International Journal of Science and Engineering Applications
Volume 7–Issue 08,153-161, 2018, ISSN:-2319–7560

Benchmark Evaluation & Proposed Electrical Architecture for a 12V BSG Vehicle

Priyamvad Mishra
Adaptation Responsible, Vehicle Integration Dept
FCA Engineering India Pvt Ltd,
India

K. Phaneendra Varma
Senior Engineer, Electrical & Electronics Dept
FCA Engineering India Pvt Ltd,
India

Abstract: This paper makes an effort to define an optimal electrical architecture for a 12V BSG system for a mid- sized diesel engine, with the help of functional validation tests and specific test cases developed by the authors. The first few sections of the paper explain various modes of a 12V BSG hybrid operations namely-ESS, torque assist and recuperation on a reference vehicle. Set of test cases have been developed to explain 12V BSG behavior as a DC motor during ESS and torque- assist mode of operation and as a 3-phase generator during regenerative coasting mode. In the final section, an optimized electrical architecture of 12V BSG system is proposed for mid-sized diesel engine with manual transmission, based on objective measurement of test cases and a Pugh Comparison matrix of various feasible architectures.

Keywords: Belt Driven Starter Generator (BSG) System; 12V enhanced flooded battery; Voltage Stabilization Module; BSG architecture

1. INTRODUCTION

Due to increase in the CO2 Emissions [1], we are currently facing the problem of Global Warming [2]. To overcome the same, automobile OEM'S are searching for the alternatives to conventional Internal Combustion Engine (ICE) and working towards hybridization of vehicle powertrain, to reduce the CO2 Emissions. This also helps for improvement in Fuel Economy without any de-gradation in vehicle performance.

Basically, there are 5 different levels of powertrain hybridization depending on hybrid function capabilities, capacity of electric motor or the machine capacity, energy savings expressed in terms of km/l used in the vehicle. Table 1 elaborates on different hybridization levels [3].

This paper concentrates on the electrical architecture of a Micro-Mild Hybrid segment, which is capable of providing hybrid functions e.g. ESS, torque assist and recuperation. For this a literature survey has been done, based on various Mild hybrid systems available in the market:

1) Low voltage (12V) start stop/ micro hybrids [4].
2) BSG mild hybrid, system voltage 12V $\leq V_{system} \leq$48V [5, 6].
3) ISG mild hybrid, system voltage V_{system}>60V.

However, cost impact, architectural complexities, high voltage system hazard [8] and other packaging constraints such as size limitations) limits the usage [6] of ISG in passenger vehicle segment.

This paper focuses on 12V and 48V hybrid systems [5, 6, and 8] which are getting popular worldwide. There are fewer hybrid vehicles operating with 48V BSG, but are not getting as popular as compared with 12V BSG, in particular for India market. This is due to lot of other factors like packaging, architectural modifications and requirement of dedicated DC-DC converter for stepping down 48V to 12V, for vehicle accessories apart from 48V BSG unit [3, 9]. In this paper, a 12V BSG system has been proposed and analyzed taking into consideration, for a bumper to bumper congested traffic with vehicle halts in excess of 90 seconds. The 12V BSG architecture proves a very economical and relatively maintenance free solution for above transit operations, for Indian urban city drive conditions.

The paper is organized into four sections: section I explains the circuit configuration. Section II provides the operating principle of a 12V BSG system. Section III evaluates the primary BSG functions with aid of special test cases. Section IV discusses the proposed EE architecture for a BSG system on a mid-sized Diesel Powertrain, followed by the conclusion of the work.

Table 1: Various Hybridization Levels Available in Global Market [Energy Saving benefits are measured on NEDC cycle [12]; for a pure Electric Vehicle Energy Savings is considered 100% in absence of secondary power source, primarily an IC engine]

Functions	Micro & Micro-Mild hybrid	Mild Hybrid	Full Hybrid	Plug in hybrid (PHEV)	EV
Start/Stop	✓	✓	✓	✓	✓
Regenerate braking	✓ (micro-mild only)	✓	✓	✓	✓
Additional electric power for few seconds	✓ (micro-mild only)	✓	✓	✓	✓
Electric power for mild distance (city)			✓	✓	✓
Electric power for long distance & recharge on grid				✓	✓
Energy Savings	5-10% (upto 25% in city traffic)	10-25%	25-40%	50-100%	100%
Electric Power	1.5-10KW	5-20kW	30-75kW	70-100kW	30-100kW
Car Examples	PSA C2	Honda Civic	Toyota Prius	GM Volt	Nissan leaf

2. CIRCUIT CONFIGURATION AND OPERATION OF A 12V BSG SYSTEM

Fig.1 illustrates the electrical architecture of key low voltage components for a 12V BSG reference vehicle. The BSG unit functions both as a motor and an alternator with modes of operation being controlled by Engine Control Unit (ECU). BSG replaces the conventional alternator and it is directly driven by the Front End Accessory Drive (FEAD) belt of engine.

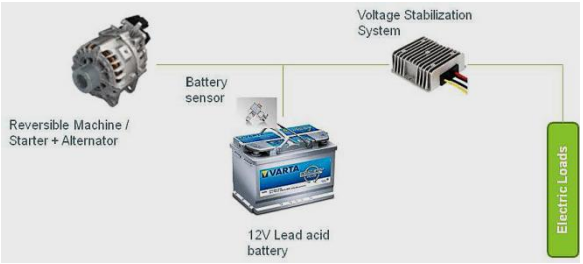


Figure 1: Electrical Architecture 12V BSG System

Hence this type of hybrid system is also known as Belt Driven Starter Generator (BSG). BSG unit primarily consists of an e-motor coupled with power control module which acts as two-way rectifier, AC to DC & Vice versa.

The Intelligent Battery Sensor (IBS) broadcasts critical battery parameters to ECU on a dedicated Local Interconnect Network (LIN), between ECU and vehicle 12V battery. IBS will communicate all the parameters like battery Voltage, battery current, Battery State of Charge (SOC) etc. Based on the driver inputs it will command the BSG system to provide various functions, based on battery state of Charge, expressed as % of full charge. Engine Control Unit which also acts as master gateway for ESS operation, also controls energy flow to & from BSG unit to battery/ engine output shaft, thus commanding BSG to switch from motor to alternator mode of operation.

A Voltage Stabilization Module (VSM) is used in the reference vehicle to supply un-interrupted 12V supply to critical electrical loads in the vehicle i.e. all vehicle control units, radio & navigation systems in this vehicle.

There are three modes of hybrid operations typically for a 12V BSG system, these are as follows:
Mode I: ESS Mode (Engine Start Stop).
Mode II: Torque assist Mode.
Mode III: Recuperation Mode.

2.1 Mode-I: ESS Mode

As shown in Figure 2, in this mode BSG unit operates as motor and it will crank the Engine. This crank is also called as warm crank, as this is post 1st cranking operation which is always via the starter motor of the vehicle. The current required during BSG crank event is relatively less as compared to the starter motor crank. This is because the starter must engage the crankshaft ring gear to overcome higher engine frictional forces under cold start. The BSG unit being part of Front End Accessory Drive (FEAD), cranks the engine by overcoming FEAD belt drive inertia of both engine & belt tensioner, which is relatively lower in magnitude when compared with crankshaft inertia. Also frictional forces to be overcome are lower on account of warmed up engine. Considering the sizing of BSG unit which is limited to 4 kW max output, it is not capable to support power equivalent for starter motor crank. Figure 2 depicts energy flow between BSG system and engine under Engine Start Stop (ESS) event via BSG crank. It is observed that the BSG operating in motor during event of engine crank/ESS, draws the maximum current from the battery as compared to torque assist mode. At the same time vehicle battery also needs to support 12V uninterrupted energy demand, to critical vehicle loads.
Hence a VSM module is connected in series between 12V battery and critical vehicle loads. Though it is not defined but BSG supports engine stop. Further BSG unit is capable of engine stall assistance, provided all conditions for ESS enable; which are discussed in next section are available prior to next BSG crank event.

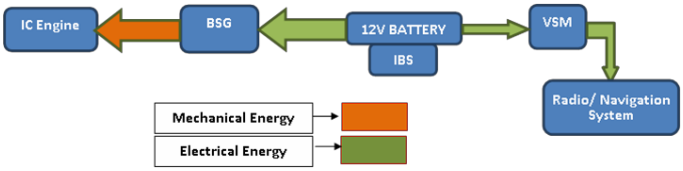


Figure 2: Energy flow during the ESS Mode

2.2 Mode II: Torque assist

In this mode, the BSG unit operates as motor and supplements ICE torque, thus reducing the energy demand from the engine during this phase. This assist is limited due to size of e-motor & battery capacity, but it helps to improve the fuel economy and CO_2 emissions of vehicle. Figure 3 shows energy flow during torque assist. During torque assist mode BSG unit acts as draws relatively lower magnitude of current to provide required assist, while the critical loads functions as explained in Mode-I.

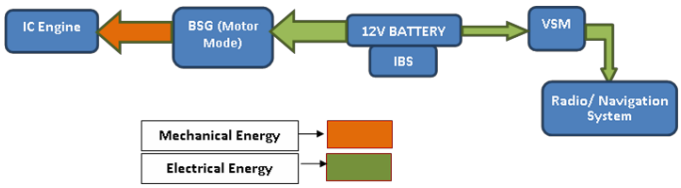


Figure 3: Energy flow during Torque Assist mode

2.3 Mode III: Recuperation Mode

In this mode, the BSG unit will act as alternator driven by ICE torque. The electrical output from BSG unit is used to charge vehicle battery and run all 12V electrical loads in vehicle. Figure 4 depicts the energy flow during the Recuperation mode. During recuperation BSG unit is driven by the ICE residual torque (during vehicle deceleration, while in gear coasting), this torque is used by BSG unit to charge the 12V vehicle batteries as a smart alternator.

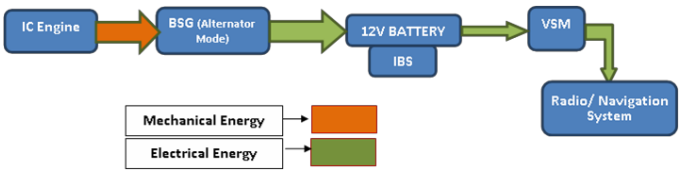


Figure 4: Energy flow during Recuperation Mode

3. OPERATING PRINCIPLE FOR 12V BSG SYSTEM OF A REFERENCE VEHICLE

Jen-Chiun Guan et al [7], has illustrated various hybrid operating modes of BSG, using MATLAB Simulink models to represent driver, engine, vehicle, CVT, BSG and battery. This paper defines a power split ratio PSR [10, 11] used to evaluate BSG mode of operation i.e. motor and alternator mode.

PSR= P_{eng}/ P_{req}; Where
P_{eng}=engine power and P_{BSG} =BSG motor output power
Preq = Power Request from driver, $P_{req} = P_{eng} + P_{BSG}$.
1) When (0<PSR<1) BSG unit operates in motor mode.
2) If PSR=1, i.e. $P_{req} = P_{eng}$, BSG unit operates in engine mode.

3) If PSR>1, i.e. P_{BSG} is negative, BSG unit is in alternator mode charging the battery.

The authors in this section have attempted to explain these primary hybrid functions of a 12V BSG system, by developing of unique Design Validation Plan & Requirements (DVP&R) or test cases, exclusively for a 12V BSG system. The various BSG functions were defined in a simplified way using combination of test cases on a reference vehicle.

Figure 5 shows the schematic diagram of the Electrical load management in reference vehicle. All the electrical loads are connected in parallel to the vehicle battery. Fuse 1 provides protection to the BSG unit against heavy ingress current at time of cranking the engine. Typically, its rating is ~ 450A. Fuse 2 (100A) is a common fuse for protection of all electrical loads except the starter motor and the BSG. The starter motor will have the protection only for its solenoid but not for the armature of the starter motor which will draw ~500A at the time of the starting. A 30A fuse is connected for protection of starter motor solenoid.

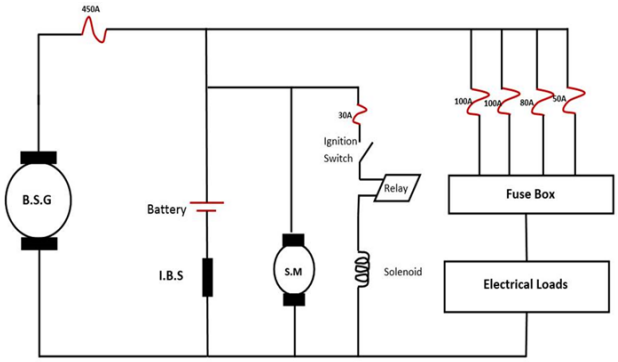


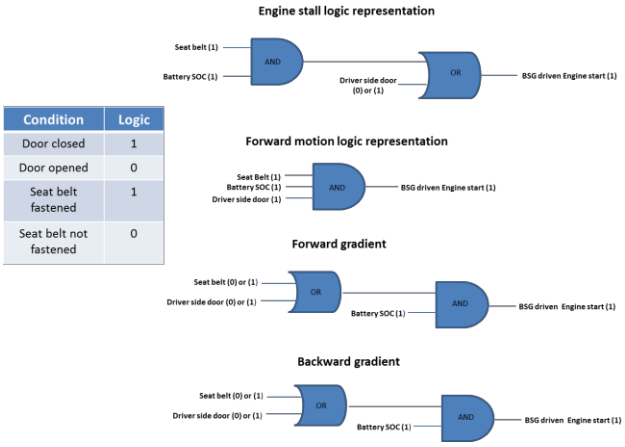
Figure 5: Schematic diagram of BSG system on reference vehicle

Table 2 (More detail is provided in Appendix at the end of paper) shows the Engine Start-Stop (ESS) logic matrix in the reference vehicle and discusses the inputs required for the activation of the BSG system [4]. The ESS Logic matrix is derived from the reference vehicle, by set of functional validation tests undertaken by enabling and disabling certain inputs which are as below:

1) Driver Detection.
2) Driver Door Detection.
3) Hood latch Detection (The hood latch switch needs to be normally closed during all conditions for ESS crank to be enabled, hence this input is not depicted exclusively in the logic diagram).

It is observed from these tests that BSG prompted/ enabled engine crank operation, better known as ESS function is available only when above listed input combinations are available as per Logic sequence explained below. This condition holds good irrespective of whether the engine is in stall condition, or engine comes to an auto-stop, while in forward or reverse motion of vehicle.

The above ESS operational matrix has been represented by the author in a simplified form using logic gates, as seen in Fig.6.



Condition	Logic
Door closed	1
Door opened	0
Seat belt fastened	1
Seat belt not fastened	0

Figure 6: Logical representation of ESS logic in reference vehicle

Note: Hood latch switch is always closed during all conditions [Priyamvad Mishra & Phaneendra Varma, 27-Feb-18]

4. EVALUATION OF BSG FUNCTIONALITY WITH SPECIAL TEST CASES

In this section primary BSG functions has been explained using system parameters viz.: battery current, battery voltage, engine RPM, along with inputs required for BSG functionality activation like accelerator and brake pedal inputs on reference vehicle are discussed.

The primary functions have been tested at different operating conditions like AC ON/OFF and ESS enable/disable during these test cases as listed below:

1) Starter motor crank or first cranking operation.
2) BSG prompted engine crank or warm crank.
3) Torque assist when accelerating in low rpm ranges from 1st thru 4th gears.
4) Recuperation available when vehicle is coasting.

The drive cycle for these test cases is a standard urban India drive cycle which is the heavy urban section of NEDC drive cycle.

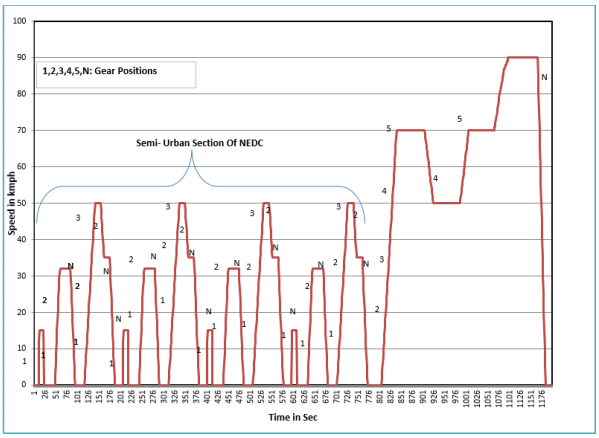


Figure 7: Drive cycle for evaluation for BSG functions

The average vehicle speed is 15 km/h and no of stops per km is 3 to 5. The test cases have been undertaken with various load conditions, viz AC load and ESS Signal enabled or disabled, with their significance as explained below:

a) AC ON ESS ON: AC load impacts the duration for which vehicle remains in auto stop condition i.e. the lower temperature set point, the lesser time vehicle is in auto stop

condition, this is to maintain cabin comfort which takes precedence with AC ON.

b) AC OFF ESS ON: During this test scenario the duration for auto stop is maximum as there is no cabin load preference here.

c) AC ON ESS OFF: With ESS signal disabled in this scenario there is no start stop event possible.

Measurement of system parameters:

- Battery Voltage: Shunt load placed in series with battery & BSG unit.
- Engine Speed, Vehicle Speed: L350 Optical sensor & CAN data logger.
- Accelerator input: potentiometer
- A CAN signal is tapped referred as hybrid system sensor signal to indicate ESS, torque assist & recuperation modes of operation.

Figures 7 and 8 explain the comparison between cranking profiles of a conventional starter motor crank and a BSG prompted crank events.

4.1 Starter crank or Cold crank:

The 1st cranking operation of vehicles equipped with BSG is always through starter. Reason for same is explained in earlier section. Since this is the first crank operation of vehicle it is referred as cold crank. Figure 7 shows changes in battery system parameters like Battery voltage, battery current, battery SOC (State of Charge) during the starter motor crank, plotted against cranking time interval in seconds.

During this period, significantly high current (~550A) is drawn from the battery, because starter motor pinion is directly engaging the crankshaft ring gear and must overcome engine static friction higher moment of inertia of crankshaft. It is also evident from significantly higher voltage drop (~2.9V) during starter motor crank.

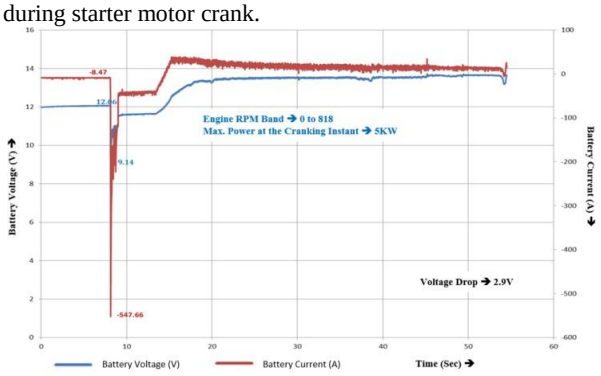


Figure 8: System parameters during starter motor crank event

Table 3: Test case of starter motor crank (cold start)

System Parameters		Cold start (@ 23ºC)
Battery Voltage (V)	Maximum	12.06
	Minimum	9.14
Battery Current (A)	Minimum	0
	Maximum	-547
Engine rpm	Minimum	0
	Maximum	818

4.2 BSG crank or warm crank:

All the subsequent cranks for a warmed up engine from initial starter motor crank is via BSG. From Table 4, it is seen that there is a significant drop in battery voltage during the BSG crank when AC is in ON condition, 12.2V ~9.71V. Hence a VSM is provided to protect in vehicle sensitive loads like radio, navigation, ECU units, from rapid surges in current during BSG crank event and provide constant voltage supply.

Table 4: Test case of BSG crank (Hot start)

System Parameters		AC ON & ESS ON	AC OFF & ESS ON
Battery Voltage (V)	Maximum	12.21	12.62
	Maximum	9.71	10.28
Battery Current (A)	Minimum	-19.64	0
	Maximum	- 420	- 414
Engine rpm	Minimum	0	0
	Maximum	1022.3	956.0

Figure 8 shows changes in the system parameters during the BSG crank. It is observed that during this period the current drawn by BSG is relatively lower (~ 400A) as compared to the starter motor crank. The negative sign indicates the current drawn by BSG in motor mode to crank the engine. Duration of BSG start is almost 1/3rd of the starter motor start operation **Table 9** (**Refer Appendix at end for details**).

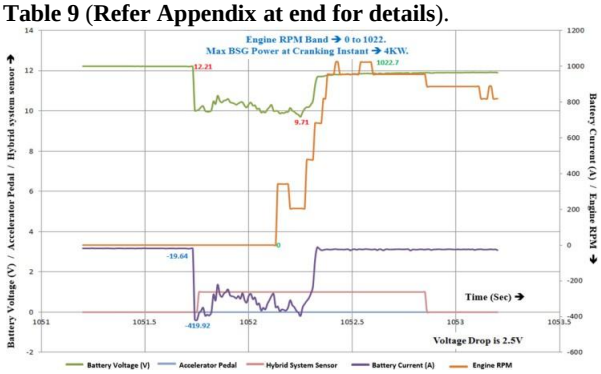


Figure 9: System parameters during BSG Prompted crank Event

4.3 Torque assist:

When the driver presses the accelerator pedal with pedal travel < 40% of total travel. With a good battery SOC %, a supplementary torque from BSG is addition to engine output torque.

This gives a sporty feel and a peppy responsive accelerator response which is clearly limited. Table 5 depicts torque assist event, during which a minor drop in the battery voltage can be observed. Also, there is a significant increase in the battery current, indicating BSG unit functions in motor mode.

Table 5: Test case of torque assist event

System Parameters		AC On ESS On	AC Off ESS On	AC On ESS Off
Battery Voltage (V)	Maximum	14.22	14.08	13.08
	Minimum	12.44	11.91	12.02
Battery Current (A)	Minimum	4.70	14.92	26.26
	Maximum	-80.1	-75.9	-83.0
Engine rpm	Minimum	1084	955	814
	Maximum	1893	1505	1819
Accelerator pedal Travel (%)	Minimum	0	0	0
	Maximum	38	22	24

Figure 9 shows changes in the system parameters during the torque assist event. In a torque assist function, BSG unit supplements the engine torque for a certain engine rpm range in each gear, starting from 1st to 4th gear. The energy required for torque assist is provided by the vehicle battery,

which is for a very short burst of time. It can also be seen that the torque assist is available for accelerator pedal travel less than 40% and engine rpm between 1050rpm to 1900rpm.

4.4 Recuperation:

During the Recuperation period vehicle is decelerating when coasting in gear without acceleration input, the battery is charged by the BSG unit, which now functions as a generator. Fig.10 shows the changes in the system parameters during recuperation mode.

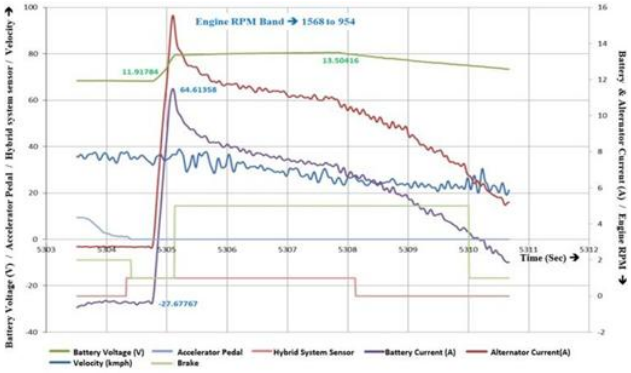


Figure 11: System parameters during recuperation mode

From Figures 8, 9 and 10, it can be summarized that the BSG unit operates as a bi-directional DC motor as well as AC generator, based on vehicle operating condition, battery SOC conservation principle or strategy. BSG unit acts as DC motor and supplements the engine torque during the torque assist mode. Also during the ESS event, BSG unit meets the energy demand to crank the engine via a belt driven starter mode of operation.

The BSG unit, also behaves as a 3-phase generator during recuperation event, generating AC current which is converted to 12V DC input to charge vehicle, through in-built rectification.

Table 6: Test Case of Recuperation Event in the Vehicle

System Parameters		AC On ESS On	AC Off ESS On	AC On ESS Off
Battery Voltage (V)	Maximum	13.61	14.16	13.5
	Minimum	12.31	12.12	11.91
Battery Current (A)	Minimum	0	-69.7	-27.7
	Maximum	61.12	71.0	64.6
Engine rpm	Minimum	1226	886	954
	Maximum	1662	1368	1568

With driver foot off accelerator pedal, coasting condition Table 6 shows test case for recuperation event, during which BSG unit can charges the battery, in smart alternator mode(SAM) during the coast down. SAM behavior is alternator mode of operation where the alternator is not charging to a fixed set point, rather there is floating reference voltage based on the engine load and electrical load demand. SAM strategy requires a continuous monitoring of battery's state of charge (IBS sensor) and a LIN communication protocol, to control the alternator. It thus aids in decreasing the fuel consumption as well as the overall emissions produced by the vehicle. SAM strategy is applicable in vehicles equipped with Intelligent Battery Sensor (IBS) and LIN communication interface through which the desired operating conditions are transmitted to the alternator.

Table 7: Fuel consumption comparison of base vehicle & reference vehicle

Variant	AC ON	AC OFF
BSG	19.5 km/l	21.40 km/l
Non-BSG	18.15 km/l	19.3 km/l

Based on Fuel economy comparison between 2 vehicles measured back to back on standard NEDC drive cycle:

- 1st is base vehicle equipped with conventional powertrain.
- 2nd is reference vehicle having same vehicle configuration as base vehicle, but equipped with BSG.

From Table 7, it is can be seen that BSG unit helps reduce fuel consumption by **~7-10%,** on account of combined benefit of SAM strategy and ESS functionality. These benefits further magnify when tested in bumper to bumper traffic with frequent stop start operations.

5. PROPOSED 12V BSG ELECTRICAL ARCHITECTURE FOR A MID-SIZED DIESEL MANUAL TRANSMISSION

Referring to comparative study of 12V versus 48V BSG systems done by previous teams [7, 4, and 5] and by authors [8], 12V BSG architecture is shortlisted for the current scope of work. The key merits for going to a 12V system over 48V system for a stop start traffic with lots of traffic signals, are listed below:

- Need of DC-DC converter to connect 48V grid to 12V.
- Simple adaptation in absence of any major modifications needed.
- Depending on battery size, separate battery cooling arrangement is required for 48V system.
- Packaging constraints to house additional batteries, DC to DC converter and a battery cooling system.

The subject vehicle under proposal is equipped with a mid-sized Diesel BS4 Engine with 6 speed manual transmission.

Table 8 (**Refer Appendix at end for details**) compares various possible combinations of electrical architectures suited for a Micro Mild Hybrid vehicle, equipped with a 12V Belt Driven Starter Generator. Further by application of Pugh Matrix optimization methodology based on selective parameters, it is clearly seen that single battery/ single VSM is an optimized proposal for subject 12V BSG architecture.

- It is comparatively cost effective with limited voltage stabilization provision available for supporting uninterrupted power supply to sensitive in-vehicle electrical loads.
- VSM scores over a dedicated DC to DC converter for a stop start traffic conditions, which requires low voltage surge issues only during cranking operations.
- DC to DC converter is more viable when there is perceived voltage loss to some of heavy vehicle load demands like headlamp and interior lights. Also a DC- DC is continuous in

operation unlike a VSM which comes in operation only during cranking.

6. Conclusion and Future Scope

Based on the architectural study, special test cases evaluation on reference vehicle, a 12V single battery (with single Voltage Stabilizer for Radio/ Navigation unit) is proposed for a diesel powertrain of subject vehicle. The objective of the proposed work has been achieved with a BSG system, achieving CO2 emissions reduction of 0.136gms/km and improvement in fuel economy by ~7.5%, over a non-BSG variant. This has been achieved without de-gradation in overall performance and NVH characteristics of the base vehicle or non-BSG variant [Fig 12 & Table 10- refer Appendix at end for more details]. Further adaptation of a 12V BSG on base vehicle requires with minimal architectural changes at a lower cost.

In accordance with rapid developments in design of e-motors, battery technology for hybrid vehicles, it's possible to target for even lower Carbon footprint for these vehicles by use of:

- ✓ More efficient electric motor (operating with η > 90%).
- ✓ Superior next generation battery technologies like AGM, Enhanced flooded and Li-ion batteries [11].
- ✓ Increasing the level of hybridization: Full Hybrids (Series, Parallel or Split HEVs), Plug in HEVs.

References

1.Ipsita Banerjee, "CO2 Emissions from Land Transport in India: Scenarios of the Uncertain", Civil & Environmental Engineering, University of California, Berkeley, Page 3-8.

2.Matthew E. Caire, "Global Warming: Is it Real?", Honor thesis, 05-May-17, Page: 8-18.

3.Roberto Capata and Antonino Coccia Roberto Capata and Antonino Coccia, "Procedure for the Design of a Hybrid-Series Vehicle and the Hybridization Degree Choice", www.mdpi.com/journal/energies, 15-Mar-2010, Page: 451-458.

4.Anand Kishor Asekar, "Stop-Start system using Micro-hybrid technology for increasing fuel efficiency", International Journal of Mechanical & Prod Engg, Vol-1, Issue-6, Dec-2013, and Page: 20-23.

5.Aditya Kumawat, Amrit Kumar Thakur, "A Comprehensive study of Automotive 48-Volt Technology", SSRG- IJME-Vol4, Issue5, May-2017, and Page: 13, 15-18.

6.Marc Angelo Z. Amador, Marc Anthony C. Lina, Alexyz G. Aquino, Filipe A. Gutteres, et al "Design and Implementation of Power Management System Utilizing Super capacitors for Hybrid Vehicles", International Journal of Scientific Engineering and Technology, Volume No.3, Issue No.8, Page: 1074 – 1077.

7.Jen-Chiun Guan, Bo-Chiuan Chen, Yin-Dar-Huang, Yu-Jen Chiu, "Adaptive Power Management Strategy for Hybrid Electric Vehicle with Belt-driven Starter Generator", Proceedings of 2015 IEEE 12th International Conference on Networking, Sensing and Control Howard Civil Service International House, Taipei, Taiwan, April 9-11, 2015, Page: 503, 506 & 507.

8.Saurabh Belsare, HP Khainar, Priyamvad Mishra, "Benchmarking, Target setting & Evaluation of a Belt Driven Starter Generator (BSG) for 2.0 L Diesel Engine", International Journal of Recent Trends in Engineering & Research Vol 3 Issue 6 Jun-2017, Page: 318-320.

9.Luke A. DeBruin, "Energy and Feasibility Analysis of Gasoline Engine Start/Stop Technology" https://kb.osu.edu/dspace/bitstream/handle/1811/54555/Start-stop_Thesis.pdf.

10.Chan-Chiao Lin, Huei Peng, Jessy W. Grizzle, Fellow, IEEE, and Jun-Mo Kang, "Power Management Strategy for a Parallel Hybrid Electric Truck", IEEE Control systems, Vol-11, No.6, Nov-2003, Page: 839-845.

11.Alan Soltis and Xiang Chen, "A New Control Strategy for Hybrid Electric Vehicles", University of Windsor, Proceedings of the American Control Conference Denver. Colorado June 4-6, 2003, Page: 1398-1399.

12."Impact of Worldwide Test Procedures on Advanced Technology Fuel Efficiency Benefits"- A. Rousseau,1 Yi Ding, EVS27 Barcelona, Spain, November 17–20, 2013, Page: 1-8.

Acknowledgments

- The authors would like to thank FCA Engineering India Pvt Ltd, in particular Mr. Ramesh Gogineni and Mr. Pankaj Dahad (APAC – Engg), for providing a challenging opportunity and guidance during course of work.

- Authors also like to express their gratitude towards Mr. Ed Kirk, Mr. Velu Saravana Kumar & Mr. Shane Berger (From FCA Engg Ltd); for their efforts to define and refine a robust and unique functional objective document for a 12V BSG Hybrid vehicle for mid-sized Diesel powertrain with Single battery & Single VSM."

Definitions/Abbreviations

BSG	Belt-driven starter generator
ISG	Integrated starter generator
HEV	Hybrid electric vehicle
IBS	Intelligent battery sensor
ESS	Engine auto start-stop
VSM	voltage stabilization module
ECU	Engine control unit
BCM	Body control module
FEAD	front-end accessory drive
ICE	Internal combustion engine
SOC	State Of Charge
AGM	Absorbent glass Material
EFB	Enhanced flooded battery

Reference Vehicle It is a compact C-segment Diesel sedan class mild hybrid. It is equipped with 5 speed manual transmission, a 12V BSG (4 kW peak output power) with 70Ah Enhanced Flooded battery. It combines the capability to provide torque assist of around 5 Nm and limited regenerative charging capability.

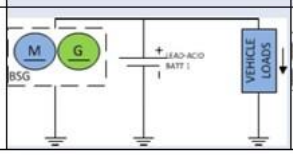
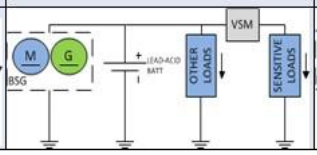
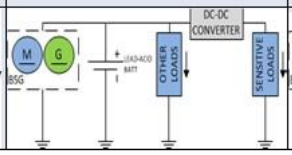
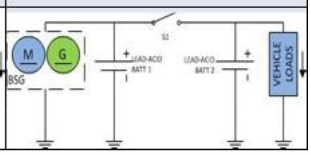
Kerb weight = 1135kg
Max available torque = 200Nm

7. Appendix

Table 2: Reference vehicle ESS Matrix

	Door	Seat Belt	Result	Remarks	Conclusion
Engine Stall	Closed	Closed	ESS Functional	BSG start available	The BSG driven start will be available if and only if seat belt is fastened. This is an input to the logic of driver occupancy.BSG will work if seat belt is fastened and driver side door open or closed irrespective of it.
	Open	Open	ESS Not Functional	BSG start not available	
	Open	Closed	ESS Functional	BSG start available	
	Closed	Open	ESS Not Functional	BSG start not available	
Forward motion	**Door**	**Seat Belt**	**Result**	**Remarks**	**Conclusion**
	Closed	Closed	ESS functional	BSG start available	BSG driven start will be available only when driver side door is closed and driver side seat belt is fastened while considering forward motion.
	Open	Open	ESS not functional	BSG start not available	
	Open	Closed	ESS not functional	BSG start not available	
	Closed	Open	ESS not functional	BSG start not available	
Forward Gradient	**Door**	**Seat Belt**	**Result**	**Remarks**	**Conclusion**
	Closed	Closed	ESS functional	BSG start available	BSG driven start will be available for all combinations of door and seat belt except for when door is open and at the same time seat belt is not fastened. This is because engine activation is needed for powering up the EPS module and having sufficient brake pressure. Safety and ability to maneuver on slope is given priority.
	Closed	Open	ESS functional	BSG start available	
	Open	Closed	ESS functional	BSG start available	
	Open	Open	ESS not functional	BSG start not available	
Backward Gradient	**Door**	**Seat Belt**	**Result**	**Remarks**	**Conclusion**
	Closed	Closed	ESS Functional	BSG start available	BSG driven start will be available for all combinations of door and seat belt except for when door is open and at the same time seat belt is not fastened. This is because engine activation is needed for powering up the EPS module and having sufficient brake pressure. Safety and ability to maneuver on slope is given priority
	Closed	Open	ESS Functional	BSG start available	
	Open	Closed	ESS Functional	BSG start available	
	Open	Open	Ess not functional	BSG start not available	

Table 8: Evaluation of Possible 12V BSG System Architectures Using Pugh Matrix Optimization Method [© Priyamvad Mishra & Phaneendra Varma, 27-Feb-18]

Comparative Parameters	12V Standalone Lead-acid Battery	12V Standalone Lead Acid Battery + Voltage Stabilizer	12V Standalone Lead Acid Battery + DC: DC converter	Dual Lead Acid Battery
Packaging	O	-	-	--
Vehicle Electric Architecture Impact	O	-	-	--
Maintenance	O	O	O	--
Cold Cranking capability	+	+	+	++
Torque Assist capability	+	+	+	+
Regeneration Performance	Limited energy recovering	Limited energy recovering	Limited energy recovering	Optimized energy recovering
Voltage regulation	Oscillation on Voltage net	Sensitive loads voltage stabilized for less than 1 sec	Sensitive loads voltage stabilized for less than 5 sec	Loads voltage stabilized
Loads Impacted	All loads	Inductive loads and rest of loads after 1 sec	Inductive loads and rest of loads after 5 sec	None of the loads
Costs (USD for annual volume: 53k)	AGM battery 60Ah: $70 Total: $70	AGM battery 60Ah: $70 VSM 200W: $19 Total: $89	AGM battery 60Ah: $70 DC: DC CONV 450W: $100 Total: $170	AGM battery 1 (60Ah): $70 AGM battery 2 (20Ah): $46 Solid State Switch: $29 Total: $145
Electrical diagram				

- Architecture Proposal for 12V µHybrid Vehicle
- The DC/DC converter costs can vary depending of the level of sensitive loads

Table 9: Cranking profile comparison of Starter motor & BSG crank

System Parameters	Conventional crank (By starter motor)	Auto Start (By BSG)
Peak current	800A	500A
Cranking current	220A	300A
Max voltage dip	3.5V	2V
Crank duration	0.9sec	0.5Sec

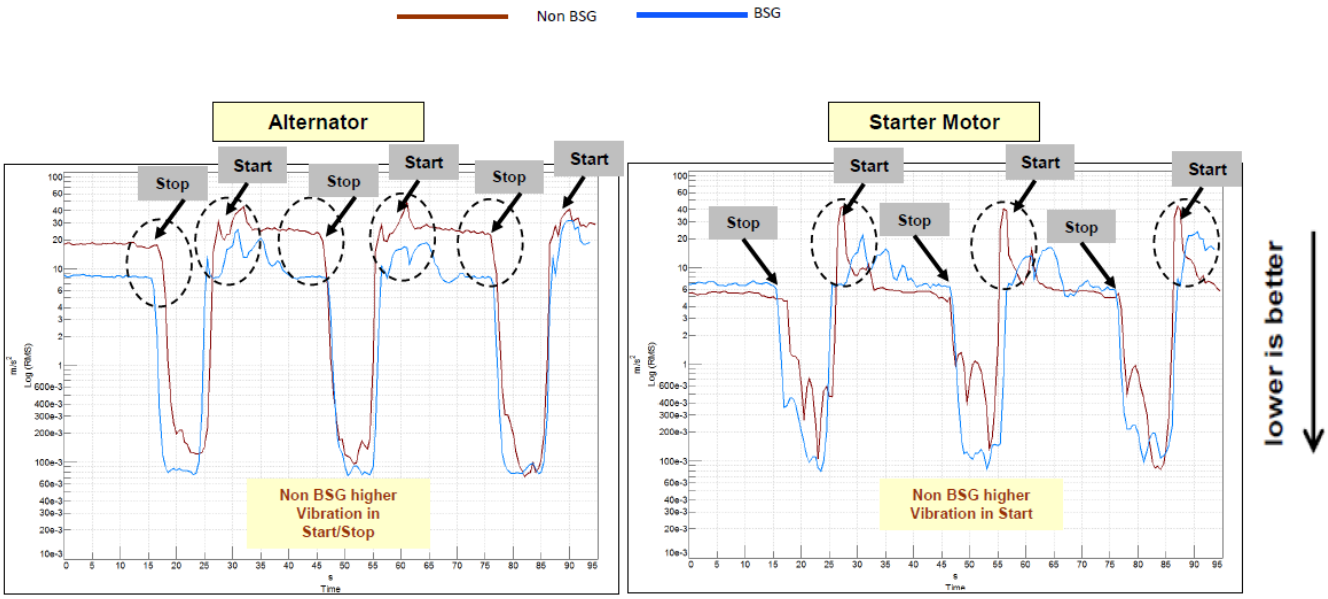


Fig12: NVH characteristics of base vehicle (non-BSG) & BSG variant

As compared to base vehicle,
- Vibration level is lesser on Alternator & starter motor locations in BSG vehicle during both Start and Stop Events

Table 11: Performance Comparison of base vehicle (non-BSG) & BSG variant

Acceleration Performance	AC ON (Time in Second)			AC OFF (Time in Second)		
Parameter	BSG Vehicle	Non BSG	BSG improvement as compared to Non BSG (%)	BSG Vehicle	Non BSG	BSG improvement as compared to Non BSG (%)
0-60 kmph	6.0 sec	6.2 sec	**3.2 %**	6.0 sec	5.9 sec	**-1.7 %**
0-100 kmph	14.5 sec	14.9 sec	**2.7 %**	14.5 sec	14.8 sec	**2.7 %**
0-120 kmph	20.1 sec	20.6 sec	**2.4 %**	20.0 sec	20.4 sec	**2.0 %**
0-400 m	19.5 sec	19.7 sec	**1.0 %**	19.7 sec	19.8 sec	**0.5 %**
0-1000 m	35.4 sec	35.8 sec	**1.1 %**	35.3 sec	36.0 sec	**1.9 %**