

Development of EV-neo, Electrical Motorcycle for Business Applications

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ABSTRACT

The acceleration of attempts to reduce CO₂ emissions in recent years in order to deal with global environmental issues has heightened expectations for the electric vehicle (EV). In general, however, an EV needs to be loaded with a larger amount of battery to realize sufficient range. This ends up making the EV heavier and more costly. Taking these circumstances into consideration, EV-neo was developed as an electric motorcycle that satisfied the requirements for business applications while keeping the amount of loaded battery minimum.

A study of usability in business applications was first conducted. Classification of travel and operation patterns as well as objectives for performance were set.

In order to achieve the performance objectives for business applications, the EV was designed to be light in weight and compact by keeping the on-board batteries to the minimum necessary and having a power unit with an integrated configuration. The electric motor was made to be at least 75% efficient throughout the practical operating range. The vehicle was given the required driving performance defined as 12-degree hill-climbing departure performance when carrying one person and a load of 30 kg, and it also realized a range of 34 km (traveling at 30 km/h on level ground).

The package configuration of lithium-ion batteries was designed to realize both of battery cooling performance and waterproof performance to stand up to actual use. A battery monitoring system was also included for control of charging and discharging. These features enable use of the vehicle in ambient temperature requirement range from -10°C to 35°C for business applications.

Furthermore, the quick charger capable of charging a battery from 0% to 80% of capacity in 20 minutes, in addition to a standard charger compact enough to be stored in the utility box, was developed to support various business users.

1. Introduction

Recent years have seen measures taken in a variety of fields to mitigate environmental impacts. There are heightened expectations for electrically powered motorcycles, as well, because they generate no CO₂ emission when they are in operation. A current issue, however, is that the vehicle has to have large capacity of battery to realize an adequate range, making the motorcycle heavy and expensive as a result.

In light of this issue, an investigation was carried out to determine the system configuration that minimized the onboard battery capacity while considering the most appropriate application patterns for the system. As a result, it was found that there would be potential in business applications such as delivery operations in which range per single trip is relatively limited and charging time is expected to be spared.

This paper introduces the technology adopted in EV-

neo, the electric motorcycle, which was developed based on these investigation results. Figure 1 shows an external view of this motorcycle.



Fig. 1 External view of EV-neo

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2. Overview of Business Applications

2.1. Classification of Business Applications

Studies were conducted on how vehicles are used in business applications by businesses such as pizza delivery, newspaper delivery, and other product delivery services currently using motorcycles. This included studies on traveled distance on a single delivery, stand-by time spent between deliveries, and so on. On the basis of those studies, applications were classified, in terms of travel patterns and operation patterns, and that classification had been concluded as that of two types shown in Fig. 2.

The first travel pattern, type one, is the short round trip-type of delivery services. This is the travel pattern typical of pizza and other delivery services from shops or business stations to nearby destinations. It involves mainly short-distance travels. A distinctive feature of this travel pattern is that the vehicle returns to a shop or a business station after each delivery. This operation pattern has the distinguishing characteristic of allowing time for recharging between one delivery and the next.

The second travel pattern, type two is the sequential multi-destination type of delivery services represented by, for example, newspaper delivery services, in which a vehicle returns to a shop or a business station after delivering things to a number of predetermined delivery destinations, and the total traveling distance can be preplanned. This operation pattern has the distinguishing characteristic of providing an interval of four or more hours ahead of the next operation after a previous delivery operation.

Both of these types are methods of use in which a shop or a business station can be considered the base, so that the place where the vehicles are charged is specified⁽¹⁾.

2.2. Performance Objectives of Business Applications

The following performance objectives were defined for an electric motorcycle with business applications based on

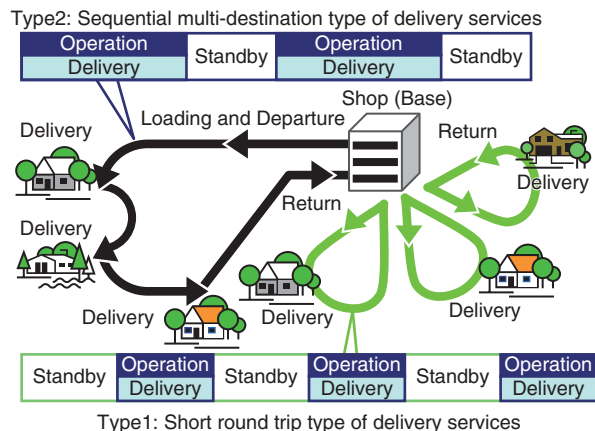


Fig. 2 Classification by operation patterns and travel cycles

the data collected on travel modes and the results of surveys on usage.

(1) Range

It is highly important to identify the necessary range of travel when the system configuration with a minimum amount of loaded battery is under consideration. Figures 3 and 4 show the distributions of travel distances derived from the data on the distances traveled in a single delivery by two types of users aforementioned.

Based on the distribution data of traveled range of those two application types, for either type, more than a half of the users, who use the vehicle for business applications targeted in the present development, can be satisfied if the vehicle meets the travel range of 15 km or more for each charging.

The sequential multi-destination type of delivery services involves frequent departing and stopping and travels over short ranges. Power consumption rates were

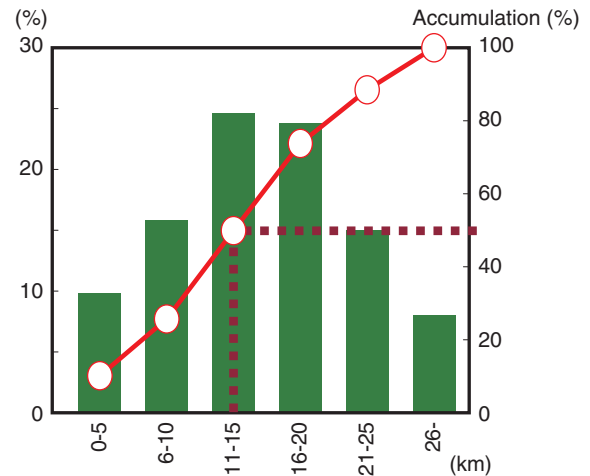


Fig. 3 Distance traveled per one operation in type 1

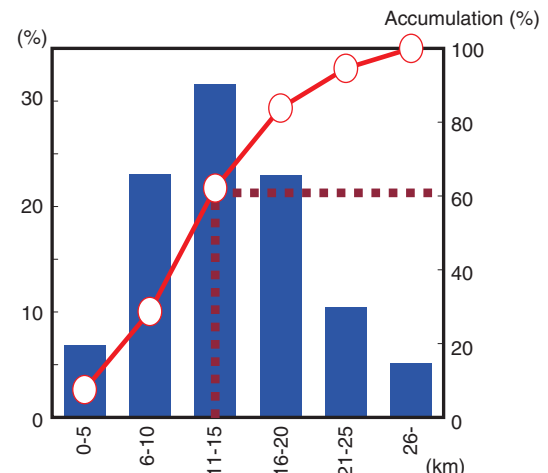


Fig. 4 Distance traveled per one operation in type 2

calculated from the travel data for users of this type, and it was found that they are approximately twice as high as the power consumption rate at constant speed of 30 km/h. Accordingly, the range objective was set as 30 km or more at constant speed of 30 km/h.

(2) Driving Performance

It was found, from the travel data of users aforementioned, that the departure capability on slope is important, in terms of usability, as departing and stopping occur frequently in business applications. Therefore, in the present development, the hill-climbing departure performance of 12 degrees, with maximum loading of 30 kg within the regulation for class 1 motorcycle in Japan, was set as one of the requirements for driving performances, which is the same performance level as conventional gasoline powered motorcycles.

(3) Environmental Durability

The vehicle requires environmental durability such that it can cope with weather and temperature differences between morning and evening or summer and winter. The objective was set as usability in ambient temperatures from -10°C to 35°C, and the ability to be driven through puddles and in the rain.

(4) Charging Time

Based on the operation patterns aforementioned, for the short roundtrip type of applications, it was considered that the scope of application could be expanded, beyond the application areas normally expected from the travel range for a single charging, if supplemental charging could be done in the intervals between deliveries. Accordingly, the charging time requirement of 20 minutes, for charging from 0% to 80% of the battery capacity, was set to make it possible to be charged when the vehicle is standby status between deliveries.

3. Overview of an Electric Motorcycle for Business Applications

3.1. Major Specifications

Table 1 shows the major specifications of the EV-neo. The dimensions (length × width × height) are 1.830 × 0.695 × 1.605 m and the vehicle weight is 106 kg, equivalent to those specifications for conventional motorcycles with gasoline engines. The nominal voltage of the battery was set to 72 V and the nominal capacity to 12.6 Ah. The rated power of the motor was set to 0.58 kW and the maximum power to 2.8 kW.

3.2. Layout of the Completed Vehicle

The EV-neo development concept was “a tough and competent business EV.” Ease of use as a business motorcycle was pursued not only in range and driving performances, but also in the system configuration of the vehicle. Figure 5 shows the installation arrangement of the main components.

The vehicle was designed so as to have the center of

Table 1 Specifications of EV-neo

Dimensions L x W x H (m)		1.830 × 0.695 × 1.065
Wheelbase (m)		1.25
Ground clearance (m)		0.120
Seat height (m)		0.756
Rear deck height (m)		0.630
Vehicle curb mass (kg)		106
Rated power (kW)		0.58
Maximum power (kW/rpm)		2.8/5000
Maximum torque (Nm/rpm)		11/2000
Cruising range at 30 km/h (km)		34
Main battery	Type	Lithium ion
	Battery (V)/(Ah)	72 V/12.6 Ah
Tire size	Front	90/90-12 44J
	Rear	100/80-12 56J

gravity lowered by carrying the battery pack, which is the heaviest component, underneath the floor to maintain the stability of driving even when the vehicle was loaded. Consequently, the height of the center of gravity when the vehicle is loaded has become approximately 6% lower than that of gasoline engine motorcycles with an equivalent size.

In addition to that, the enhancement of energy efficiency and the compact design were achieved with the integrated drive train unit, located behind the battery pack, in which the power drive unit (PDU), the motor, the automatic centrifugal clutch and the reduction gears were incorporated into one. The charger was not designed as an onboard type for weight reduction of the vehicle considering the circumstances of business applications where the charging would take place only within the designated places. To cope with the differences in the requirement for charging devices among users of various application patterns, two types

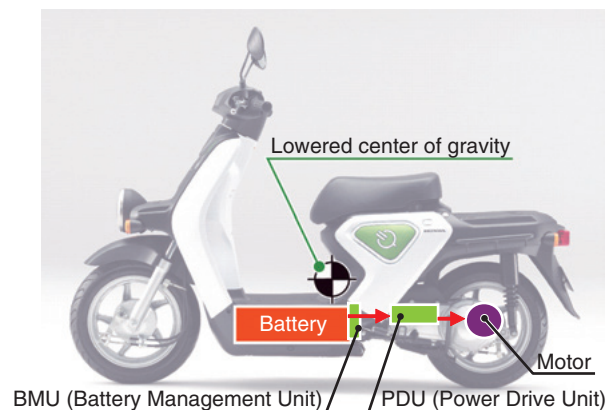


Fig. 5 Layout of components

of chargers as shown in Fig. 6, standard type and quick charging type, were developed allowing the users to select either or both of those types, of any numbers, depending on the vehicle operation pattern, the needs for sharing one charger with multiple vehicles or the needs for combined use of those two types.

The charging connector, which serves as the interface when charging the battery, was placed on the left side of the vehicle body where users are more likely to stand when getting on and off the motorcycle. A compact connector suited to the size of the motorcycle body was developed. For security and prevention of tampering, a lock mechanism was installed on the lid of the connector receptacle, and the lock manipulation knob was located inside the luggage box, which was designed to be locked by a key. Figure 7 shows



Fig. 6 External view of chargers (standard type and quick type)



Fig. 7 Charging connector and lock of charging receptacle lid

the connector configuration.

The meter unit shown in Fig. 8 was positioned in the center of the steering handle on the body. On the meter unit, together with a digital speedometer, the battery charge indicator, which consisted of five display segments, was installed to linearly display the remainder of the battery charge. When the battery remainder goes down to 10%, one of the segments starts to blink with a buzz, inducing awareness of the user with visual and auditory stimuli. The user is also notified when restricted power (to be explained later) is applied by illumination of the restricted power status indicator located inside the meter unit.

3.3. System Overview

Figure 9 shows the block diagram of the system. The basic operations are designed as same as gasoline-fueled motorcycles so as to avoid confusions by operators who are accustomed to use conventional motorcycles. When

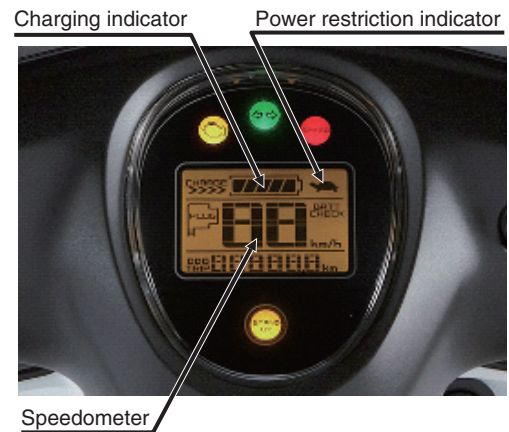


Fig. 8 External view of meter

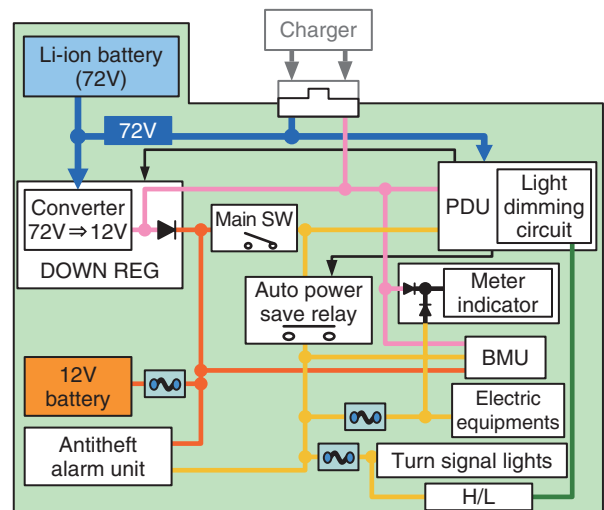


Fig. 9 System diagram

the main switch is turned on, PDU is supplied with the voltage from the sub-battery followed by activation of the whole system. A signal from the PDU activates the down-regulator, which supplies electrical components with 12 V system power. This makes it possible to share electrical components with conventional gasoline powered motorcycles for lighting devices, meters and other such devices. Rider's intention delivered through the throttle grip operations is converted into voltage signals by the accelerator position sensor (hereafter APS) and transferred to the PDU. The battery management unit (hereafter BMU), which is integrated into the battery pack, transfers the battery information such as voltage, current, temperature, etc. to the PDU via Controller Area Network (CAN). The PDU calculates an optimum output to drive the motor based on the APS signal, the motor speed and the battery information. The PDU dims lighting devices by Pulse Width Modulation (PWM) when a vehicle is at a stop to efficiently use the limited power. Furthermore, when the vehicle is in standstill for more than 3 minutes, the lighting system is automatically shut down by turning off the output signal to the automatic power save relay.

4. Integrated Drive Unit

The drive train unit was designed with the primary goal of converting energy without waste from the energy in battery into the energy for propulsion.

In order to minimize the electrical power loss, parts were positioned to have the high-voltage wiring to a minimum length. The battery, PDU, and motor were wired together at the shortest distance, and the total length of high-voltage line from the battery to the motor is 895 mm.

4.1. Motor

Figure 10 shows the integrated drive unit mechanism. The motor employs a three-phase brushless system with eight poles on the rotor and 12 slots on the stator. It is built with an interior permanent magnet (IPM) that uses rare earth magnets. The use of a high-speed motor with reduction gears enables generation of the rear wheel torque of 150 Nm, which is required for business applications, with

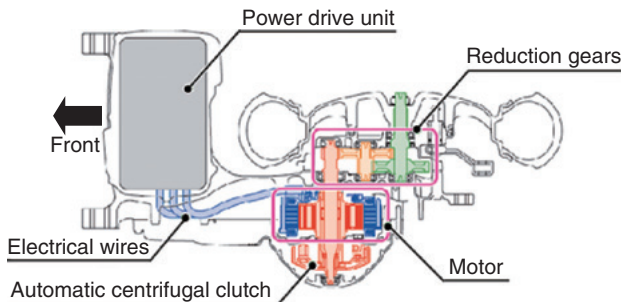


Fig. 10 Layout of drive train unit

a compact size of 149 mm in outside diameter and 35 mm in cumulative thickness.

4.2. Automatic Centrifugal Clutch

The following two benefits have been obtained by arranging the automatic centrifugal clutch on the same axis as the motor.

(1) Reduction of vehicle handling effort

For motorcycle users it is very common, apart from driving astride on a vehicle, to move the vehicle around manually. This maneuverability is a crucial matter for business applications as well. By installing an automatic centrifugal clutch, the motor spindle is left apart without rotational movement when the vehicle is manually moved and the necessary power for maneuvering has been reduced to the level equal to or smaller than the one for a gasoline-fueled scooter.

(2) Enhanced efficiency

Efficiency map of the motor within the drive train unit is shown in Fig. 11. The efficiency of a motor ordinarily goes down in the low revolution speed range with low torque, but this range has been successfully avoided in vehicle operations by installing the automatic centrifugal clutch and by designing the stall revolution speed at 1900 r/min. Together with the motor structure aforementioned, the maximum efficiency of 92.7% and the efficiency above 75% for the whole conventional operation range have been achieved.

4.3. Motor Control

The PDU decides the torque instruction value based on the APS signal and the motor speed, and calculates the duty and the advance angle of PWM control to get the highest efficiency. The advance angle was set to utilize

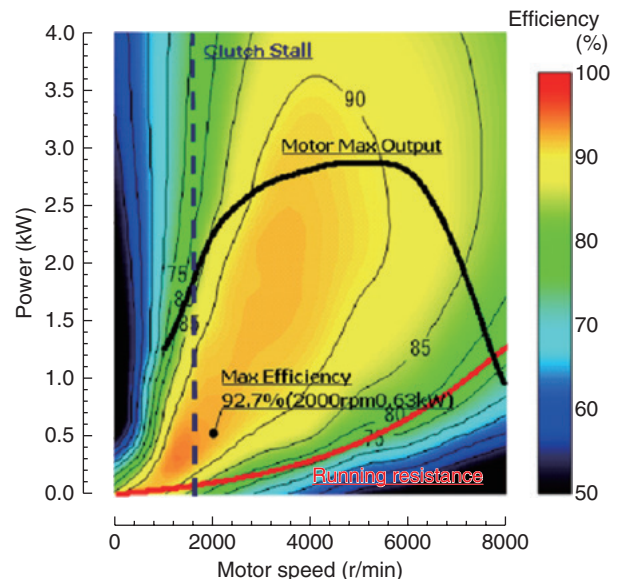


Fig. 11 Power and efficiency of motor

the benefit of weak field control and wide rotational range characteristic of the motor was realized to cover from 0 to 9000 r/min. Consequently, the gear transmission has been made unnecessary and the efficiency has been enhanced by eliminating the mechanical loss derived from the transmission. Figure 12 shows the transmission efficiency of a scooter of the same class⁽²⁾.

Eliminating the transmission also allowed the PDU to be placed where the crank drive pulley is located on a gasoline engine scooter. The space that would have been occupied by the cylinder head and air intake system became available for stowing the standard type of battery charger, which will be explained later. Figure 13 shows a comparison of the contours of the EV-neo drive unit and the drive unit of Honda Today, which is one of the Japanese class 1 scooters.

Energy regeneration control is activated responding to the rotation speed of the motor, when the throttle grip angle is small enough to retrieve energy back to the battery, while generating an equivalent level of braking force as the engine brake in conventional gasoline-fueled motorcycles, resulting in the contribution for longer range.

With these configurations in the integrated power train unit, the targeted power unit performances for business applications, which are hill-climbing departure capability for 12 degree slope loaded with a rider plus 30 kg load and 34 km range for a single full charging, at 30 km/h constant speed, have been achieved.

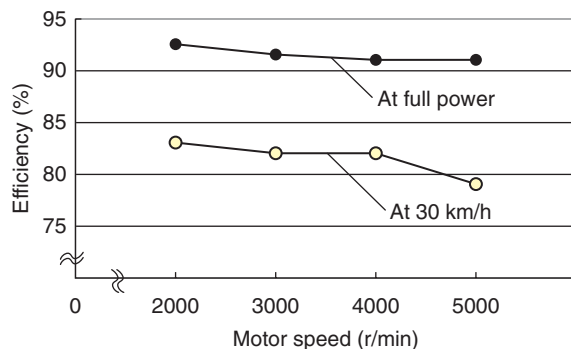


Fig. 12 Belt torque converter efficiency

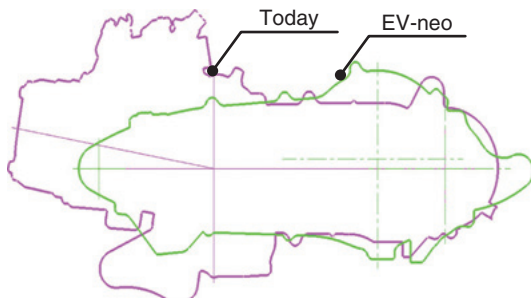


Fig. 13 Comparison of contours

5. Battery

5.1. Selection of Battery

To satisfy the target performances in the business applications, a lithium ion battery made by Toshiba, SCiB™ has been selected because the deterioration in discharging capacity at low temperature is small and the charging current acceptance is large. The unit cells, with the nominal voltage of 2.4 V and the nominal capacity of 4.2 Ah each, are connected in parallel by 3, and by connecting those groups of cells in series by 10 the unit module is formed. The battery pack is made of 3 modules connected in series and has the nominal voltage of 72 V and the nominal capacity of 12.6 Ah.

5.2. Battery Pack Structure

Figure 14 shows the structure of the battery pack. BMU located within the battery pack monitors the battery status information, the voltage and the temperature, constantly collected by Voltage/Thermal Monitoring Board (VTM board), which is incorporated into the battery module. The battery pack is equipped, in its upper portion, with the cooling fan and the contactor unit, which turns off the high voltage circuit when the main switch is off. With these structures, the specifications required for business applications, shown below, have been achieved.

(1) Battery cooling performance

When a lithium ion battery is exposed to a high temperature, the battery capacity goes down. To satisfy enough battery life for business applications, the cooling system with the structure shown in Fig. 15 has been developed. The cooling fan operates when the temperature of the battery exceeds 42°C, and the air is blown into the battery pack through the filter that prevents the invasions of dust, for example, from the intake vent, which is installed under the steering handle. The air goes through the gaps between the cells located so as to have clearances among them and is discharged out of the battery pack. With this cooling system, it has been achieved that the maximum temperature of the battery is suppressed under 55°C even

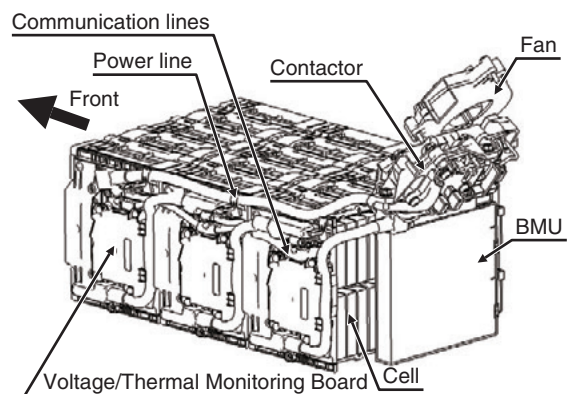


Fig. 14 Battery pack

at the condition of continuous hill climbing in the ambient temperature of 35°C.

(2) Environmental durability

The battery package is structurally sealed and the intake vent and the outflow opening are located where they do not get drenched directly by water. With this measure, it has been realized to have sufficient environmental durability performances against running in puddles and driving in rains.

(3) Battery output restriction control

It is characteristic of a lithium-ion battery that the internal resistance increases when the battery is at a low temperature, resulting in a decline in output voltage according to the discharge current. This can cause the vehicle to stop operating even though there is battery capacity still remaining. The present system implements battery output restriction control as shown below (MAP1–MAP4 in Fig. 16) so that the battery capacity can be used effectively.

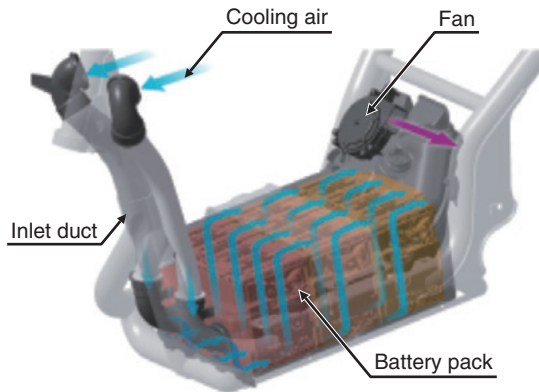


Fig. 15 Battery cooling system

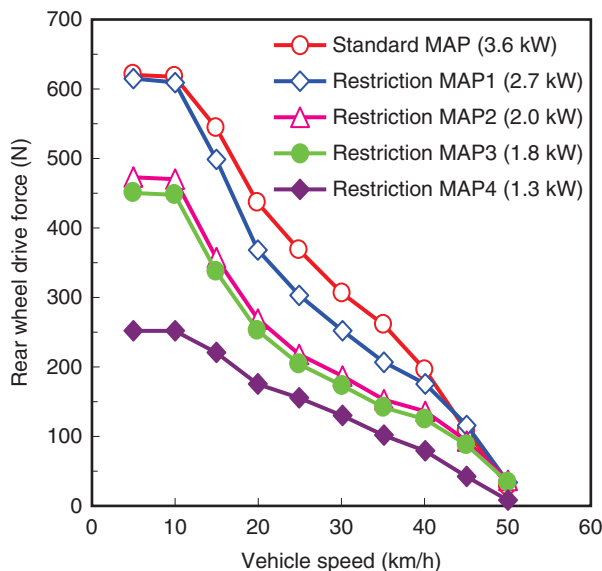


Fig. 16 Characteristics of output power

- After receiving voltage information of all cells from the BMU, the PDU is switched to use the output restriction MAP1 when the lowest voltage becomes 1.95 V or less.
- While driving using the output restriction MAP1, if the lowest voltage goes down to 1.95 V or less, it makes the next transition to the output restriction MAP2 which is one step down to the MAP1.
- There are 4 patterns of output restriction MAPs, the transition is made to the next lower MAPs in sequence.
- When the vehicle stops, it is reset to use the unrestricted MAP because the internal resistance goes down with the rise of battery temperature, which is increased by the heat generation while driving.
- However, the shift of output restriction status to MAP4, which is to be the most restricted output condition, has been designed to happen only when the lowest voltage goes down to 1.90 V or less. This status is considered as the situation in which the State of Charge (SOC) is close to 0% and the current output is terminated when the integrated current of the output exceeds a predetermined value without recovering to the upper levels of MAPs.

Applying those measures to the battery pack structure and the output restriction controls, it has been made possible to satisfy the target specifications for business applications, which are the operation temperature range from -10°C to 35°C and the environmental durability against driving in puddles and rain.

6. Charging System

Figure 17 is a schematic drawing of the charging system and the battery remainder management system. For charging, the AC plug on the charger is connected to a commercial AC power source and the output connector from the charger is plugged into the receptacle on the vehicle located on its side. Battery information that is monitored by the BMU is sent to the PDU through CAN communication. The PDU controls the charger and sends signals to the battery charge indicator located in the meter.

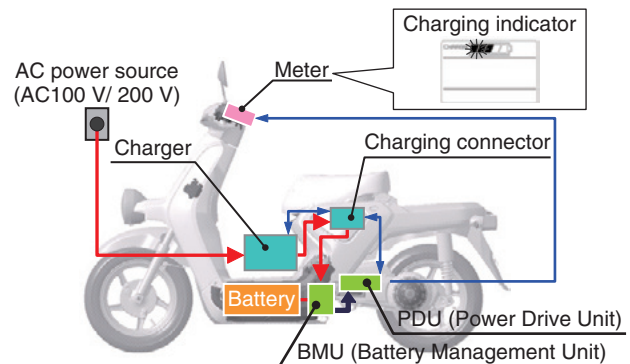


Fig. 17 Schematic drawings of charging system

Table 2 Quick charger specifications

Size	W526 mm × H400 mm × D274 mm
Weight	18.8 kg
Charging time	Approx. 30 min (at ambient temp. of 25°C)
AC power source	Single-phase 200 V
Charging current	1st stage: 28.4 A ⇒ 2nd stage: 3.2 A
Input	200 V 2900 VA 50/60 Hz
Output	DC86 V: 14.2 A × 2 DC14 V: 2 A

6.1 Quick Charger

The principal specifications are shown in Table 2. The input power is provided from single-phase 200 V power source to provide the output power at DC 86 V with the output current of 28.4 A, and it is capable of charging the battery from 0% to 80% within 20 minutes.

To ensure to reach the full-charged status (SOC 100%), two-step current charging method has been applied, in which the output current is switched from 28.4 A to 3.2 A when it gets close to the full-charge status. The relation between the charging time and the capacity of the battery with two-step current charging method is shown in Fig. 18.

In order to obtain current output of 28.4 A, the charger is configured with two converters, each of which has the output capacity of 14.2 A. Compact size and light weight, 526 mm in width, 400 mm in height, 274 mm in depth and the weight of 18.8 kg, are realized with optimized arrangement of the circuit boards and the cooling mechanism. In addition, it has a holding grip to make it portable and handy without any specific location needed for its operation.

As shown in Fig. 19, the output connector has two sets of charger output terminals to use both of them for the quick charger which needs larger charging current and one of them for the standard charger, described below, which needs only small charging current. That allows sharing the same charging cable to realize the convenience of using it without care of the charger type.

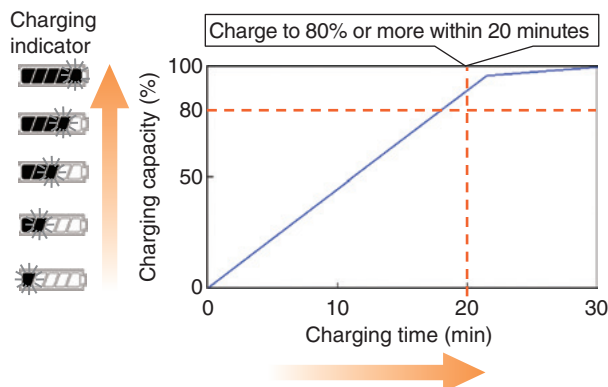


Fig. 18 Quick charge characteristics

Table 3 Standard charger specification

Size	W244 mm × H189 mm × D172 mm
Weight	3.2 kg
Charging time	3.5 h (at ambient temp. of 25°C)
AC power source	Single-phase 100 V
Charging current	3.2 A
Input	100 V 275 VA 50/60 Hz
Output	DC86 V: 3.2 A

6.2. Standard Charger

The main specifications of the standard charger are shown in Table 3. The input is single-phase 100 V power and the output voltage is 86 V with output current of 3.2 A. It was made capable of charging a battery from 0% to 100% of capacity in 3.5 hours.

The optimized positioning of the circuit boards and cooling mechanisms realizes a compact size and light weight with 244 mm in width, 189 mm in height, 172 mm in depth, and 3.2 kg in weight. As shown in Fig. 20, it can be stored in the utility box.

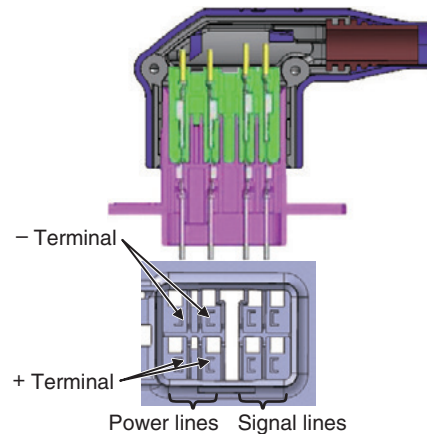


Fig. 19 Charger connector



Fig. 20 Storage of standard charger

7. Conclusion

The target performances of an electric motorcycle that satisfied the requirements of the driving patterns and operational patterns in business applications were determined based on the survey results on the usage patterns in those applications, which could be divided into two types, i.e. the short round trip type of delivery services and the sequential multi-destination type of delivery services.

With these processes, an electric motorcycle, EV-neo, was developed to meet the aforementioned performance objectives with a minimum amount of onboard battery and the following results had been achieved:

- (1) Compact size and the efficiency of 75% or more for all the operation range of practical use were achieved by applying the IPM motor with rare earth magnets, the automatic centrifugal clutch and the integrated power train unit with the PDU, and performances of hill-climbing departure capability of 12 degrees with a rider plus 30 kg load and range of 34 km per one charging at constant speed of 30 km/h was realized.
- (2) The operational capability for ambient temperature from -10°C to 35°C together with the durability that withstands the environmental conditions in practical use including driving in puddles and rains was achieved by applying the aforementioned battery package structure, which fulfilled a good cooling capability and a good impact resistance, and the battery output restriction controls.
- (3) With the quick charging system, which adopted two-step charging current control, the quick charging from 0% to 80% within 20 minutes was realized that satisfied the performance requirements for business applications with the minimum battery loaded on the vehicle.

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