Direction of Powertrain Technology for CASE Deployment in Railway Vehicles

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CASE (Connected, Autonomous, Shared & Service, and Electric) must be recognized as a comprehensive technology resulting from the rapid progress achieved in the field of automobiles, in terms of development and introduction of the newest technologies. It is also a fact that these individual technologies were incorporated into the railway vehicle sector from a relatively early stage. In automotive industry now, the key to realizing fresh value from CASE lies in EVs (Electric Vehicle). This paper first introduces the CASE technologies that have already been applied to railway vehicles. Then these technologies are compared with the latest advances emerging from the development of EV automobiles, in order to understand the nature of these changes in relation to on-vehicle powertrain and power electronics equipment. Finally, the technical aspects of these changes are outlined.

Keywords: powertrain, power electronics, CASE, MaaS, EV, railway vehicle, modularization

1. Introduction

The fast development and introduction of new comprehensive technologies “CASE” (Connected, Autonomous, Shared & Service, and Electric) in automobiles over the last few years can inform the development of railway vehicles despite the individual technologies of CASE having been applied to railway vehicles from a relatively early stage. In the automobile industry, new value has been added by CASE primarily because of its application to the electrification of vehicles.

This article first summarizes each of the CASE technologies, and then looks at these technologies to see how CASE has been incorporated in railway vehicles to date. Then, we characterize the changes in the technological environment surrounding on-vehicle powertrains and power electronics equipment by comparing the latest technologies in development for automobiles. Finally, some technological items are proposed in response to these new trends.

2. CASE corresponding categories implemented in railway vehicles

2.1 Technical essence of each CASE category in automobiles

CASE was first proposed by Dr. Dieter Zetsche, the CEO of Daimler, at the Paris Motor Show on September 29, 2016. CASE has been described as the “CASE revolution = IoT x AI x electrification of vehicles [1].” Each initial of the word CASE corresponds to a concept, which are presented below: it is important that they are integrally packaged in a seamless manner.

2.1.1 Connected

Telematics is “the combination of the terms telecommunication and informatics. Some representative examples of this include, Intelligent Transport Systems (ITS), which in turn include a Vehicle Information and Communication System (VICS) and Electronic Toll Collection System (ETC); and telematics insurance determined by insurance premium rates linked to driving behavior data (driving distance, maximum speed, sudden start/stop frequency, etc.) [1].” In other words, it is streamlining driving related matters as well as increased entertainment by connecting with car-mounted multimedia and “out-car” area information using smartphone linking, partial sensor information, and voice recognition. This does not intervene in the control of the vehicle itself.

In response to this, Connected, which was proposed as “internet ITS” (IITS) at the time, is a “concept where the entire platform is organically included as a result of the car itself acting as an IoT terminal to connect with the network. Includes firmware updates using Over The Air (OTA) wireless connection, remote control of self-driving cars, and development of new services linked with big data. A Higher-level concept than telematics [1].” In other words, this signifies not only multimedia information connection but also the development of a single system that links vehicle controls and the out-car area, and includes in-car area applications, such as vehicle software updates, which include vehicle OS and vehicle control application program interface (API); initiatives for transit-time map and traffic information and reflecting on route setup; and remote maintenance due to the collection and analysis of transit-time data as control results.

Necessarily, this presumes an Internet of Things (IoT) information network in the form of a mobility service platform, and requires transmission infrastructure, cloud computing, data centers, and software development as a set. However, there are only a few automobile manufacturers in the world which can handle the necessary scale of investments, and other automobile manufacturers need to choose one of the above-mentioned automobile manufacturers or IT businesses as a platformer. A point of caution is IT businesses taking control of in-car area factors such as the vehicle OS, making automobiles a commodity and rendering them as simply moving boxes in terms of IoT architecture. A countermeasure on the automobile manufacturer side requires open / closed tactics that prevent IT businesses from control-
ling the core of vehicle controls, such as setting up an open architecture vehicle-connected OS, or closed gateways against smartphone linking; these have been put into practice.

2.1.2 Autonomous

The level of automatic operation [2] varies depending on service cars presumed to be used for public use (MaaS vehicles: Mobility as a Service) and personally owned vehicles (POV). For this reason, future introduction ratios are expected to be different.

In a narrow sense, MaaS is “the multimodal movement that combines public and private transportation methods” and in a wider sense, is “a mobility solution that resolves social issues indicated by Society 5.0, such as environmental problems, declining birth rates and an aging population, and depopulation.” In addition to existing taxis, buses, and ride-shares/car-shares, there is ongoing development on unmanned fixed-route buses, automatically-operated taxis that may even be on the “last mile” method (robot taxis), and drones that automatically deliver packages. Japan has set target levels as defined by the Society of Automotive Engineers (SAE) [2] for driverless MaaS vehicles to be at automatic operation level 4 (all operational tasks are conducted by the system under specific conditions, and responsibility lies with it: brain free) by 2020, level 3 (system conducts operation but the driver holds responsibility: eyes free) on highways with owner cars by 2020, and level 2 (system conducts steering, braking, and turning, and the driver holds responsibility for observation and all other operations: hands free) on standard roads by 2025.

This is due to the difference between service cars and owner cars: “owner cars have more diverse uses and are not geographically limited in their movement and require a sufficient amount of time for the implementation of fully automatic driving. Meanwhile, service cars such as buses or logistics vehicles (MaaS vehicles) have limited uses and ranges, so automatic driving implementation will be relatively faster.”

The movement distance ratio of MaaS vehicles among current total automobile driving distances worldwide (approximately 1.6 x 109 km) is approximately 2% [1]. Meanwhile, the annual vehicle operation rate of owner cars (2013) was 4.8%, and the remaining 95.2% was in parked conditions. From the above, an expansion of driving distances of automatically-driven MaaS vehicles is expected.

2.1.3 Shared and Service

Rideshares have expanded with the combination of “Connected” aspects, and in addition to the transition from taxis for dispatch services, has begun to be alternatives of owner cars or rental cars. There is currently a driver involved, but the development of a multimodal MaaS that is connected with automatic operation is expected in the future. There have been announcements in Japan that dispatch service operators will begin operation using hybrid vehicles specifically for ride-shares from 2021; and MaaS-specific multi-purpose automatically driven EVs developed in 2018, which transports cargo as well as people, will come into commercial service from 2023 onwards.

2.1.4 Electric

“If AI (artificial intelligence and also augmented intelligence) are technological revolutions that will bring about freedom of movement, then electrification of vehicles is the (for the automobile industry, supreme) technological revolution that ensures that freedom in the truest sense [1],” but it is also understood that motorization will not become easily widespread without any significant technological breakthroughs. Storage batteries, or fuel cells particularly, present major challenges as energy sources. For this reason, progress of electrification of vehicles is predicted to be both rapid and gradual.

The federal and municipal governments in The Netherlands approved a ban on the sale of engine-mounted vehicles in combination with bans on driving them into the capital from 2030 onwards [3], and similar measures have also been adopted by the Bundestag in Germany [4]. However, the situation is difficult, with only a fraction of EVs making up global passenger car sales in 2017, at 1.4%.

Volkswagen (VW), was forced to switch tactics after its diesel emissions scandal, and suggested the entire group seek to reach an EV sales rate of 25% (45% when including HEVs and PHEVs) and storage battery cell purchase volumes of 150 GWh / year by 2025 [5]. Meanwhile, Daimler views the gradual decrease of storage cell prices for the time being, and the difficulty of obtaining storage cell material as well as its price increases due to rapid electrification of vehicles, as risks and has therefore decided not to be overly dependent on a single power source [6].

This is the so-called powertrain mix strategy.

Specifically, this involves producing and selling region-specific ratios of engine vehicles (including diesel), hybrid vehicles (HV), plug-in hybrid electric vehicles (PHEV), electric vehicles (EV), and fuel cell vehicles (FCV), meeting the minimum requirements to clear regulations such as the zero emission vehicles (ZEV) in California, new energy vehicles (NEV) in China, and corporate average fuel efficiency (CAFE) in Europe. The greenhouse gas emission intensity at the time of power generation in that region is dependent on the power generation method’s distribution ratio (i.e., energy mix), so the distribution ratio of the electric vehicle production / sale is also optimized according to this as well.

Mechanical/electric integral-type turnkey products such as the “e-axle,” which combines an inverter, motor / generator, and reducer as a single unit, have also recently been introduced. This results in installation space efficiency, increase in performance, weight reduction, makes its generic use for different powertrains much simpler, and is expected to increase development productivity.

2.2 Previous railway vehicle technologies corresponding to each CASE category

The technological items that correspond with the origins of each CASE category can be said to have developed at a relatively early stage in railway vehicles. The railway technologies corresponding with the above-mentioned automobile CASE technologies and their future developments are shown in Table 1.
3. Changes in the environment surrounding powertrains

3.1 Shifts from an integral to modular style of design architecture

The added value of assembly process parts has decreased in many manufacturing industries, and this is gradually becoming a “smile curve” design where added values either move upstream to materials and devices, or downstream to businesses and services. MaaS progress in the future will increase demand of driverless service cars in the automobile industry, and there is the possibility of...

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**Table 1: Previous railway vehicle technologies corresponding to each CASE category**

| Technic category | Preceding technology in train vehicles | Advancing technology in the automobile industry | Novel technologies with potential for the railways |
|------------------|---------------------------------------|-----------------------------------------------|-------------------------------|
| Connect          | Inner-train                           | In-car                                        | In-vehicle                    |
|                  | Multiple unit tandem control          | ECU (electronic control unit) integrated control | Deployment of analysis and maintenance of big data |
|                  | Control command train line by metal wire | CAN-FD (Control Area Network with Flexible Data rate) bus | “Self-maintenance” |
|                  | Monitoring information train line     |                                               | Customer service               |
|                  | (automatic collection of failure detection / condition monitoring data) |                                               | · Pleasant/unpleasant control |
|                  | Automatic aggregation of train data by wayside LAN (partially wireless) to data driven action bases on ground | Telematics (ITS) | (E.g. temperature or smell of air conditioning, restrooms, etc.) |
|                  | Train control communication network (drive / brake command) by Ethernet bus | On-board multimedia with voice recognition, smartphone linking | · Partial automation of cleaning operations inside turnaround trains at terminal stations |
|                  | Outside-train train radio (to digitalized) | OTA | · In-vehicle sale timing control |
|                  | Ground linkage                        | Driving data automatic collection Firmware updates | using catering-service robots |
|                  | Temperature anomaly detection based on axle detector | Remote automatic driving | |
|                  | Abnormal wear diagnosis (contact strips of current collector, etc.) by depot entrance camera | Inter-vehicle communication, road-to-vehicular communication | |
|                  |                                        |                                               | |
| Autono-mous      | Driving and operation Coupled driving | Driving and operation Vehicle platooning | Driving and operation IoT platform for train operation control |
|                  | · Automatic acceleration (ACR: automatic current regulation) by resistor stage notch up to by automatic torque control | · Route finding: A* (A-star search) algorithm | · Detour driving, route changing |
|                  | · Automatic protection system (ATP): ATS against red signal violation | · Lane following, obstacle-avoidant driving (with Laser image detector, radome radar support) | · Turnout control from train on the move |
|                  | ATS-P with speed check to braking pattern | · Automatic driving (autonomous driving) | On-board CTC (centralized traffic control) / PRC (programmed route control)) |
|                  | ATC with multi-step or continuous pattern | · Automatic map correction based on data of huge numbers of cars | “Self-steering” and “Self-routing” |
|                  | TASC for automatic stopping |                                               | Dynamic signal control |
|                  | · ATO with automatic power / braking |                                               | Autonomous on-board signal |
|                  | (driving based on given running curve) |                                               | Moving block section |
|                  | Driver-less automated operation        |                                               | |
|                  | (driving based on given running curve) |                                               | |
|                  | TE (one Touch Emergency train protection device) |                                               | |
|                  | · Wireless train control               |                                               | |
| Shared & Service | Passengers Omnibus ride (rideshares since the beginning) | Passengers Buses | Passengers Partial on-demand operation |
|                  | Mutual direct through operation        | Ride shares / service undertakers First / last one mile | Operation service undertakers MaaS: linking with intermodal passenger transport (other modes) |
|                  | · Vehicle sharing (leasing)            | · Passenger car ride / car-shares              | · Smart city: transport modes selection which removes trade-offs between minimal fees, minimal times, and minimal energy |
|                  |                                        | · On-demand taxis dispatch linked with smartphone application | · Automatic fare collection when riding “Self-check” |
| Electric         | Vehicle powertrain                    | Vehicle powertrain HEV, EV, FCEV | Vehicle powertrain From integrated to modular design (new architectures) |
|                  | · Motor drive: DC- to AC-, or linear motor | · Range extender for PHEV | · Example: modular power pack “Self-power” |
|                  | · Power transformer/converter: transformer, chopper, various rectifiers, inverter (including: liquid cooling) | · Permanent magnet- reluctance-type synchronous motor | |
|                  | · Power semiconductor (materials: Si, SiC) (structure: diodes, GTO, IGBT, FET) | · PCU (power control unit) | |
|                  | · Lead acid / Lithium ion battery      | · Mechanically / electrically integrated motor (inverter type) | |
|                  | Outside train physical interface      | · Contactless charging at general road intersections, contact charging while driving on highways (electrofied road), contactless charging at highway SA (service area) / PA(parking area) | · Functionally-integrated unit Inverter embedded motor |
|                  | · Power collection (overhead-catenary/ rigid trolley), contact charging | · Out-vehicle physical interface | · Gearless-axial gap motor (transverse flux type) |
|                  | · Inductive interference countermeasures, track rail short circuit | | · Transformer-less rectifier |
|                  | (telecommunications line, electronic train detector for crossing, track circuit) | | · Charging / discharging function build-in inverter |
|                  |                                        | | · Contactless electric supply |

**QR of TRI, Vol. 61, No. 3, Aug. 2020**
increased demand in frequent operation of trains if inter-modal passenger transport can be effectively linked. It is likely in such cases that trains will be operated with fewer cars, and there will be even more demand of small lot production of many railway vehicles, both at lower cost and in a shorter time frame. In other words, productivity increases in the “design process” that require a shift in the bulk of the workload: from an integral style of design, that Japan has been proficient in, to a modular style of design. And the modular style of design is in the stage of apparent expansion.

3.2 Unitization of powertrain components

It has been recognized that progress in the electrification of automobiles requires more time, and common to both automobiles and railways, particularly with regards to the issues of primary on-board power sources, electric-charging, and hydrogen-filling. Changes are needed in the vehicle electrical components themselves from a space-saving and weight reduction perspective as well.

4. New powertrain items which need further attention

4.1 Modularization of powertrains

Design productivity improvements are none other than a review of the underlying architecture. Modular concepts have been proposed from an early stage in Europe. There is an example of embodied modular power packs supporting recent various energy sources [7] (Fig. 1). As a result of modularization, selecting energy sources and attaching / detaching devices have become easier without changing the basic structure and configuration of trains, which enables manufacturers to rapidly meet the various requirements of railway undertakings.

4.2 Built-in components (unitization)

This is the act of gathering functions and unitizing them in order to reduce the number of parts in a device. Devices can be miniaturized, and their weight reduced, while the number of parts can be reduced by combining multiple functions into a single unit, for example, mechanically / electrically integrated motors (inverter-embedded motors, reducer-less traction motors), charging / discharging function built-in inverters (chopper-included inverters, etc.), transformer-less rectifiers, radiative integrated power storage modules. Note that “integration” does not simply mean “combination,” as it requires the removal of excess parts or functions and the slimming down of the device from a design standpoint.

5. Conclusions

This paper presented evidence of and compared how technologies that have been applied in the railway in the past, correspond to individual component technologies forming ‘CASE’ in automobiles. This study then showed how modularization during the design phase is essential to be able to keep up with changes in the environment surrounding powertrains. Areas of technology that need to be addressed from now, include modularization of various power sources and integration of onboard equipment components.

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