A Comprehensive Study of Automotive 48-Volt Technology

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Abstract

The increasing rate of pollution due to vehicles has forceddown all the major nations to set the new limits of emission rate as well as fuel consumption rate, for both present and future. To meet these limit values, theautomotive industry is continuously developing various technologies such as improved aerodynamics, lightweight design, more efficient transmission, regenerative braking, advanced exhaust pipe, low rolling resistance tires etc. But almost all the technologies have reached their performance limits and their further improvement results in very small changes. The advantages of high voltage system have already been purposed by the Hybrid vehicles and Electrical vehicles. The introduction of 48V technology has produced highly efficient and advanced mild-hybrid vehicles which are showing improved results compared to both the normal and hybrid vehicles. The 48V technology is advanced to the other high voltage technologies as well as being within the safety limits of 60V for prevention of human shock. The system has introduced various new technologies such as Starter-Generator which can work as the starter as well as torque provider during the motion of avehicle, advanced regenerative braking, electrically driven rearaxle, electric compressor, electric pumps, electric power steering pump etc. The best feature of the technology is that it can be installed easily in any vehicle segment along with the conventional 12V system, with slight variation in thearchitecture of vehicle, in both gasoline and diesel engine vehicles. The 48V system can provide from 12 to 15kw power, reduced fuel consumption by 10-20% and reduced exhaust emissions up to 15%. The technology gives an advanced base for the further trend of future technologies such as advanced electronic powertrains, replacing the conventional mechanical and hydraulic loads from powertrains with the electrical loads and the new electrical components in vehicles, resulting in further improvement in performance and efficiency. The commercialization of 48V technology can bring a new revolution in theautomotive industry.

Keywords – 48V technology, emissions, fuel economy, high-voltage, mild-hybrids.

I. INTRODUCTION

With the increasing number of automotive along with the increment of exhaust emissions, the emission standards for various countries are becoming strict. US, China and Europe have already set their targets for vehicle economy and emission control. Car makers in the US have to double their average fuel economy up to 54.5mpg by 2025, while China being strict on carbon emission has set the limit to down CO_2 to 117gm per km by 2020 and for same year Europe has set fleet averages of 95g/km only [1].



The automotive industry has made many advancements to achieve higher efficiency and lower emissions, especially after the introduction of the emission standards. For the efficient vehicle, automotive companies have designed various types of engines, transmissions, chassis, exhaust system, suspension system, electric system, tires and other automotive parts. They have also come up with completely new concepts of additives in fuels, full and mild hybrid vehicles, alternative fuels etc. to sustain for the future competition. The developments in theelectric system of vehicles have resulted in highly efficient models. One more advancement has been successfully implemented by few automakers that is to change the existing electric system of 12V to 48V.

Although at the beginning of the 90s, major vehicle manufacturerswere evaluating the benefits of high voltage and even a 36/42V system was

introduced in two car models in Japan and US. The system was effectively a 36V system which was named as the 42V system [2]. Thought it ensure three times the voltage as the 12V system but at thattime it was not cost effective compared to the functional benefits. Further at that time, the importance of high voltage was neglected which resulted in thefailure of the36/42V system. But in recent years again the importance of high voltage was recognized because of increased number of electric circuits in a vehicle and need of high efficiency along with low emissions. A new system of 48V came into existence which gives four times the voltage and being under the limit of 60V (the maximum permissible contact voltage)[2].



Overvoltage countermeasures to be activated,

Upper Limited Operation Range 52...54 V Regenerative braking peak admittance

Standard Operation Range 36...52V Full Components Performance

Lower Limited Operation Range 24...36V Countermeasures to be activated to return to the standard operation range

Operation to be monitored as event by diagnostics

Figure 2: Voltage Ranges

The 48V electric system in mild-hybrid vehicles has resulted in downsized engine with higher fuel efficiency and minimum loss of engine performance along with the lower exhaust emissions [3]. The existing non-hybrid vehicles can barely continue to meet the coming emission standards, while on other hand full-hybrid vehicles are highly costly. So this new concept of mild-hybrids has been more promising in both aspects of efficiency and cost. The introduction of 48V technology helps to replace the components of the conventional 12V system that runs the engine with advanced electrically driven systems, resulting in improved performance and efficiency.

A study by HELLA, a German-based automotive supplier, found that a 48V mild-hybrid system has the best potential to reduce CO₂ emissions for all car segments for both NEDC (New European Driving Cycle) and WLTP (Worldwide harmonized Light vehicles Test Procedure) [4]. Various automotive companies like Delphi with Honda, Mercedes-Benz, BMW, Continental, Schaeffler with Audi, Daimler, Porsche, Volkswagen etc. have already made prototypes or models with this technology. Leading auto-industry experts also say that the 48V system can be really promising in lowering the emissions to a great extent along with capturing energy lost in braking and can provide a good torque even in the low rpm range to start-stop hybrids [3].

II. ARCHITECTURE

Over the past few years, there has been an increased load on theelectrical system of vehicles due to the advanced engine technologies, sensors, safety, infotainment etc. to make smarter vehicles, but this increment in electrical components are at the same time becoming challenging with the conventional 12V To meet the challenge of high voltage, system. automakers have also developed Power Electronics Circuits which make the system smaller and lighter. This provides the basis for improving the fuel efficiency as well as providing sufficient power to other electrical components [5]. Thus the increased electrical circuitshave led to the demand of high voltage system such as 48V system.

The best thing about the 48V system is that it doesn't replaces the conventional 12V electrical system of a vehicle, rather it is connected to the 48V system via a DC-DC converter [1]. This also provides a benefit of using the 48V system in the vehicles which are runningon the 12V system. The automakers have presented various possible architectures of the 48V system. Delphi has proposed a 12V-48V Base Architecture which can be installed in all types of vehicle i.e. Non-Hybrid, Mild-Hybrid and Full-Hybrid vehicles [2],[6].



Figure 3: 48V Base Architecture

The base architecture comprises the conventional 12V system being powered via a DC/DC converter at thepower of 3kw, and the 48V system at 12kw for high voltage requirement such as for Motor/Generator, acceleration support etc. with a storage device on 48V. After the installation of the48V system in a vehicle all the functions of high power can be easily operated as almost all the

functions have power levels around 500Wto 5kW. Currently, the automakers are not planning to substitute the whole 12V system with the48V system since the conventional 12V system is standard worldwide [6].



Figure 4: 12V/48V Electrical Architecture

In mild-hybrid vehicles, the electric energy is mainly used to enhance the overall energy from the combustion engine. With the proper control system of the two energy sources of themild-hybrid vehicles, significant savings in fuel can be obtained typically up to 10% - 15%, but even up to 30% has been obtained in some demonstrator vehicles [7]. With the installation of a 48V system, not only the high-voltage issues are resolved but also the electrical architecture has theadvantage of four times the voltage than the normal 12V system, hence the vehicle gets four times the power at the same current. Though this 48V electric architecture is comparatively costly but far better with the simple and less dangerous than the current electric systems. With the 48V architecture, the vehicle can run on 12V for lowpower accessories and on 48V for high-power systems at the same time [8].

III.BENEFITS

The main purpose of the 48V system is to reduce the emissions with advanced ignition technologies, start-stop features, powering high load components etc.The 48V system gives an advantage to the components like air conditioning compressors, coolant and oil pumps, power steering pump etc., which can be run on high voltage directly, to be cut-off from the engine. Furthermore, the high voltage gives the advantage to use more efficient fuel technology and to run the additional electric components such as superchargers. Thus directly resulting in high performance with high efficiency and lower emissions [9]-[11]. Furthermore, the installation of 48V technology provides additional torque which gives abetter dynamic performance and handling over the conventional 12V system [2].



Figure 5: Benefits of 48V system

The leading automotive developers working on the 48V technology are claiming that hybridization with 48V technology can reduce the fuel consumption from 10% to 15%, and with some additional technologies, it can reach up to 21% [12]-[14]. The reduction in fuel consumption is mainly due to the removal of additional loads of engine which can be directly operated by ahigh voltage of the48V system. Furthermore, the recovery of the kinetic energy lost in braking helps to make an efficient system [14]. Delphi claims that the 48V system can significantly reduce the NOx emissionsas well which directly result in alow cost of exhaust after-treatment components [13]. The reduction in CO_2 emissions can be 12%-15% for passenger cars and light commercial vehicles. In addition to this, the 48V system can also provide the boost in engine performance up to 15kw [15]-[17].

Figure 6 shows the additional power gain with the increment of voltage level along with keeping the current limit at the safety limit [6].



The 48V provides a very good torque at engine start which helps in a quicker engine start with less vibrations. In addition to that, it gives better torque even at low rpm rangeand improves the startstop function. The strong electrical system easily allows the internal-combustion engine to shut off in more situations directly resulting in enhanced fuel saving [9],[13]. The industry experts believe that the 48V system can also help in reducing the engine size for the same power output and efficiency without the loss of engine performance [12]-[13].

There is increasing trend in the additional features in a vehicle such as automatic airconditioning system, automatic headlamps, automatic parking system, advanced infotainment system and various safety features like more number of airbags, rain-sensing wipers, advanced rearview and side-view mirrors, various sensors etc., which totally depends upon the electric system of thevehicle. Here the 48V system provides the ease of using all the electronic components because of availability of more voltage and current than the 12V system. Further development of such new technologies will directly have the benefit of the48V system [6]. In addition to that, there is no requirement of protection system such as High Voltage Interlock System (HVIL) for anelectric shock as the 48V system is under the limit of 60V (the limit of DC-Voltage of ashock for humans) [5].

IV.LIMITATION

The main challenge to the 48V system is converting the huge number of vehicles to 48V systems when the 12V system is being standard from the beginning [9]. Though the 48V system does not replace the 12V system, but still the manufacturer needs to redesign the components and electrical system which will run over the48V electrical system. Furthermore, the 48V system will need space in thevehicle to be installed and that mean redesigning of thecar for that additional system, electrical circuit and required space.

In addition to that additional safety precautions are needed while designing the 48V electrical system. Even a single malfunction between 48V and the12V electrical system will lead to short circuit and this can damage the complete 12V system due to overvoltage. Since chassis is common ground potential for both 12V and 48V, loss of this common ground may lead to the damage of 12V system due to the reverse voltage on the12V system [6].

The components running on the 48V system are to be designed accordingly, for example, the belt should be designed for increased torque, change in tension load and start-stop feature, crankshaft bearing is to be more durable etc. The 48V system increases the cost from \$800 to \$1000 of a car, while almost all the manufacturersare working on decreasing the cost of the vehicle. Hence this system is only practical when it gives a good cost/benefit ratio [9].

V. DEVELOPMENT & IMPLEMENTATION

The incompatible benefits of the48V system over the 12V or another volt systems (less than 60V i.e. in therange of safety for theshock to human) have been identified by various automakers, hence they have made their prototypes and models for the real testing of the 48V system. Though the system has been applied only on mild-hybrid vehicles because of two obvious reasons: first the use of advanced hybrid technologies such as Start-Stop feature, Regenerative Braking, Advanced fuel system etc. by almost all the OEMs in their vehicles and the second reason is the less cost-effective benefits on applying the 48V system on very normal vehicles.The leading automakers Audi, BMW, Daimler, Porsche and Volkswagen originally proposed the use of the48V system in vehicle [7]. After then many other industries and researchers are developing the 48V technology continuously to bring a new emerging technology in Auto-Industry.

Audi was the first who used the 48V technology in its production car SQ7. Though the car wasn't hybrid rather it had a 48V driven turbine so as to force additional air into the combustion chamber to provide surplus power when needed. The car also has active suspension system running on 48V [10]. Audi has shown their 48V electrical system in their concept cars RS 5 TDI and A6 TDI, which works alongside the conventional 12V system. Audi believes a 10kW gain of power from the48V system. Audi is using 48V Lithium-ion battery so as to supply 48V to the system when theengine is not running, while a DC-DC converter provides 12V supply to the accessories running on 12V. It also comprises a 48V compressor which can feed extra air to theengine to have increased acceleration independent of the load. Audi believes the reduction of up to 10gm CO₂/Km and saving of around 0.4-liter fuel per 100Km [18]-[19].



Figure 7: Audi RS 5 TDI 48V system

The renowned technology developer Bosch has developed 48V technologywith Audi. Bosch believes that the 48V system could provide up to 10kW power along with the increase in fuel efficiency by 15% along with providing more dynamic acceleration. The company also says that mild-hybrid concept allows theuse of less expensive components and claims that with the use of ultrasonic sensors, the 48V technology can assist in theautomated parking [20].

Schaeffler presented a 48V mild hybrid concept vehicle, based on Audi TT. The demonstrator vehicle comprises a 48V belt-driven starter generator. The vehicle has an electric rear axle running on the20kW motor while the front axle being driven by theengine. The rear electric axle can provide pure electric driving up to 35Km/h along with a starting torque of up to 2,000 Nm and smoother driving after 70km/h. Further, the use of two axles provides more improved torque vectoring to the wheels improving both the driving and safety of vehicle [21].

UK's leading automotive companies and academia Ford, Ricardo, CPT, EALABC, Faurecia and the University of Nottinghamare working together on a project known as ADEPT, which is a 48V mild hybrid system comprising various advanced mild hybrid technologies. ADEPT has been implemented on demonstrator car Ford Focus, using an advanced Lead-Carbon battery [10],[17],[19],[22]. It has an advanced water-cooled starterwhich offers advanced and fastacting Start-Stop feature. The starter provides additional functionality of working as asupplementary motor drawing current from the48V system, giving better torque-assist at launch and quick acceleration, improved cruising, in-gear coast-down and leaner fuel calibration along with harvesting more energy from regenerativebraking [10],[19]. The ADEPT team also believes that the 48V system along with turbocharged technology can provide same power output with 1liter engine as that obtained by a normal 2-litre engine, hence providing the reduction of engine size and other components at same power output, reduced fuel consumption of 10-12% and lower emissions [10],[17]. The ADEPT claims that its powertrain concept can also be used in gasoline and other alternative-fuel driven vehicles [17].

Mercedes-Benz is introducing 48V mild-hybrid technology in its S-Class series which will have a 48V crankshaft-mounted Integrated Starter Generator along with a powerful 48V battery [12]. The company is developing a new series of both the petrol and diesel engines which will run on 48V technology. The 48V technology enables the company for developing new advanced technologies such as Integrated Starter-Alternator (ISG), advanced intelligent turbocharging and electric auxiliary compressor, providing excellent engine response and no turbo-lag. Mercedes-Benz claims that with the 48V technology on thenew engine a boost of up to 15kw and energy recovery of up to 12.5kw can be obtained. Further, the company claims to have improved fuel economy, Start-Stop feature, cylinder activation-deactivation, coasting with engineoff, quick start and lower exhaust emissions [23].

Founding the advantages of 48V system, ACCUMOTIVE, subsidiary ofDaimler, will produce Lithium-ion battery for Mercedes Benz's 48V mild hybrid vehicles [24].

Delphi has developed a48V system with a customized vehicle architecture so as to obtain maximize battery power and to reduce the burden on theengine with more advanced technologies. Delphi has designed the 48V system in such a manner that it can work along with the existing 12V system of a vehicle without any specific change in thedesign of thevehicle, with sticking on its 48V system architecture. Delphi is focusing mainly on passenger cars and light commercial vehicles and claims that it can significantly improve torque in low rpm range, regenerative braking, start-stop feature and can quicken engine starting with less vibrations [13]. Delphi also purposed of using 48V technology for dynamic chassis control. Further adding to its uses Delphi says that the components running on engine power such as ac-compressor, power steering pump, coolant pump etc. can be removed from theengine and can directly be run on 48Vsystem. Delphi believes that car can also start for 100m with electric propulsion [16]. Delphi is testing the 48V mild hybrid system on Honda Civic 1.6-liter turbo-diesel and have found significant results [25].



Figure-8: Delphi's 48V system architecture

Delphi claims to have an increment of fuel saving up to 15% along with a reduction in CO_2 emission up to 15% and asignificant reduction in NOx emissions as well. It also says the reduction in engine size is possible without any loss of engine performance and with the 48V system up to 10-12% extra power can be obtained from the engine. The 48V system can provide 70% of benefit compared to the higher voltage mild-hybrid vehicles at only 30% of the cost [13].

Lead-Acid The Advanced Battery Consortium (ALABC) and Controlled Power Technologies (CPT) are working on a program called as low-costlead-carbon LC Super Hybrid which is based on 48V technology [26]. The technology is being experimented on a 1.4 liter Volkswagen Passat car, which has shown impressive results on their existing 12V LC Super Hybrid technology. The technology is aiming CO₂ emissions of 120g/km with theacceleration of 0 to 100 km/h in less than 9 seconds and additional 4-8% improved fuel economy compared to its 12V LC Super Hybrid [27]. The technology is further claimed to be advanced to use the other advanced technologies as well with 48V which are suggested and being used by other companies, but at a comparatively low cost [15].

Valeo has developed the 48V technology, which can be installed in all vehicle segments, to both petrol and diesel engines, and is well suitable even for the commercial vehicles. Valeo has made a 48V e4Sport Hybrid system which consists of three components: a 48V Belt Starter-Generator with integrated electronics, a 48V electric supercharger and a 48V electric rear-axle [28]-[29]. The system is claimed to provide quicker start/stop of theengine, high torque at low engine speed, more efficient regenerative and braking overall improved performance [29]-[30].Further, the fuel economy is claimed to be improved by 3-8% in medium duty vehicles, 5-10% in light-duty vehicles and up to 20% less CO₂ emissions [29].

Continental is also producing 48V hybrid drives which will be used in Renault's new diesel models: Renault Scenic and Grand Scenic. They say that with the 48V drive, theengine can be started in 0.2 seconds only. Renault is aiming an improved fuel consumption of 3.5 Liters per 100 Km, reduced CO₂ emissions of 92 gm/Km and reduction of NOx emissions by 10% [14]. Continental claims to have 13% more fuel saving at affordable system costs with the 48V technology [31].

VI. CONCLUSION

The automotive industry has to evolve itself to meet the requirements of the current as well as future limits of fuel consumptions, emission standards, electric components, improved performance etc. and with the conventional 12V system it is very difficult to meet all the requirements. The 48V technology is more promising, highly efficient and cost effective to meet all the current and future requirements for both mild-hybrids as well as non-hybrids. The outputs of 48V technology and its potential have been found by various automakersand they are continuously working on the development of this technology on the vehicles.

The Navigant Research firm predicts that by 2024 there will be nearly 60 million vehicles will have thestart-stop technology and more than 7 million vehicles will have the 48V technology as mild-hybrids [9]. Delphi's chief technology officer says that by 2025, 10% of new vehicles across the world will be mild-hybrids based on 48V technology [25]. Bosch also expects that by 2020 around 4 million new vehicles worldwide will be based on its 48V mild-hybrid technology [20]. The Global Insight IHS anticipates that 1 out of 10 cars sold across the world will be a 48V mild hybrid by 2025. By thesameyear, it is also expected that more than 95% of total mild hybrids and around 50% of fullhybrids will be based on the48V system [13].



Worldwide 48-volt, Mild Hybrid Production Volumes





Figure 9: Growth rate of 48V System Worldwide

The interest of the technology developers clearly shows that the 48V technology will be one of the new leading technology in the future vehicles. The 48V system will not just reduce the fuel consumption and emissions, rather it will give more vehicle power, active safety systems, advanced electrical systems and reduced cost of electrical components. The technology will provide a more advanced platform for the development of new future technologies such as smart connectivity between cars and traffic system, automated parking, advanced electrical features etc. [25],[32]. Definitely, the continuous improvement and

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developments of new technologies based on the48V system will set a different trend of development in theautomotive sector and the technology will soon dominate the future market.

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