Feasibility Study of Three-Phase Power Supply Using Hybrid / Plug-In Hybrid Electric Vehicles

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ABSTRACT: With because massive natural disasters occurring more frequently, preparation for power outage has become one of the most important issues for local governments and companies. Despite high installation costs, some large-scale evacuation centers are installing the emergency power sources such as generators. In contrast, widely available hybrid (HEVs), plug-in hybrid (PHEVs) and battery electric vehicles (BEVs) that are equipped with a power supply function are good candidates as affordable alternatives. However, this function outputs single-phase 100V, which cannot drive three-phase power equipment. This study examined the feasibility of three-phase power supply using HEVs and PHEVs, to help increase the number of local governments and companies HEVs and PHEVs as an emergency power supply.

KEY WORDS: **EV and Hybrid vehicle**, **charge/discharge**, external power supply (A3)

1. INTRODUCTION

With massive natural disasters occurring more frequently, local governments and companies to formulate a business continuity plan (BCP) and implement business continuity management (BCM) in addition to disaster preparedness activities.(1) Although ensuring sufficient power resources through photovoltaic, rechargeable batteries, or generators is very important, it is difficult for many local governments or smaller companies to install such equipment due to the initial and running costs.(2) The use of electrified vehicles as a power source could be a feasible solution for these governments and companies. Efforts to use electrified vehicles as power sources in the event of a power outage due to a disaster have become widespread.(3)-(5) However, low power output limits the use of these vehicles, mainly to home appliances that require little power, such as smartphone chargers, rice cookers, and electric kettles.(6) The output from a power outlet installed in these vehicles is typically single-phase, 100 V, and 1.5 kW. In addition, even most vehicle-to-home (V2H) and vehicle-to-load (V2L) outputs in Japan are single-phase and 10 kW or less.(7) Therefore, at present, electrified vehicles cannot be effectively adopted as power outage countermeasures by local governments and smaller companies that use three-phase power facilities such as water pumps, air conditioners, and elevators.

For the reasons mentioned above, this study examined the feasibility of three-phase power supply using hybrid (HEVs) and plug-in hybrid electric vehicles (PHEVs), targeting mainly smaller companies and local governments. Figure 1 shows the specifications of generators sold in Japan. The maximum output of 20 kW was set as the target, which is widely used by smaller companies and local governments. HEVs and PHEVs are becoming increasingly popular in Japan and are expected to maintain a certain market share in scenarios for achieving carbon neutrality in 2050. (8) In addition, since HEVs and PHEVs can produce electricity by running the engine during a power outage, the development of a three-phase power supply using these vehicles has the potential to create an effective power outage countermeasure for more municipalities and businesses.

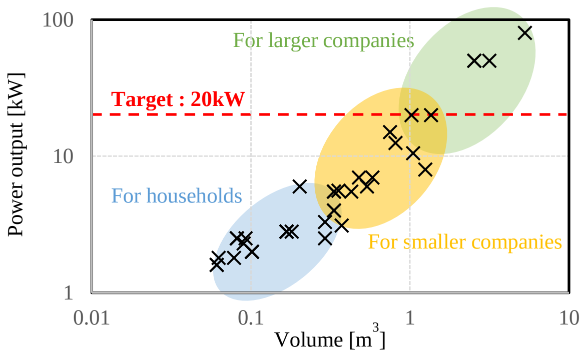


Fig.1 Generator specifications and target of vehicle power supply

Fig.2 Test vehicle

Table 1 Test vehicle specifications

Vehicle type	Hybrid sport utility vehicle
Model year	2020
Drive system	2WD
Engine type	Water cooled, in-line 4-cylinder, 4storoke port and direct injection gasoline engine
Engine displacement	2,487 cm^3
Fuel tank capacity	5,500 cm^3
Motor output	88 kW

2. VEHICLE POWER SUPPLY PROTOTYPING

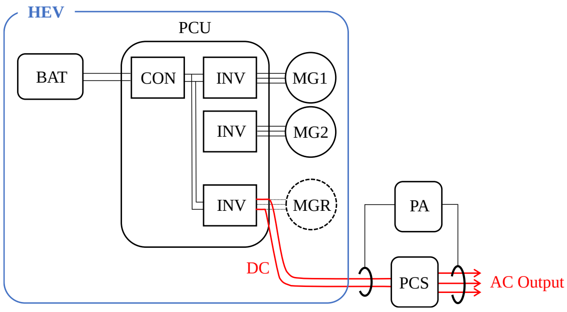
2.1. VEHICLE SPECIFICATIONS

Figure 2 shows the test vehicle. In this study, a hybrid sport utility vehicle (SUV) was chosen as the test vehicle. Its specifications are shown in Table 1.

2.2 MODIFICATION OF POWER CONTROL SYSTEM

Figure 3 shows the power supply system of an electric 4WD vehicle and the modification carried out for three-phase power supply. Although the easiest way to extract power is to create a branch in the line between the battery (BAT) and converter (CON), this might cause high heat loading during power supply because the low battery voltage (around 150 to 300V) results in high current. Therefore, high voltage power must be extracted directly from the power control unit (PCU).

In this study, a PCU of an electric 4WD vehicle was adopted and the line between the inverter (INV) and rear motor (MGR) was modified. As a result, this system is capable of supplying power to a power conditioning system (PCS) simply by changing the output line and control software. To use existing HEVs or PHEVs, it will be important to minimize the necessary modifications in this way. A power analyzer (PA) was installed to analyze the output from the vehicle.



PCU：Power Control Unit
BAT：Battery
CON：Converter
INV：Inverter
MG1：Generator
MG2：Motor
MGR：Rear Motor
PCS：Power conditioning system
PA：Power analyzer

Fig.3 Power control system of electric 4WD vehicle and modification for supplying power (shown as red lines)

2.3. POWER CONDITIONING SYSTEM

Table 2 shows the specifications of a modified two-way PCS equipped with a communication function for load sharing to enable power supply of more than 10 kW by adopting parallel PCS units. This PCS weighs 30 kg, making it relatively easy to transport. Figure 4 shows the external view of the PCS and the luggage compartment of the test vehicle installed with two PCS units. The PCS is compact enough to be installed in the luggage compartment of the test vehicle. Note that no isolation transformers were installed in this study.

Table 2 PCS specifications

Dimensions	W:200 mm x D:700 mm x H:250 mm
Weight	30 kg
Nominal power	10.0 kW
Nominal output voltage	AC 200 V
Nominal output current	28.6 A
DC input voltage range	350 - 400 V
Power factor	> 95 %
Efficiency	> 90 %

Fig.4 External view of PCS and luggage compartment of test vehicle installed with two PCS units

Figure 5 shows the line voltage and line current histories of the AC supply line while running two induction motors with a rated power of 2.2 kW from a grid power supply. The supply side is connected as a delta connection, while the load side is connected as a star connection. A current of over 100 A is observed as inrush current. In this study, to prevent the PCS being stopped by inrush current, a new control was added where the maximum current into the PCS is restricted and the voltage is reduced when the current reaches the limit.

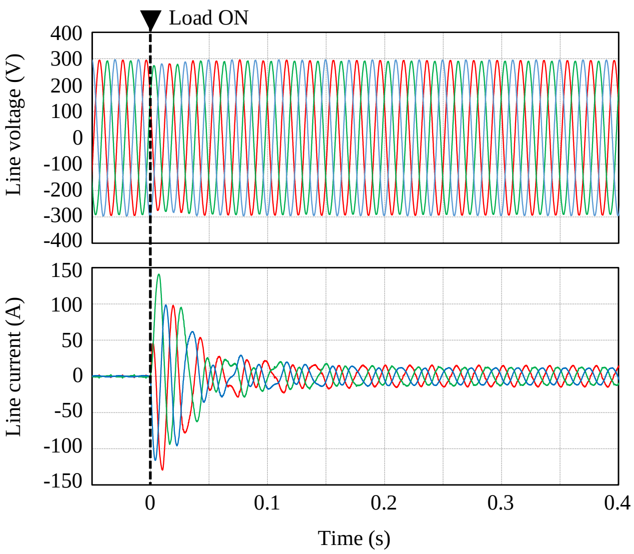


Fig.5 Line voltage and line current histories of AC supply line while running two induction motors with rated power of 2.2 kW from grid power supply

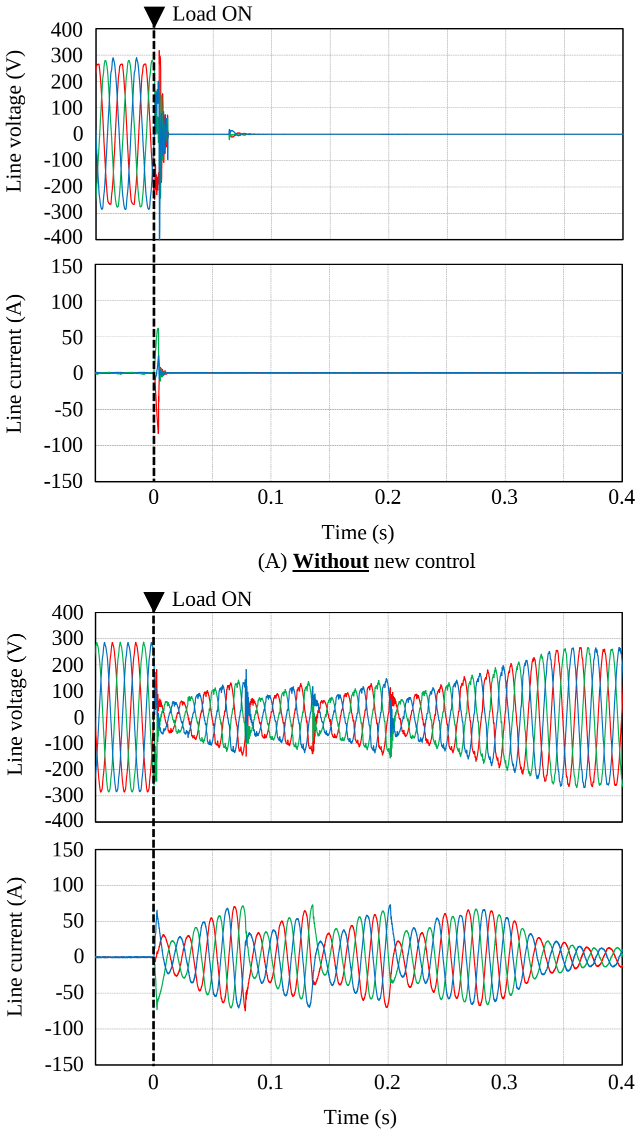


Fig.6 Line voltage and line current histories of PCS AC supply line while running two induction motors with rated power of 2.2 kW from vehicle power supply :(a) without control described in Section 2.3, (b) with control.

3. POWER SUPPLY MEASUREMENT

3.1. INDUCTION MOTOR RUNNING TEST

Figure 6 shows the line voltage and line current histories of the PCS AC supply line while running the same motor as shown in Fig.3 from vehicle power supply. Figure 6 (a) shows the histories without the control described in 2.3 and (b) shows the histories with the control. Without the new control, the inrush current caused the PCS to shut down and the motor could not be driven. The new control allowed the induction motor to be driven without the PCS shutting down. It is generally said that induction motors require generators with about three times the output.

Owning a large output generator could be a significant burden for smaller companies and local governments. It indicates that adopting this kind of control in an HEV or PHEVs, which have a low power generating capacity, enables a vehicle to run equipment such as induction motors.

3.2. EFFECT OF PCS PARALLELIZING

Figure 7 shows the line voltage and line current histories of two parallel PCS AC supply lines with PCS parallelizing when two induction motors with rated power of 2.2 kW are started under 10 kW load conditions. Note that the control parameters were changed from those of the control shown in Figure 6. It is confirmed that the slave follows the master without delay as the load increases, and the load is shared appropriately.

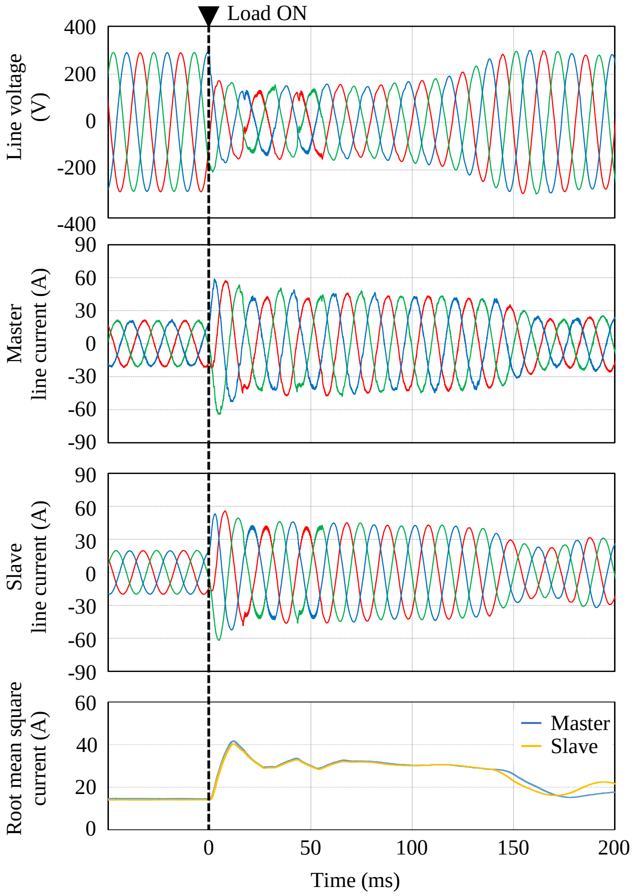


Fig.7 Line voltage and line current histories of two PCS AC supply lines with PCS parallelizing when two induction motors with rated power of 2.2 kW are started under 10 kW load conditions

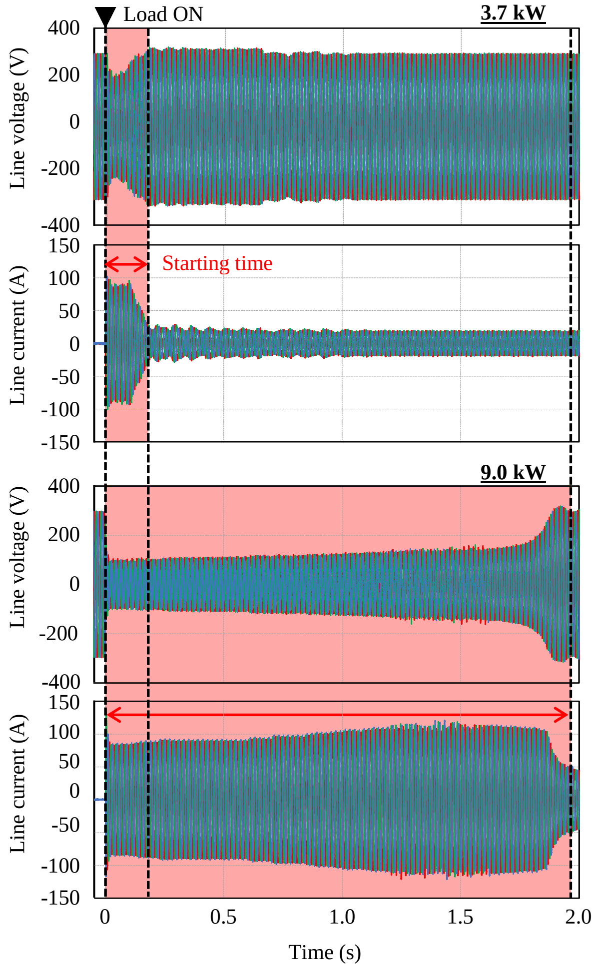


Fig.8 Line voltage and line current histories of AC supply line while running induction motor with rated power of 3.7kW and 9.0kW.

Figure 8 shows the line voltage and line current histories of AC supply line while running an induction motor with a rated power of 3.7 and 9.0 kW. The starting time for the motor with a rated power of 3.7 kW was about 0.2 s, whereas this increased to about 2.0 s for the 9.0 kW motor because the control to suppress inrush current worked longer. Although the startup time was longer, it was confirmed that the 9.0 kW motor could be driven from the vehicle power supply. Since the histories of current and voltage vary greatly depending on the equipment to be driven, the optimal control also varies. Improving the control method to be able to drive a variety of devices is a subject for future study.

3.3. ESTIMATION OF GENERATING CAPACITY

Figure 9 shows the continuous operating time without refueling at each power output of a vehicle power supply equipped with a 55-liter fuel tank. The continuous operating time is calculated from the fuel consumption assuming that 50 liters of fuel is available in the tank. At a test vehicle output of 20 kW, the continuous operating time is 6.3 hours, and the total power output is 126 kWh. These numbers are higher than the battery capacity of any BEV adopting a V2H system on sale in Japan. Furthermore, HEVs and PHEVs can repeatedly generate power by refueling even during a power outage. Assuming a rated load of 10 kW, one refueling can provide power for half a day. These results demonstrate that HEVs and PHEVs can function as effective power sources during a power outage.

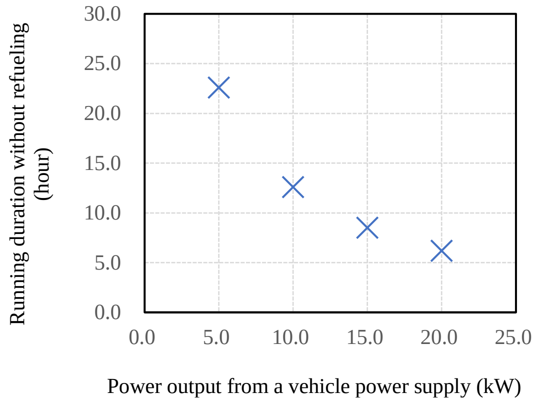


Fig.9 Continuous operating time without refueling at each power output of the vehicle power supply.

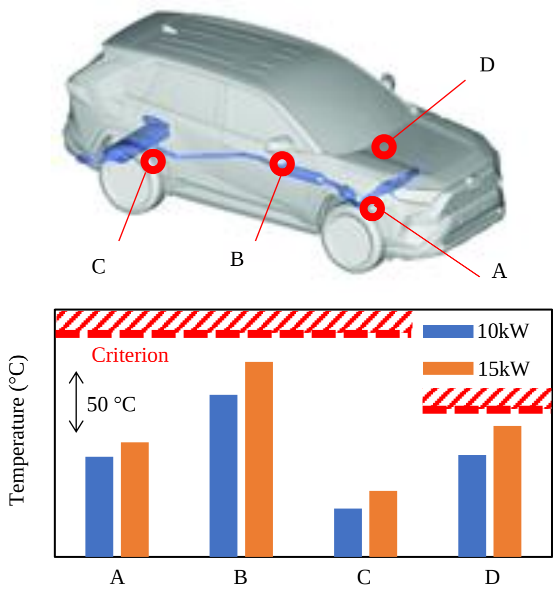


Fig.10 Saturated temperature of plastic or rubber parts close to test vehicle exhaust pipe at room temperature (25°C) with no wind while generating 10kW and 15kW

However, HEV and PHEV power supplies have some issues. Figure 10 shows the saturated temperature of plastic or rubber parts close to exhaust pipe of the test vehicle at room temperature (25°C) with no wind while generating 10 kW and 15 kW. The lack of air cooling during power generation and the higher power output raises the temperature of these parts because of the increased exhaust heat from the engine. Therefore, extended or high-power power generation by the vehicle will require measures to cool parts close to the exhaust pipe.

In addition to these parts, while generating power, it is also important to manage the temperature of the generator (MG1) by maintaining high engine speed to keep the rotation speed of MG1 high and the torque of MG1 low to reduce the MG1 current. As this might increase the engine noise, the operating points for an HEV or PHEV power supply system must be determined factoring in both thermal and noise issues.

Figure 11 shows the maximum noise level 1.0 m from the test vehicle at a height of 1.5 m (the typical measurement method for an emergency generator). It is confirmed that noise levels can be kept as low as 70 dB at an output of 20kW. Confirming the safety of each part and the noise under various operating conditions is a subject for future study.

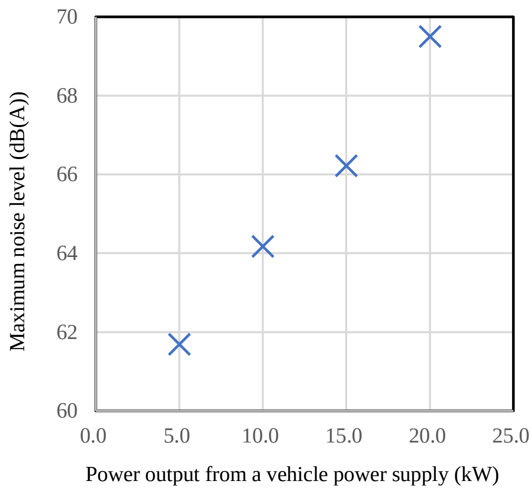


Fig.11 Maximum noise level 1.0 m from test vehicle at height of 1.5 m at each vehicle power supply output.

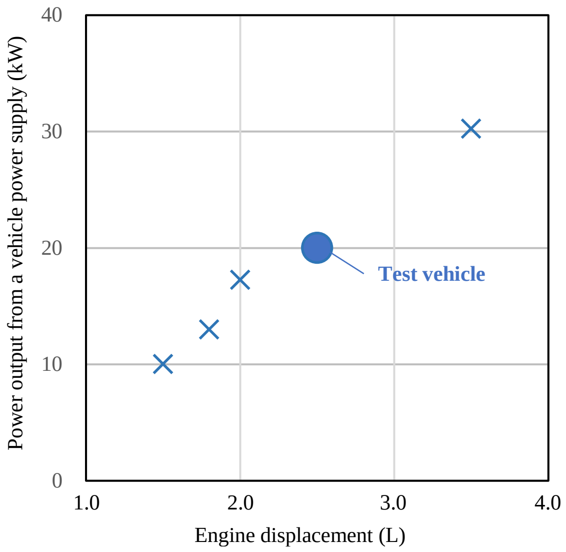


Fig.12 Estimation of generation capability of several HEVs with different engine displacements

Figure 12 shows the estimated power generation capacity of several HEVs with different engine displacements. Representative vehicles were selected for each engine displacement. The MG1 rotation speed and load ratio for these engines was assumed to be the same as for the test vehicle used in this study. Since the amount of the exhaust heat from the engine depends on the type of vehicle and power output, the temperatures around the exhaust pipe need to be confirmed, but it is clear that HEVs and PHEVs have a high potential for use as a power resource during a power outage.

4. CONCLUSION

This study modified a 2.5-liter gasoline engine HEV and measured its power generating capability to examine the feasibility of using HEVs and PHEVs to supply three-phase power. The following conclusions were reached.

- The power output of the test vehicle was 20 kW and its generating capability without refueling was 126 kWh.
- A 9.0 kW induction motor could be driven from vehicle power supply.
- It is important to resolve thermal issues when an HEV or PHEV is used to supply power.

5. FUTURE RESEARCH

As the number of electrified vehicles increases in the future, the social role to be played by these vehicles will increase more and more. In addition to this study, the authors will continue to examine the social contributions that can be made by utilizing electrified vehicles.

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