Technology Development of Dual Power Supply System for Mild Hybrid System and Micro Hybrid System

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Abstract

CO_2 emission control in a vehicle has been being strengthened in each country, and further fuel efficiency improvement is required for gasoline engine vehicles toward year of 2020 and 2025.

As for the measure of fuel efficiency improvement, conventional methods such as high efficiency of engine and others reach their limit. Therefore the fuel efficiency improvement by electrification such as electric vehicles and hybrid vehicles is needed. Among them, a dual power supply system which is called mild hybrid system and micro hybrid system, which is able to be build a system at much lower cost, is adopted in each automotive manufacturer.

At this time, we would like to introduce 12V-based dual power supply system under development by DENSO TEN, digital type DC/DC converter, and semiconductor relay used in this system.

1. Introduction

Fuel economy regulations have been being gradually strengthened in each country with the aim of reduction of fossil-fuel consumption and CO_2 emission. This is why each automotive manufacturer is encouraged to improve an average fuel consumption of selling vehicles. **(Fig. 1)**

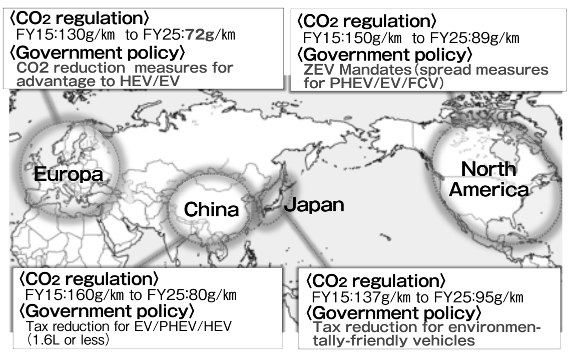

Fig. 1 Regulation and Governmental Policy in Each Country

Each automotive manufacturer introduced various systems such as plug-in hybrid vehicle, hybrid vehicle, idling stop system, and others as well as fuel-cell vehicle and electric vehicle without CO_2 emission while driving to comply with regulations in each country. **(Fig. 2)**

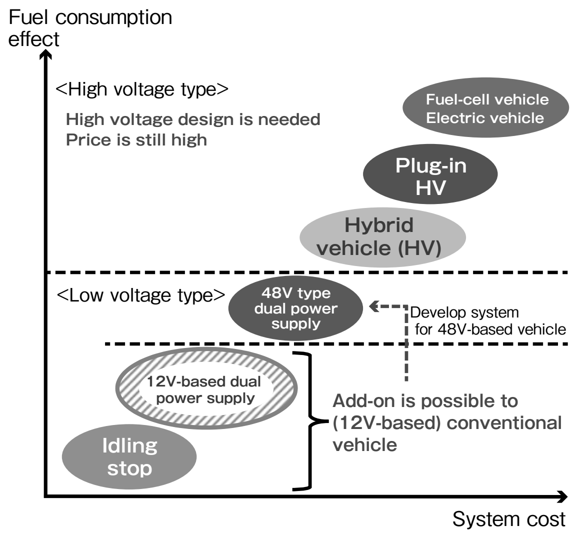

Fig. 2 Fuel Consumption Effect and System Cost

As for fuel-cell vehicle, electric vehicle, and hybrid vehicle driven with a motor, their fuel consumption effect is high. However, high voltage design is needed for them, of which system cost is very high. Therefore, 12V-based dual power supply system easily added-on to conventional vehicle is expected to be highly demanded in future.

2. Dual Power Supply System

Easily added-on idling stop mechanism to conventional vehicle is now equipped with most vehicles. Idling stop system is a system which reduces unnecessary fuel consumption by turning the engine off when the vehicle stops or just before it stops, and turning the engine rapidly on as needed. However, this system has to cover power supplies for starting vehicle engine, light, navigation system, and etc. with one battery, which has contradictory problems for merchantability such as flickering light resulting from battery drop at starting engine timing.

Therefore, a system equipped with auxiliary power unit such as capacitor and nickel-hydrogen battery etc. was introduced, which used appropriate power supply depending on the situation for starting engine and for auxiliaries such as light and navigation system. This is the beginning of dual power supply system.

After that, some companies launched various types of dual power supply system. Electric Double Layer Capacitors (EDLC) and lithium ion batteries (LiB) with superior charge/discharge characteristic are mainly used to a storage device as the auxiliary power unit in the current system so that recovery of kinetic energy of vehicle deceleration is more effective than lead batteries, which can improve fuel consumption.

Currently, main dual power supply system is classified into two groups, "Regenerative braking system" and "Mild hybrid system and Micro hybrid system". "Regenerative braking system" charges the battery with energy regeneration while vehicle deceleration, but not performs driving assist and the like. It is a system to reduce just generator load based on fuel by supplying the energy to electrical components.

On the other hand, "Mild hybrid system and Micro hybrid system" assist engine, which are equipped with LiB in which can store much energy as a storage device, and with integrated starter generator (ISG) which is a generator (alternator) with motor function. As vehicle basically cannot drive only with ISG, this system can improve fuel consumption by reduction of engine load by driving ISG with electric power stored in LiB.

Then, we explain a structure of actual dual power supply system. **Fig. 3** shows the structure of dual power supply system under development by DENSO TEN.

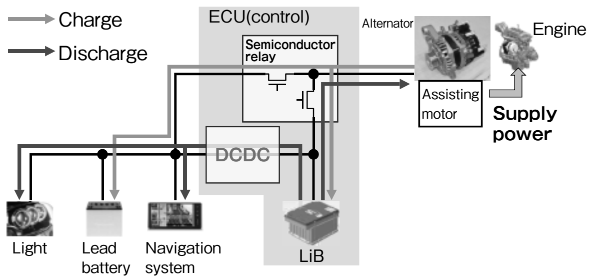

Fig. 3 Structure of Dual Power Supply System

Dual power supply system consists of LiB (or EDLC), relay that switches charge/discharge channel and DC-DC converter (hereafter, DCDC).

As charge/discharge channel needs frequent switching according to driving state, semiconductor relay is used instead of mechanical relay due to its longer life.

Also use of DCDC makes voltage adjustment possible between lead battery/auxiliary side and storage device (EDLC and ternary LiB etc.) of which output voltage changes by charging condition, and the fuel efficiency can be improved by using all capacity of storage device up with adjustment of supply current.

Fig.4 shows the relationship of voltage between lead battery and ternary LiB (example). When remaining capacity of LiB is much enough, in terms of voltage, as LiB is higher than lead battery, LiB is stepped down so that it equals lead battery. Thereby discharge of useless current from LiB can be prevented by focusing supply current on the power for auxiliaries. In case of few remaining capacity of LiB, voltage of LiB is stepped up.

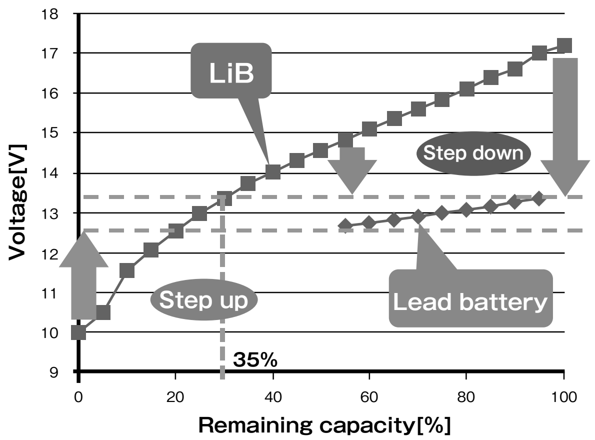

Fig. 4 Relationship between Voltage Characteristics of LiB and Battery Voltage of Lead

Our dual power supply system aims to save fuel consumption by optimum control of relay and DCDC according to vehicle driving state as shown in **Fig. 5**.

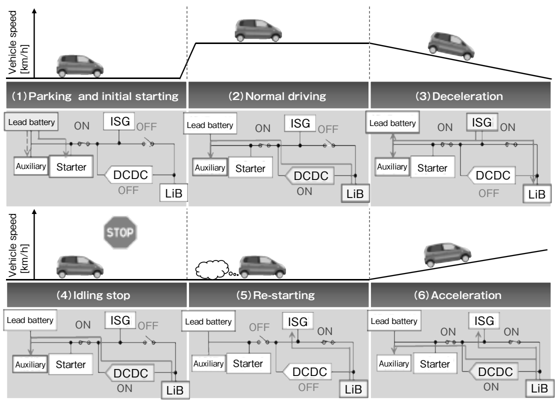

Fig. 5 Vehicle Driving Status, and Operation of Relay and DCDC

(1) When parking and initial starting
Considering startability at low temperature and the like, start an engine with a starter motor through lead battery.

(2) When normal driving
Supplying only the current enough for auxiliary to consume through LiB via DCDC, minimize load of lead battery and electric generation by fuel.

(3) When decelerating
Maximize charging by directly connecting ISG to LiB and lead battery.

(4) When idling stopping
Supplying only the current enough for auxiliary to consume through LiB via DCDC, minimize load of lead battery and electric generation by fuel.

(5) When re-starting
Re-start an engine by driving ISG through LiB. Prevent voltage of lead battery from dropping by separating relay of lead battery side.

(6) When acceleration
Driving ISG through LiB, assist an engine. Concurrently supplying only the current enough for auxiliary to consume through LiB via DCDC, minimize load of lead battery and electric generation by fuel.

As shown above, high performance of semiconductor relay and DCDC are essential to switch operation state according to driving state quickly and efficiently.

Therefore, we introduce digital DCDC and semiconductor relay developed by DENSO TEN below.

3. Development of digital DCDC

As described in the previous section, a roll of DCDC in a dual power supply system is voltage adjustment between lead battery and LiB. We adopted "digital DCDC converter" (hereafter, digital DCDC) to meet this function. we describe the feature and the reason of selection here.

3.1 Difference from conventional DCDC

Conventional DCDC processes voltage and current which is fed back to the control block in analog value, and creates a switching timing of output MOS. This is mainly realized by using analog IC **(Fig. 6)**

Replacing this, method which processes in digital form by microcomputer (hereafter, DCDC microcomputer) is a digital DCDC. **(Fig. 7)**

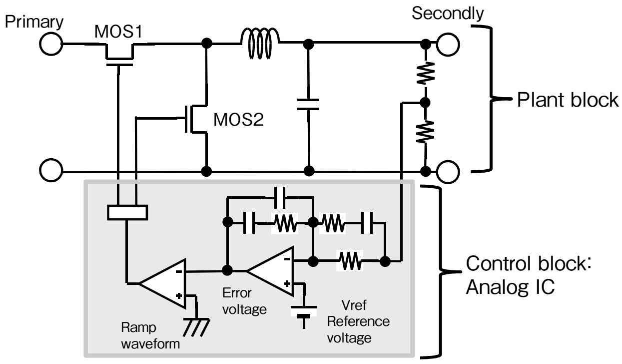

Fig. 6 Analog type DC/DC (Voltage feedback)

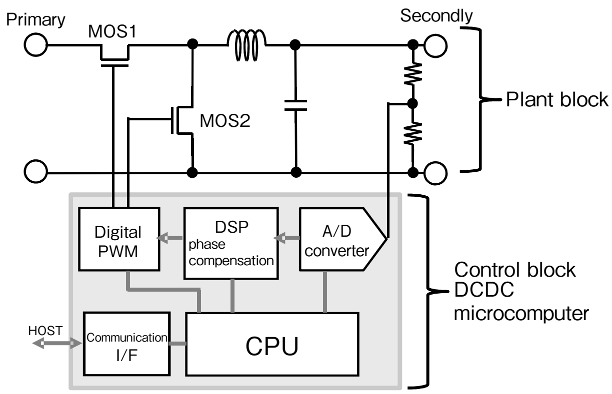

Fig. 7 Digital type DC/DC (Voltage feedback)

Compared to a structure of control block, analog type needs physical reconstruction of the IC and circuit when process specification (gain and feedback object) is changed. On the other hand, digital type can respond it only by changing software.

In addition, creating the plant block (DCDC block) model on simulation in advance, it is possible to combine the plant model with DCDC-microcomputer model on simulation, and to check the functions and the characteristics of overall system before making prototype.

In this way, digital DCDC is greatly suited to model-based development and contributes to the reduction of development man-hour.

3. 2 Innovative ideas taking advantage of digital DCDC

(1) Response to large current output

Although DCDC microcomputer is an expensive part same as analog IC, it is more advantageous than analog IC for responding to large current. This is because one DCDC microcomputer can simultaneously control more DCDC than conventional analog IC, with which cost merit is expected when responding to large current.

Multi-phased DCDC is effective method for large current. Multi-phasing is the method, for example, in case of DCDC design capable for current output of 150A, to connect three 50A type DCDC in parallel, of which phase are shifted in 120 degrees each other, and switch them. If DCDC consists of one circuit for large current over a certain level, (heat generation is represented as formula $P=RI^2$ and if current increase by two times, the loss increases by 4 times), it generates too large amount of heat, which causes large part and heat radiation structure in size. Furthermore, there is other problem that the number of electrolytic capacitors increases because of increase of a ripple current.

In response to this, we adopted multi-phased DCDC taking advantage of DCDC microcomputer which can simultaneously control more DCDC (4 circuits for H bridge, 8 circuits for half bridge) than analog IC. As a result, we achieved reduction of the heat radiation structure in weight and of the coil in size by reduction of loss. Furthermore, it was possible to reduce the number of electrolytic capacitors. **Fig. 8** shows the DCDC block of prototype.

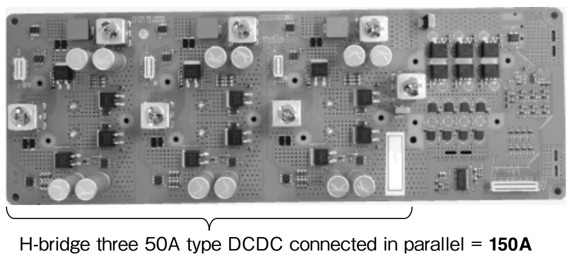

Fig. 8 Digital type DCDC by Multi-phase

As for mass production, the balance of circuit size and cost which is changed depending on multi-phased DCDC is an issue. We investigate the relationship of phase number and cost / size, as shown in **Fig. 9** and determine the structure depending on priority item.

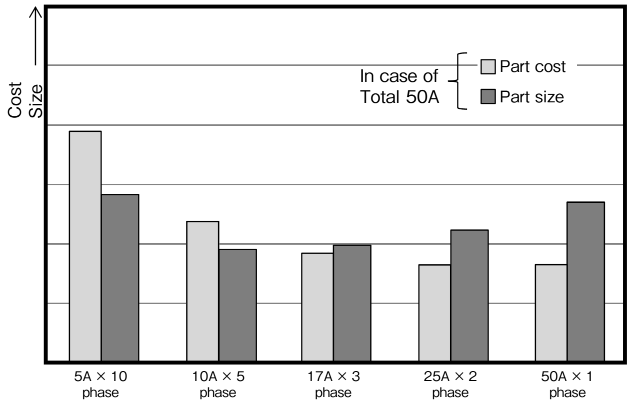

Fig. 9 Studying Optimal structure for 50 Ampere

(2) Improving efficiency of stepping up and down

The aim of improving efficiency of DCDC in in-vehicle is extending continual operation time of DCDC, reducing weight by simple heat radiation structure, and mounting on vacant space without impact for mounting of other auxiliary.

We are planning to incorporate ① and ② below to DCDC to realize these.

① Proper use of control for 2 types of MOS

Verification result of DCDC loss shows about 50% of total loss was switching loss of MOS and on-resistance loss as shown in **Fig. 10** at the worst condition.

For example, considering only stepping down from 48V to 12V in **Fig. 7**, MOS1 is on-state 25% of one period and off-state 75%, and MOS2 is the reverse thereof. Comparing the ratio of switching loss and on-resistance loss in on-state 25% of MOS1, the percentage of switching loss becomes large within this time. The shorter on-time is, the more remarkable this trend is. In reverse, as on-time of MOS2 is 75%, which is long, the percentage of on-resistance loss becomes large, Then the longer on-time is, the more remarkable this trend is.

Therefore, the efficiency can be improved by proper use of MOS with individual characteristics, for example by applying less switching loss MOS to MOS1 and less on-resistance loss MOS to MOS2. This is the case for stepping down at half bridge as shown in **Fig. 7**. This circuit can be applied to the case for stepping up, in which the relationship of on-time between MOS1 and MOS2 is turned upside down.

In other words, in order to improve the efficiency in case of using this DCDC for both stepping up and down, 2 types of MOS, low switching loss type and low on-resistance type, need to be allocated as MOS1 in parallel and used appropriately. The same is true of MOS2. Therefore, four signal lines to MOS are needed (Two signal lines are typically needed in analog type). Control logic for MOS is complex, because 2 types of MOS are necessary to be controlled to be used appropriately so as to always minimalize loss of MOS in real time. However, DCDC microcomputer allows to configurate a flexible and optimal logic by software.

② Soft-switching

Soft-switching is a technology which suppresses heat generation resulting from reduction of MOS switching loss by timing shift of voltage and current applied to MOS.

Fig. 10 shows image of the effect. P is loss of MOS and Vds is voltage between drain and source, and Id is drain current. **Fig. 10** shows the reduction of loss of MOS "P "by eliminating overlap of Vds and Id.

Then cost for heat radiation can be reduced.

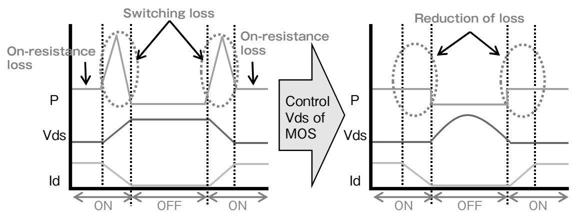

Fig. 10 Principle of Soft Switching (Example)

We are studying adoption of an active-clamped method, which can artificially generate resonant condition as a circuit of soft-switching, because it is possible to be applied to an isolated DCDC for high voltage in case of responding to high-voltage type dual power supply system. Because of requirement of creating complex resonance timing, DCDC microcomputer can work effectively along with its property. We will be focusing on new technology to develop small, light-weight, and low-cost DCDC.

4. Development of semiconductor relay

4. 1 Difference between conventional mechanical relay and semiconductor relay

On/off life time of conventional mechanical relay is about from tens of thousands to hundreds of thousands. The reasons are deterioration of moving parts resulting from friction and deterioration of contact area resulting from electrical spark and others. Moreover there are other problems as mechanical relay characteristic, such as operation noise during contacting, large size and heavy weight, and necessity of absorption part of surge which is generated by sudden turn-off of large current. Especially, the weight of mechanical relay which is used for hundreds ampere current band in our dual power supply system is from hundreds to thousands gram in weight.

In response to this, a relay, in which mechanical part is replaced with switching semiconductor as represented by MOS is a semiconductor relay. **(Fig. 11)**

On/off lifetime of semiconductor relay is semi-permanent because of no deterioration without moving parts and contacts physically.

Furthermore, it is small and light-weight, from several to tens gram.

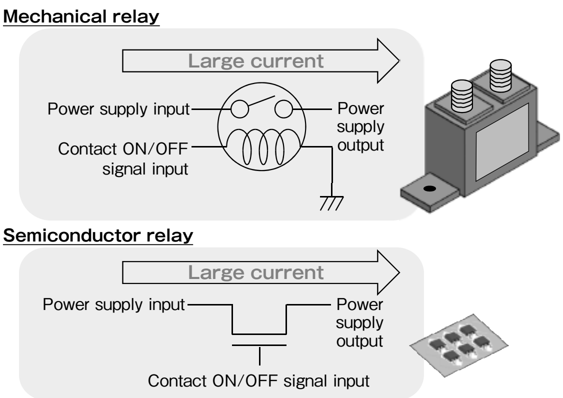

Fig. 11 Mechanical Relay and Semiconductor Relay

4. 2 Innovative ideas taking advantage of semiconductor relay

(1) Measure for voltage surge

As mentioned above, mechanical relay generates voltage surge, but semiconductor relay also generates voltage surge. However, semiconductor relay can suppress voltage surge by a control method, which can reduce suppression parts. The method is to prolong the transition duration through full shut down of MOS.

Calculation formula of voltage surge is given as follows.

$$E = -L\frac{di}{dt}$$

Time change ratio (di/dt) of current directly links with a magnitude of generated voltage i.e. voltage surge (E). Then, voltage surge is controlled by decreasing the time change ratio of current by increasing the transition duration through full shut down.

However, as there is possibility for MOS to be destroyed by increase of switching loss at turn-off timing of MOS, combination of acceptable voltage surge, transition current, and transition duration within safe operating area is important.

(2) Absorption of OFF time lag when MOS connected in parallel

As shown in **Fig. 12**, MOS1 and MOS2 are assumed to be connected in parallel. Turn-off threshold voltage of each MOS is set as Vth1 and Vth2 **(Fig. 13)**. Vg is signal voltage from controller. In case of same timing of Vg to MOS1 and MOS2, when Vth1 is higher, MOS1 turns off first and MOS2 has time when Id1 flows which flowed in MOS1. This means that current of MOS2 increases by two times of expected current, thereby MOS2 can be destroyed in the worst case.

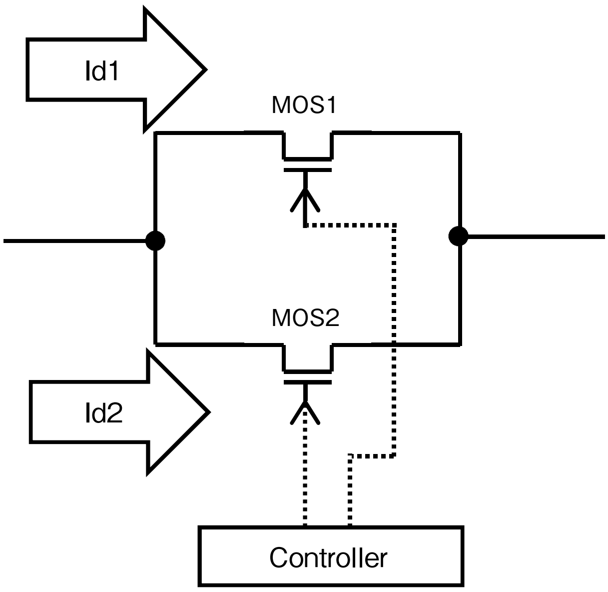

Fig. 12 Parallel-connected MOS

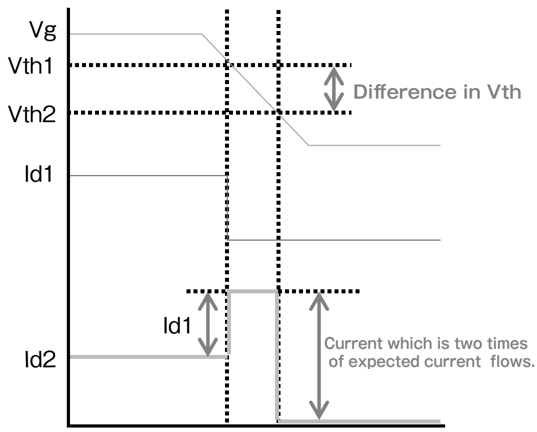

Fig. 13 Influence of differences in Vth

To solve this problem, we study the method which absorbs inherent difference of Vth, which is calculated from Vth measured for all of MOS mounted in product when shipped, by timing adjustment of OFF command output from controller. Only semiconductor relay can quantitatively define inherent difference, and reflect the result to control.

5. Conclusion

We explained 12V-based dual power supply system under development now, and the development of digital DCDC and semiconductor relay which are used in the system.

The field of low voltage type (12 to 48V) is expected to be in great demand in future. Especially, large-scale investment of European companies to 48V-based Mild Hybrid System is considered certain. This market will rapidly expand, and cannot be ignored.

Grasping such changes of these market trends, we timely reflect them to future product development and key technology development to improve the product performance and we will satisfy expectations of the market.

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