success was the fact that it was a mature technology, widely available, cheaper and did not require complex controller. Permanent magnet brushless direct current (PMBLDC) motors are one of the motor types rapidly gaining popularity because of higher efficiency, long operating life, high dynamic response, noiseless operation, higher torque per weight ratio. Thus, automobile is undergoing a revolution in the design of its electrical system.

2. BODY OF PAPER

Aim of Project: To Improvement Fuel Economy with Use of Brushless Dc Motor in Automotive Radiator Fan Assembly.

3. PROBLEM STATEMENT

Fuel efficiency is a historical goal of automotive engineering. The government of India has proposed to introduce Corporate Average Fuel Efficiency (CAFÉ). CAFÉ norms means from April 1,2017, India will adopt CAFÉ norms which requires cars to be 30 percent or more fuel efficient from 2022 and 10 percent more between 2017 and 2021. The fuel efficiency or the improvement of the mileage will be decided based on the consumption of fuel by a vehicle to run 100kms. the introduction of CAFÉ norms is aimed at reducing the carbon emission of the automobile industry. Twenty-five years after Congress enacted the Corporate Average Fuel Economy (CAFE) standards, petroleum use in light-duty vehicles is at an all-time high. It is appropriate to ask now what CAFE has accomplished, and at what cost. This chapter begins by addressing energy and CAFE: What is the current rationale for fuel economy standards? How have vehicles changed, in particular in regard to fuel economy? What is the impact on oil consumption? The first section addresses a series of questions the committee was asked about the impact of CAFE. The second section explores the impact of CAFE on the automotive industry, the final section reviews the impact on safety. To understand how the fuel economy of passenger vehicles can be increased, one must consider the vehicle as a system. High fuel economy is only one of many vehicle attributes that may be desirable to consumers. Vehicle performance, handling, safety, comfort, reliability, passenger and load-carrying capacity, size, styling, quietness, and costs are also important features. Governmental regulations require vehicles to meet increasingly stringent requirements, such as reduced exhaust emissions and enhanced safety features. Ultimately, these requirements influence final vehicle design. Technology content and-the subject of this report-fuel economy. Manufacturers must assess trade-offs among these sometimes-conflicting characteristics to produce vehicles that consumers find appealing and affordable.

Engines that bum gasoline or diesel fuel propel almost all passenger cars and light-duty trucks. About two-thirds of the available energy in the fuel is rejected as heat in the exhaust and coolant or frictional losses. The remainder is transformed into mechanical energy, or work. Some of the work is used to overcome frictional losses in the transmission and other parts of the drive train and to operate the vehicle accessories (air conditioning, alternator/generator, and so on).

In addition, standby losses occur to overcome engine friction and cooling when the engine is idling or the vehicle is decelerating. As a result, only about 12 to 20 percent of the original energy contained in the fuel is actually used to propel the vehicle. This propulsion energy overcomes inertia when accelerating or climbing hills, the resistance of the air to the vehicle motion (aerodynamic drag), and the rolling resistance of the tires on the road. Consequently, there are two general ways to reduce vehicle fuel consumption: increase the overall efficiency of the powertrain (engine, transmission, final drive) in order to deliver more work from the fuel consumed or reduce the required work (weight, aerodynamics, rolling resistance concepts are illustrated in figures

4. CURRENT CONDITION

BRUSHED MOTORS

Direct current electrical motors function through the creation of magnetic fields whose attraction and opposition keeps a central rotor turning. In a brushed motor, fixed magnets are placed on either side of a rotating electromagnet, one oriented to a positive pole, the other to a negative one. The electromagnet is formed by a series of coils (usually three placed at equidistant points around the rotor) called the commutator. When electricity is passed through these coils, they generate their own magnetic field that is repelled and attracted to the magnetic fields generated by the fixed magnets. Current is transferred to the coils of the commutator by metallic brushes, which rotate along with the rotor. When the motor is switched on, current is passed to the electromagnets whose magnetic fields are repelled by one fixed magnet and attracted to another, causing the rotor to turn. As the rotor turns, the metallic brushes come into and out of contact with each coil in series so the opposition and attraction between the resulting magnetic fields and the fields of the static magnets keeps the electromagnet turning.

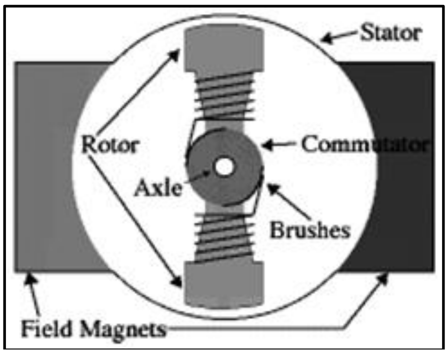


Fig. 4.1: Brushed DC motor.

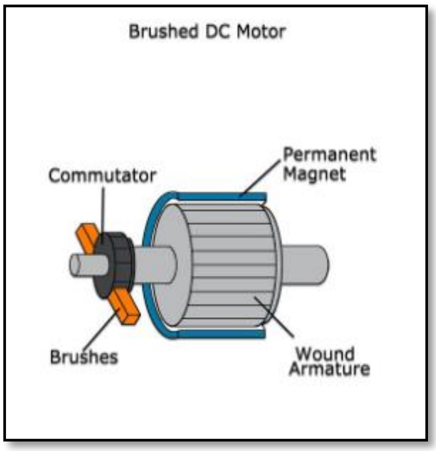


Fig. 4.2: Brushed DC motor.

5. PROPOSED CONDITION

BRUSHLESS DC MOTOR

In a brushless DC motor, the positions of the fixed magnets and the electro-magnetized coils are reversed. The fixed magnets are now placed on the rotor and the coils are placed in the surrounding casing. The motor functions via current being passed through each surrounding coil in series, so repulsing and attracting the fields of the fixed magnets and keeping the rotor they are attached to turning. For a motor of this kind to work, the coils of the commutator need to be kept synchronized with the `` magnets so that the fields are continually in opposition and the rotor is kept turning. This requires an electronic controller or microprocessor to coordinate the application of current to each electromagnetic coil

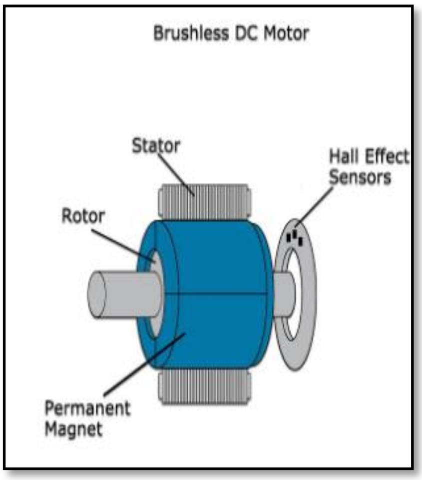


Fig. 5.1: Brushless DC motor

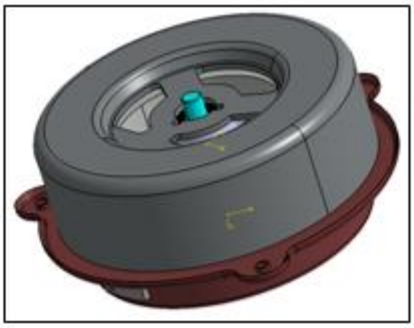


Fig. 5.2: Assembled brushless DC motor.

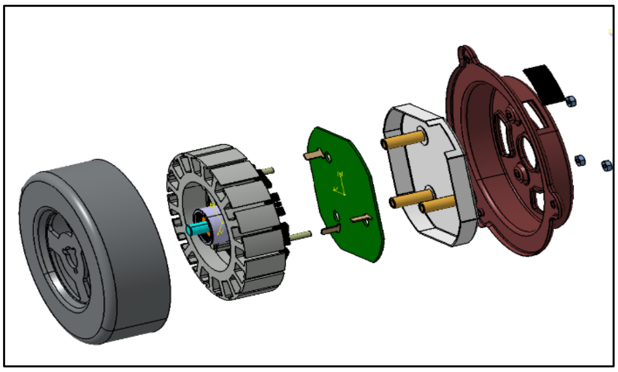


Fig. 5.2: Exploded view of Brushless DC motor

6. DIFFRENCEBETWEEN BRUSHLESS & BRUSHED MOTOR

Feature	BLDC Motor	Brushed DC Motor
Commutation	Electronic commutation	Mechanical brushes and Commutator
Efficiency	High (Voltage drop on electronic device is smaller than that on brushes)	Moderate
Maintenance	Little/None	Periodic/limited brush life
Thermal performance	Better	Poor
Communication	With ECU using LIN/CAN	No ECU communication
Speed Range	Variable	Two speed with Resistor Or fix
Electric Noise	Low	High
Lifetime	Long	Short

7. METHODOLOGY

The experiment for validation of this idea will be conducted as follows:

1. Instrument a vehicle with fuel economy measuring equipment – flow meter, data logger and heat exchanger (to normalize temperatures of fuel in the tank and fuel returning from engine)
2. Conduct a baseline fuel economy test basis a known drive cycle (in this case, MDC or Mumbai Drive Cycle and CDC or Combined Drive Cycle) on the vehicle using a chassis dyno
3. Replace the brush-type DC motor in the radiator fan assembly with a brushless DC motor of equivalent specification
4. Install the modified radiator fan assembly on the vehicle
5. Repeat the fuel economy test with the update configuration
6. Compare the results and check for improvement in fuel economy over baseline.

8. EQUIPMENT

1) Donor vehicle
2) Brushless DC motor – T.B.D.
3) DFL fuel flow measurement device
4) DAS2A data logger
5) Panasonic Toughbook laptop
6) Chassis dynamometer
7) Climate chamber – Hot Chamber.

9. TEST CONDITION

The test conditions will be as follows:

1) Test cycle – MDC and CDC cycles as described above. These cycles are based on actual data logged driving in metro city traffic.
2) Environment controlled at 45 degrees Celsius and at a relative humidity of 40%
3) Air conditioner ON at all times
4) Donor vehicle's engines run-in for 1000 km to ensure representative engine friction losses
5) New tires to ensure safety using the dynamometer
6) Vehicle kerb weight and coefficients for rolling and aerodynamic friction entered in the dynamometer control system to represent correct resistance loads *(values obtained from manufacturer).*
7) Test cycle – MDC and CDC cycles as described above. These cycles are based on actual data logged driving in metro city traffic.
8) Environment controlled at 45 degrees Celsius and at a relative humidity of 40%
9) Air conditioner ON at all times
10) Donor vehicle's engines run-in for 1000 km to ensure representative engine friction losses
11) New tires to ensure safety using the dynamometer
12) Vehicle kerb weight and coefficients for rolling and aerodynamic friction entered in the dynamometer control system to represent correct resistance loads *(values obtained from manufacturer)*

By taking a baseline and updated measurement on the same vehicle, with the same test cycle and using the same test equipment, any variation experiment to experiment is minimized. The instruments used will return accurate readings within an error range of 0.1 kpl. Thus, using this method, any substantial improvement in fuel economy can be robustly verified.

10. TEST PROCEDURE

1. Clamp the vehicle on chassis dynamometer rollers with the follow safety instructions and procedures of respective lab.
2. Set ambient conditions: Preconditioning to be started once desired conditions reached.
3. Check instrumentation: Make sure all the desired vehicle and engine parameters to be acquired are displaying data properly.
4. Fuel Leakages: Make sure there is no fuel leakage in the fuel meter circuit.
5. Preconditioning: Vehicle preconditioning warms the engine, driveline fluids and exhaust emission control equipment, and raises vehicle-operating temperatures, so the vehicle is warmed up. Ideally, the engine coolant, oil and drivetrain lubricants should reach an operating temperature that would be consistent with those expected during multiple repetition of the associated test cycle. To accomplish these objectives, the test vehicle shall be driven through a warm up cycle prior to the test. Two standard EUDC 90 cycle or 15 minutes' constant drive at 80 km/h before every test run.
6. Road Load Adaptation: Conduct adaptive coast down with test weight and vehicle resistance equation after preconditioning.
7. Load desired Drive cycle in chassis dynamometer.
8. Set cluster trip to 0 at the start of each cycle.
9. Start data acquisition system for distance, fuel and other desired channels.
10. Drive the vehicle as per required velocity profile.
11. Drive trace accuracy: Cycle violation allowed is +/- 2 kmph from the desired velocity unless violation is because of engine power limitation.
12. Record fuel efficiency after competition of each test cycle, 2 consistent reading of fuel efficiency within +/- 0.15 kmpl from the average is required.
13. Complete test in Mumbai and Chennai Drive cycle.
14. Replace radiator fan motor and repeat the above procedure and compare the results.

11. CHASSIS DYNAMOMETER TYPES:

There are many types of chassis dynamometer according to the target application - for example, emissions measurement, miles accumulation chassis dynamometer (MACD), Noise-Vibration-Harshness (NVH or "Acoustic") Application, Electromagnetic Compatibility (EMC) testing, end of line (EOL) tests, performance measurement and tuning. Another basic division is by type of vehicle - motorcycles, cars, trucks, tractors or the size of the roller - mostly 25", 48", 72", but also any other. Modern dynamometers used for development are mostly one roller to the wheel construction and the vehicle wheel is placed the top of the roller.

DYNAMOMETER

Measured variables on a roller dynamometer:

Directly measured variables are only force on the torque transducer (i.e. loadcell) and revolutions measured on the role encoder dynamometer. All other variables are calculated based on known design (i.e. roller radius and loadcell mounting).

Power measurement on Chassis dynamometer:

Due to friction and mechanical losses in various parts of the power train, the measured power at the wheels by about 15 to 20 percent lower than the power measured directly at the output of engine crankshaft (measuring device with this purpose is called engine testbed).

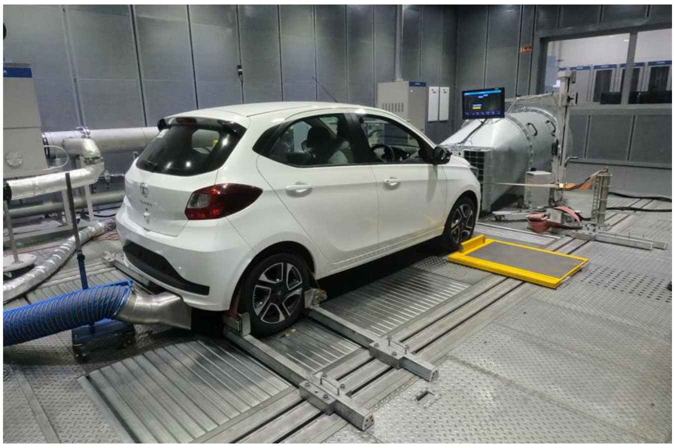


Fig. 11: Chassis dynamometer.

Road load simulation principle on chassis dynamometer:

Vehicle do not behave the same way on chassis dynamometer as on the road. For example, aerodynamic shape of the vehicle does not matter. Sum of all forces on the vehicle on a real road are simulated through tires on chassis dynamometer. Increasing air drag with the speed on the road manifests as increasing braking force of the vehicle wheels. The aim is to make the vehicle on the dynamometer accelerate and decelerate the same way as on a real road. First you need to know the parameters of the "behavior" of the vehicle on a real road. In order to get "road parameters", vehicle must be driving on ideal flat road with no wind from any direction, gear set to neutral and time needed to slow down without braking is measured in certain intervals e.g. 100–90 km/h, 90–80 km/h, 80–70 km/h 70–60 km/h etc. Slowing down from higher speed takes shorter time mainly due to air resistance. Those parameters are later set in dynamometer workstation, together with vehicle inertia. Vehicle is restrained and so called vehicle adaptation has to be performed. During vehicle adaptation dynamometer automatically slowing down from set speed, changing its own "dyno parameters" and trying to get same deceleration in given intervals as on real road. Those parameters are then valid for this vehicle type. Changing of set simulated inertia it is possible to simulate vehicle ability to accelerate if fully loaded, with setting gradient it is possible to simulate force if vehicle going downhill etc. Chassis dynamometers for climatic chamber does exists, where it is possible to change temperature in give range i.e. -40 to +50 °C or altitude chamber where it is possible to check fuel consumption with different temperatures or pressure and to simulate driving on mountain roads.

Drive trace accuracy:

The test vehicle must be driven according to the drive cycle in terms of required speed at a given time as closely as possible, to ensure a reproducible test result. Driver error of +/- 2 km/h is allowable. Speed variations greater than the tolerances in the events such as may occur during gear changes or braking spikes are acceptable. Deviations during accelerations are permitted only if they are limited by vehicle power.

Chassis Dynamometer Requirements

Chassis dynamometer test cells shall have the capacity of simulating the test vehicle's inertia and shall fulfil the following requirements:

It shall permit the user to convert coast down data for the test vehicle to the proper horsepower absorption setting for the chassis dynamometer. Results of coast down test conducted on test track must be available.

Either type of chassis dynamometer (single or twin roll) shall be equipped with a cooling fan to provide cooling air flow to the vehicle during testing. A road-speed modulating fan shall be used, rather than a fixed-speed cooling fan.

Ambient conditions: Chassis dynamometer must be employed with air conditioning unit. Following ambient conditions are to be maintained:

	AC ON	AC OFF
Temperature (deg. C)	32	25
Humidity (%)	60	40
Solar Load (W/m3)	800	0

A chassis dynamometer, sometimes called a rolling road, is a device used for vehicle testing and development. It uses a roller assembly to simulate a road in a controlled environment, usually inside a building.

12. RESULTS AND DISCUSSION

10.1 Results of Descriptive Statics of Study Variables

Table10.1: CITY MODE

<table>
<tr><th>Tip IN</th><th colspan="2">Neutral</th><th colspan="2">1st gear</th><th colspan="2">2nd gear</th><th colspan="2">3rd gear</th><th colspan="2">4th gear</th><th colspan="2">5th gear</th></tr>
<tr><th>%</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th></tr>
<tr><td>5</td><td colspan="2" rowspan="6">No A/C Cut-off (0-30%)</td><td colspan="2" rowspan="6">No A/C Cut-off (0-30%)</td><td colspan="2" rowspan="6">No A/C Cut-off (0-30%)</td><td colspan="2" rowspan="8">No A/C Cut-off (0 - 40%)</td><td colspan="2" rowspan="14">No A/C Cut-off (0 - 70%)</td><td colspan="2" rowspan="14">No A/C Cut-off (0 - 70%)</td></tr>
<tr><td>10</td></tr>
<tr><td>15</td></tr>
<tr><td>20</td></tr>
<tr><td>25</td></tr>
<tr><td>30</td></tr>
<tr><td>35</td><td rowspan="14">Accelerator pedal 30 % and above</td><td rowspan="14">MINIMUM: 3 sec MAXIMUM: 6 sec or tip out to 5% whichever is earlier.</td><td rowspan="14">Accelerator pedal 30 % and above</td><td rowspan="14">MINIMUM: 3 sec MAXIMUM: 6 sec or tip out to 5% whichever is earlier.</td><td rowspan="14">Accelerator pedal 30 % and above</td><td rowspan="14">MINIMUM: 3 sec MAXIMUM: 6 sec or tip out to 5% whichever is earlier.</td></tr>
<tr><td>40</td></tr>
<tr><td>45</td><td rowspan="12">Accelerator pedal 50 % and above</td><td rowspan="12">MINIMUM: 3 sec MAXIMUM: 8 sec or tip out to 5% whichever is earlier.</td></tr>
<tr><td>50</td></tr>
<tr><td>55</td></tr>
<tr><td>60</td></tr>
<tr><td>65</td></tr>
<tr><td>70</td></tr>
<tr><td>75</td><td rowspan="6">Accelerator pedal 80 % and above</td><td rowspan="6">MINIMUM: 3 sec MAXIMUM: 8 sec or tip out to 5% whichever is earlier.</td><td rowspan="6">Accelerator pedal 80 % and above</td><td rowspan="6">MINIMUM: 3 sec MAXIMUM: 8 sec or tip out to 5% whichever is earlier.</td></tr>
<tr><td>80</td></tr>
<tr><td>85</td></tr>
<tr><td>90</td></tr>
<tr><td>95</td></tr>
<tr><td>100</td></tr>
</table>

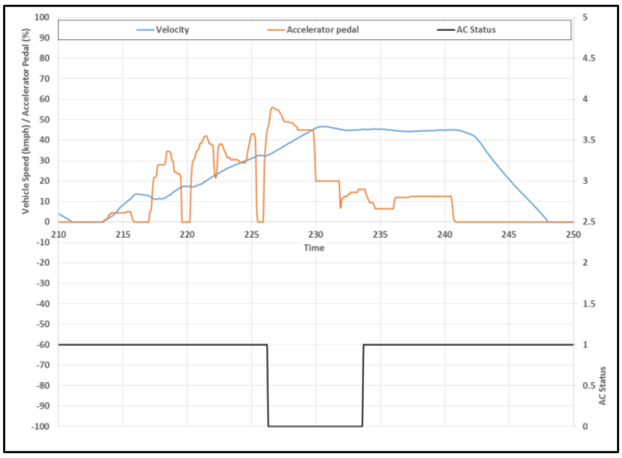
Table 10.2: ECO MODE

<table>
<tr><th>Tip IN</th><th colspan="2">Neutral</th><th colspan="2">1st gear</th><th colspan="2">2nd gear</th><th colspan="2">3rd gear</th><th colspan="2">4th gear</th><th colspan="2">5th gear</th></tr>
<tr><th>%</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th><th>AC Cut off Threshold (Acc Pedal Base)</th><th>AC Cut off duration</th></tr>
<tr><td>5</td><td colspan="2" rowspan="6">No A/C Cut-off (0-30%)</td><td colspan="2" rowspan="6">No A/C Cut-off (0-30%)</td><td colspan="2" rowspan="6">No A/C Cut-off (0-30%)</td><td colspan="2" rowspan="6">No A/C Cut-off (0-30%)</td><td colspan="2" rowspan="10">No A/C Cut-off (0 - 50%)</td><td colspan="2" rowspan="10">No A/C Cut-off (0 - 50%)</td></tr>
<tr><td>10</td></tr>
<tr><td>15</td></tr>
<tr><td>20</td></tr>
<tr><td>25</td></tr>
<tr><td>30</td></tr>
<tr><td>35</td><td rowspan="14">Accelerator pedal 30 % and above</td><td rowspan="14">MINIMUM: 3 sec MAXIMUM: 6 sec or tip out to 5% whichever is earlier.</td><td rowspan="14">Accelerator pedal 30 % and above</td><td rowspan="14">MINIMUM: 3 sec MAXIMUM: 6 sec or tip out to 5% whichever is earlier.</td><td rowspan="14">Accelerator pedal 30 % and above</td><td rowspan="14">MINIMUM: 3 sec MAXIMUM: 6 sec or tip out to 5% whichever is earlier.</td><td rowspan="14">Accelerator pedal 30 % and above</td><td rowspan="14">MINIMUM: 3 sec MAXIMUM: 6 sec or tip out to 5% whichever is earlier.</td></tr>
<tr><td>40</td></tr>
<tr><td>45</td></tr>
<tr><td>50</td></tr>
<tr><td>55</td><td rowspan="10">Accelerator pedal 50 % and above</td><td rowspan="10">MINIMUM: 3 sec MAXIMUM: 8 sec or tip out to 5% whichever is earlier.</td><td rowspan="10">Accelerator pedal 50 % and above</td><td rowspan="10">MINIMUM: 3 sec MAXIMUM: 8 sec or tip out to 5% whichever is earlier.</td></tr>
<tr><td>60</td></tr>
<tr><td>65</td></tr>
<tr><td>70</td></tr>
<tr><td>75</td></tr>
<tr><td>80</td></tr>
<tr><td>85</td></tr>
<tr><td>90</td></tr>
<tr><td>95</td></tr>
<tr><td>100</td></tr>
</table>

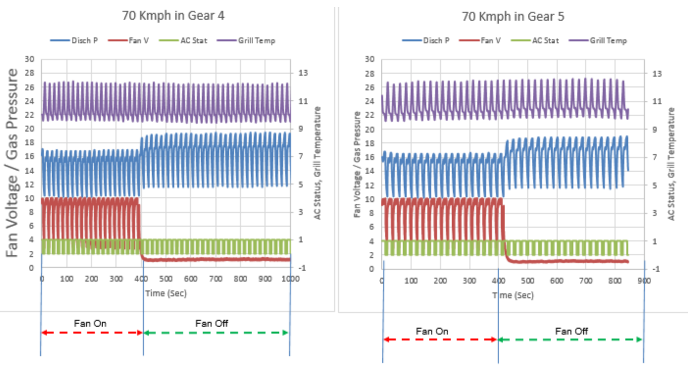
13. EXPECTED OUTCOME

- Fuel efficiency improvement by more the 0.5% KMPL
- Lower rate of field failures and decreased the maintenance requirements as well as cost.
- Due to compact design easy to engine bay design & packaging.
- Improvement in vehicle NVH.

Test Cycle Data – Logic Operation



Assessment of fan off logic at medium ambient conditions (32Deg) Constant Speed 70 Kmph.



No abnormal increase in operating pressures and coolant temperatures in moderate ambient conditions with fan off conditions.

High-speed test without radiator fan running at severe ambient temp (45°C)

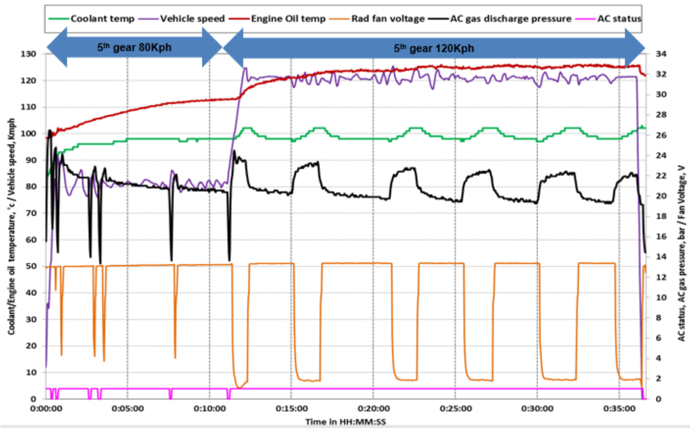
- 5th gear road load 60-80-100-120Kph test is performed without running radiator fan.
- Test is conducted to see stabilization temperature for coolant, engine oil and AC gas discharge pressure.
- Idea behind test was to drop radiator fan motor power consumption during vehicle high speed running so that it will give benefit in fuel economy.
- In like to like comparison following are the results with and without running radiator fan:

Radiator fan condition-212Watts (Speed - 2350rpm)	Veh driving condition	UCL, °C	Engine oil, °C	AC gas discharge pressure, bar
Running	5th gear 80Kph	90.6	108.8	20
	5th gear 120Kph	94.5	123.1	19.4
Without running	5th gear 80Kph	101.1	118.6	21.9
	5th gear 120Kph	98.8	127.2	19.7

Observations:

1. In 5th gear 80Kph, without running radiator fan, coolant and engine oil temperatures are increased by ~10°C which is acceptable. AC gas discharge pressure increased by ~2bar.
2. In 5th gear 120Kph, without running radiator fan, coolant and engine oil temperatures are increased by ~4°C which is acceptable. AC gas discharge pressure is comparable in both conditions of radiator fan.

High-speed test without radiator fan running at severe ambient temp (45°C)



City Fuel Economy comparison	
Configuration	City Fuel efficiency
Baseline	12.4 Kmpl
BLDC motor	12.9 Kmpl

14. CONCLUSION:

The goal of the project was to study the **Fuel economy improvement with use of brushless DC motor in radiator fan assembly.**

It can be concluded that by using a brushless DC motor, we can achieve a surge of fuel economy by 0.5Kmpl which is an 4% increase.

15. REFERENCES

1. Carunaiselvane.C and S. Jeevananthan, "Generalised procedure for BLDC motor design and substantiation in MagNet 7.1.1 software", International Conference on Computing, Electronics and Electrical Technologies [ICCEET], 2012
2. Jun-Hyuk Choi, Se-Hyun You, Jin Hur and Ha-Gyeong Sung, "The Design and Fabrication of BLDC Motor and Drive for 42V Automotive Applications", IEEE International Symposium on Industrial Electronics, June 2007
3. Pranshu Upadhayay and K. R. Rajagopal, "Permanent Magnet Overhang Effect in PM BLDC motor using 2D & 3D Finite Element Analysis", Nirma University International Conference on Engineering, NUiCONE-2012, December, 2012
4. Pinaki Mukherjee and Mainak Sengupta, "Fabrication, Parameter Evaluation and Testing of a surface mounted -Brush-less DC Motor", 7th National Power Electronics Conference, NPEC-2015, December-2015

[5] Jerome Cros, Mehdi TaghizadehKakhki, Geraldo C.R. Sincero, Carlos A. Martins, Philippe ViarougeJérômeCros, Mehdi TaghizadehKakhki, Geraldo C.R. Sincero, Carlos A. Martins, Philippe Viarouge, "Design Methodology for Small Brush and Brushless DC Motors", In book: Vehicle Engineering, Chapter: Design Methodology for Small Brush and Brushless DC Motors, Publisher: Academy Publish, Editors: Academy Publish team, pp.207-235

[6] Yonggang Liu, Songfa Tang- Zhongshan (CN) "Brushless DC Motor Structure having Fan Radiator for Dissipating Heat from The motor and the controller"

[7] Pinaki Mukherjee and MainakSengupta, "Fabrication, Parameter Evaluation and Testing of a surface mounted -Brush-less DC Motor", 7th National Power Electronics Conference, NPEC-2015, December-2015"

[8] Meihua Xu - Shanghai University, Da Teng - Microelectronic R&D Center, Shanghai, University Guoqin Wang - Shanghai University. Yu Fei Microelectronic R&D Center Shanghai University "High Efficient BLDC Controller for Automobile Cooling Fan"

[9] Anurag Dwivedi and A. N. Tiwari "Speed Control of Brushless DC Motor".

[10] Huang Qi 1, Xi Wei, Wang Sheng and Wu Quan, "Design of Position Sensorless Controller for BLDC Cooling Fan"

[11] You Tian, Wenyan – Shanghai (CN) "Brushless DC motor and Radiator thereof"