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# A NOVEL CONCEPT OF AI-EV (AIR-CONDITIONER INTEGRATED ELECTRIC VEHICLE) FOR THE ADVANCED SMART COMMUNITY

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## ABSTRACT

After the Great East Japan Earthquake, it has become necessary to reduce nuclear power dependence and $CO_2$ emissions. In one of the solutions, a Smart PV & EV System which is combined the photovoltaic power generation (PV) and electric vehicle (EV) system has been proposed. In the system, it is not only to improve the energy efficiency of a car, but also to reduce the $CO_2$ emissions from the total energy consumption of homes, vehicles and the work places. In the Smart PV & EV System, it is important that EV becomes popular. In order to spread and expand EV, it should solve the issues of short cruising range, the high cost of storage battery and the risk of dead battery. Therefore, the authors have proposed Air-conditioner Integrated Electric Vehicle (hereinafter referred to as AI-EV).

In this paper, a car air-conditioner capacity is determined based on the heat transfer between inside and outside of the car. A mathematical simulation model which evaluates for the AI-EV energy consumption has been developed. And then, the value of the AI-EV is compared with a gasoline vehicle, hybrid vehicle (hereinafter referred to as HV) and EV using the mathematical simulation model. In the comparison, $CO_2$ emissions, the amount of energy consumption and economic efficiencies are evaluated in the Smart PV & AI-EV System. In addition, the performance of AI-EV as a vehicle is compared with the conventional EV.

As a result, it is clarified that the minimum displacement of the small-engine is 120 cc for AI-EV. In the Smart PV & AI-EV System, AI-EV is expected to reduce $CO_2$ emissions of 20% which is compared with a gasoline vehicle. The effect is almost the same as EV. Additionally, the performance of AI-EV as a vehicle in a city area, AI-EV is able to gain the maximum cruising range approximately twice as long as EV. As the results, AI-EV can solve the issues of conventional EV. Therefore, it is considered that the Smart PV & AI-EV system can be adapted for Europe and America that is long commuting distances of over 50 km for one way.

## NOMENCLATURE

| | | |
|---|---|---|
| $t$ | [sec] | Elapsed time |
| $q_0$ | [kJ /sec] | Enthalpy of outside air |
| $q_1$ | [kJ /sec] | Enthalpy of air-conditioner output air |
| $q_2$ | [kJ /sec] | Amount of heat transferred from outside |
| $q_3$ | [kJ /sec] | Amount of heat reserving material |
| $q_4$ | [kJ /sec] | Amount of heat reserving inside |
| $q_5$ | [kJ /sec] | Enthalpy of discharged air to outside |
| $q_n$ | [kJ /sec] | Required capacity of air-conditioner |
| $T_1$ | [K] | Air-conditioner output air temperature |
| $T_2$ | [K] | Outside air temperature |
| $T_3$ | [K] | Material temperature |
| $T_4$ | [K] | Inside temperature |
| $T_5$ | [K] | Discharged air temperature to outside |
| $A_c$ | [m$^2$] | Surface area |
| $A_l$ | [m$^2$] | Material area |
| $A_{ac}$ | [m$^2$] | Air conditioner outlet area |
| $A_{ex}$ | [m$^2$] | Exhaust port area |
| $M_l$ | [kg] | Mass of the material |
| $U_c$ | [W/(m$^2$·K)] | Total heat transfer coefficient of the car |
| $U_l$ | [W/(m$^2$·K)] | Total heat transfer coefficient of the material |
| $c_{pa}$ | [kJ/(m$^3$·K)] | Specific heat of the air |
| $c_{pl}$ | [kJ/(kg·K)] | Specific heat of the material |
| $V_{in}$ | [m$^3$] | Inside volume |
| $u_{ac}$ | [m/sec] | Velocity of air-conditioner output air |
| $u_{ex}$ | [m/sec] | Velocity of discharged air to outside |
| $COP_C$ | [-] | Coefficiency of Performance of cooling |
| $COP_H$ | [-] | Coefficiency of Performance of heating |
| $h_1$ | [kJ/kg] | Enthalpy of refrigerant at compressor |
| $h_2$ | [kJ/kg] | Enthalpy of refrigerant at condenser |
| $h_3$ | [kJ/kg] | Enthalpy of refrigerant at expansion valve |
| $h_4$ | [kJ/kg] | Enthalpy of refrigerant at evaporation |
| $\eta_\alpha$ | [-] | The efficiency of mechanical |
| $\eta_\beta$ | [-] | The efficiency of adiabatic compression of the gas |
| $E_\gamma$ | [-] | The particular energy variation of time $\gamma$ |
| $C_m$ | [-] | The electrical conversion factor each fuel |
| $EF_{ijmt}$ | [-] | The energy variation of HEX with Outflow, Inflow energy |
| $ES_{ijmt}$ | [-] | The energy variation of HEX with generating energy, consumption, storage |
| Special characters | | |
| $\gamma$ | [sec] | Calendar time |
| Subscripts | | |
| $i$ | | HEX position of study area in a $x$-axis direction |

| | |
|---|---|
| *j* | HEX position of study area in a *y*-axis direction |
| *m* | Kind of Energy |
| *n1* | Number of energy |
| *n2* | Number of HEX position of study area in an *x*-axis direction |
| *n3* | Number of HEX position of study area in a y-axis direction |

## INTRODUCTION

After the Great East Japan Earthquake, it has become necessary to reduce nuclear power dependence and $CO_2$ emissions. In one of the solutions, a Smart PV& EV System has been proposed [1]. In the system, it is not only to improve the energy efficiency of a car, but also to reduce the $CO_2$ emissions from the total energy consumption of homes, vehicles and the work places. As a concrete method, PV power is charged directly to the EV battery, and EV is used as energy storage, energy transportation and levelling of PV output fluctuations. In the Smart PV & EV System, it is important that EV becomes popular. In order to spread and expand EV, it should solve the issues of short cruising range, the high cost of storage battery and the risk of dead battery. Therefore, the authors have proposed Air-conditioner Integrated Electric Vehicle.

In this paper, a car air-conditioner capacity is determined based on the heat transfer between inside and outside of the car. A mathematical simulation model which evaluates for the AI-EV energy consumption has been developed based on the thermodynamics that is the difference of the thermal efficiency between the power plant and the small-engine. And then, the value of the AI-EV is compared with conventional vehicles. In the comparison, the reduction of $CO_2$ emissions, and the performance of a vehicle are evaluated in regards to total system which includes the home and workplace.

## 1. INNOVATIVE CHANGES OF THE ENERGY SYSTEM

### 1-1. NEW TWO-WAY ENERGY SYSTEM

Figure 1 shows comparison between “Conventional System” and “New Energy System” which is expected in the future. The conventional system is adjusted supply quantity of fuel and electric power to consumption by fuel and electric company. Therefore, energy flow is one direction from supplier to consumer.

In order to introduce PV in the conventional system as shown in Figure 2, PV power has to convert Direct Current power (hereinafter referred to as DC) to Alternating Current power (hereinafter referred to as AC) into the current power system. In addition, PV power is converted from AC to DC when it charges the EV from the current power system. On the other hand, PV generated power, which depends on the weather, has a wide fluctuation. For this reason, supplying the PV power directly into the current power system causes fluctuations in the system frequency. Therefore, it is necessary to install a large secondary battery for levelling of PV output fluctuations when the supplied PV power will be increased into the power system.

In this case, the total PV power utilization efficiency which is defined as “Electric power consumption／Amount of PV power generation” approximately 59% when PV power is supplied to a house through the use of a storage battery in EV. This value is low. If the total PV power utilization efficiency is low, installation area and cost for PV are increased. Therefore, the system cost performance is deteriorated.

The total PV power utilization efficiency can be calculated using the conversion efficiencies which are shown in Table 1 [2].

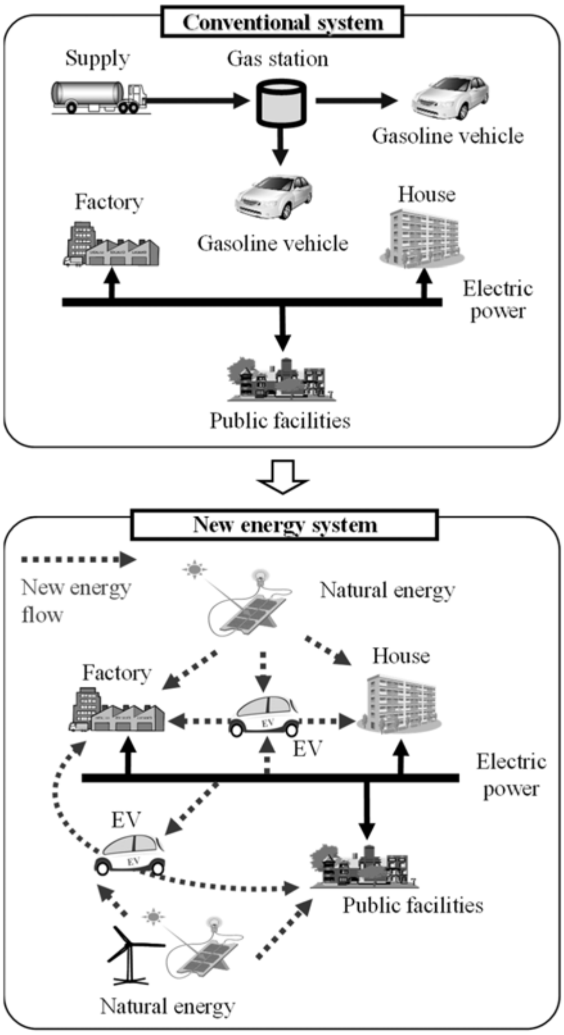

**Figure 1** New energy system

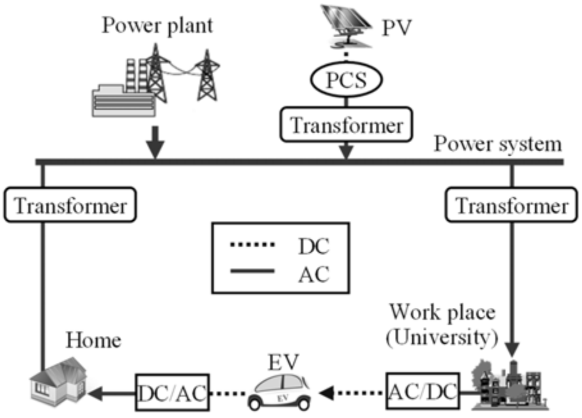

**Figure 2** Conventional PV-EV system

**Table 1** Conversion efficiency

| | |
|---|---|
| PCS execution efficiency | 0.88 |
| Transformer efficiency | 0.97 |
| From charge to discharge efficiency | 0.94 |
| Motor efficiency | 0.90 |
| AC/DC converter efficiency (charging to EV) | 0.90 |
| DC/AC inverter efficiency (supplying from EV) | 0.85 |
| DC-DC converter (supplying from EV) | 0.94 |

### 1-2. SMART PV-EV SYSTEM

As shown in Figure 3, the Smart PV-EV System has been proposed to solve the issues which are described above. In the system, PV power is charged directly to the EV battery as DC. In the new system, it is considered to combine with a commuter EV and PV. The commuter EV is parked at an office or factory during the daytime on weekdays. So, PV is installed at the office or factory side of the workplace, but is not installed at the house. The generated PV power charges the EV storage battery directly in DC. When the EV battery level is full, generated PV power is supplied into the power source for the workplace after being converted from DC to AC. And, if the charging level of the EV storage battery has some surplus power which is not included the necessary power for the next commute, the surplus power can be supplied directly to the home. So, this system is possible to be minimized the number of conversions between DC and AC involving energy losses. When PV power is consumed only by EV driving, the total PV power utilization efficiency, which is calculated by the conditions of Table 1, is 85%. When PV power that has been converted to AC is supplied to home through the use of EV, the efficiency is 80%. On the other hand, the efficiency of 88% is achieved when PV power is supplied into DC to power electrical appliances such as LED lights. In addition, the new system reduces the electric load of the current cable networks without the reverse power flow.

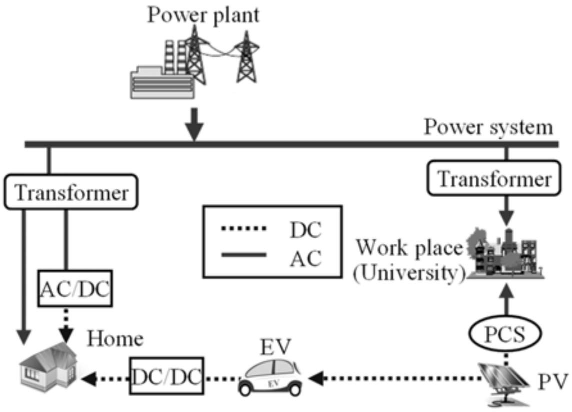

**Figure 3** Smart PV-EV system

### 1-3. ISSUES OF EV

In the Smart PV-EV System, it is important to spread and effectively utilize EV as shown in the preceding paragraph. Table2 shows a performance estimation of gasoline vehicle, HV vehicle and EV. In table2, in order to spread and expand EV, it should solve the issues which of short cruising range, high cost of storage battery and the risk of dead battery. For solving these issues, a new concept vehicle is proposed.

**Table 2** Performance estimation of each vehicles

| | | Gasoline vehicle | HV | EV |
|---|---|---|---|---|
| Conventional | Energy consumption | × | ○ | ◎ |
| | Accelerating performance | ○ | ○ | ◎ |
| | Cruising range | ○ | ◎ | × |
| | Quitness | × | ○ | ◎ |
| | Eco-friendly | × | △ | ◎ |
| | Running cost | × | △ | ○ |
| | Vehicles cost | ○ | △ | × |
| | Risk of losing energy | ○ | ○ | × |
| Future | Energy transport | × | △ | ○ |
| | Disaster response | × | △ | ○ |
| | $CO_2$ emissions | × | △ | ○ |

### 2. AIR-CONDITIONER INTEGRATED ELECTRIC VEHICLE

### 2-1. BASIC DESIGN OF AI-EV

The new concept vehicle is utilized as not only an apparatus for locomotion, but also electricity transportation and a storage medium of electricity. The new concept vehicle is called AI-EV (Air-conditioner Integrated Electric Vehicle), which is integrated car driving power system, power storage system, power generation system and air-conditioning power system. A simplified image of AI-EV is shown in Figure 4.

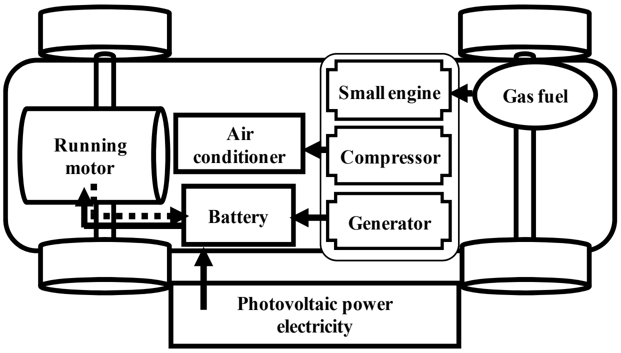

**Figure 4** The Simplified image of AI-EV

As shown in the Figure 4, AI-EV has a novel hybrid system which drives the air-conditioning system and generates electric power in the case of a low air-conditioning load through the use of a small-engine less than 200cc displacement. The generated power is charged to the AI-EV battery. For this reason, AI-EV has a great possibility to solve three issues which are held by conventional EV. These issues are a short cruising range, the high cost of storage battery and the risk of the dead battery. At the same time, it is possible to largely reduce the initial cost of EV.

## 2-2. NECESSARY CAR AIR-CONDITIONING CAPACITY

### 2-2-1. HEAT BALANCE MODEL IN THE CAR INSIDE

A car air-conditioner capacity is determined based on the heat balance model between the inside and outside of the car. As shown in Figure 5, the inside of the car is heated or cooled depending on the weather conditions outside. This is shown by the heat balance equation in Eq. (1) [3].

**Figure 5** The heat balance model with cooling

$$0 = \frac{\partial}{\partial t}\sum_{k=1}^{5} q_k \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

Each amount of heat transferred is shown by equations in Eq. (2) ～ (7).

$$\frac{\partial q_1}{\partial t} = u_{ac} \cdot A_{ac} \cdot c_{pa} \cdot T_1 \quad \cdots\cdots\cdots\cdots (2)$$

$$\frac{\partial q_2}{\partial t} = U_c \cdot A_c \cdot (T_2 - T_4) \quad \cdots\cdots\cdots\cdots (3)$$

$$\frac{\partial q_3}{\partial t} = M_l \cdot c_{pl} \cdot \frac{\partial T_3}{\partial t} \quad \cdots\cdots\cdots\cdots (4)$$

$$\frac{\partial q_4}{\partial t} = -V_{in} \cdot c_{pa} \cdot \frac{\partial T_4}{\partial t} \cdots\cdots\cdots\cdots (5)$$

$$\frac{\partial q_5}{\partial t} = -u_{ex} \cdot A_{ex} \cdot c_{pa} \cdot T_5 \quad \cdots\cdots\cdots\cdots (6)$$

$$\frac{\partial q_3}{\partial t} = U_l \cdot A_l \cdot (T_3 - T_4) \quad \cdots\cdots\cdots\cdots (7)$$

Constraint condition is shown by equations in Eq. (8) ～ (12).

$$u_{ac} = u_{ex} \cdots\cdots\cdots\cdots\cdots\cdots (8)$$

$$A_{ac} = A_{ex} \quad \cdots\cdots\cdots\cdots\cdots\cdots (9)$$

$$T_5 = T_4 \quad \cdots\cdots\cdots\cdots\cdots\cdots (10)$$

$$T_3\big|_{t=0} = T_{3(0)} \quad \cdots\cdots\cdots\cdots\cdots\cdots (11)$$

$$T_4\big|_{t=0} = T_{4(0)} \quad \cdots\cdots\cdots\cdots\cdots\cdots (12)$$

In Eq. (7), $q_3$ is heat transfer due to the temperature difference between the inside air of the car and material. In order to calculate the heat transfer rate due to the temperature difference between the inside and the outside, Eq. (3) can be used. For that, it is necessary to know the total heat transfer coefficient $U_c$. So, $U_c$ is obtained through the following experiment. [4]

### 2-2-2. THE EXPERIMENT

$U_c$ can be obtained by $T_2$, $T_4$, $q_1$, and using Eq. (3). In this method, solar radiation is disturbance factor to calculate the total heat transfer coefficient $U_c$. For this reason, $T_2$, $T_4$ and $q_1$were measured at night while there is nothing solar radiation. The measured result is shown in Figure 6.

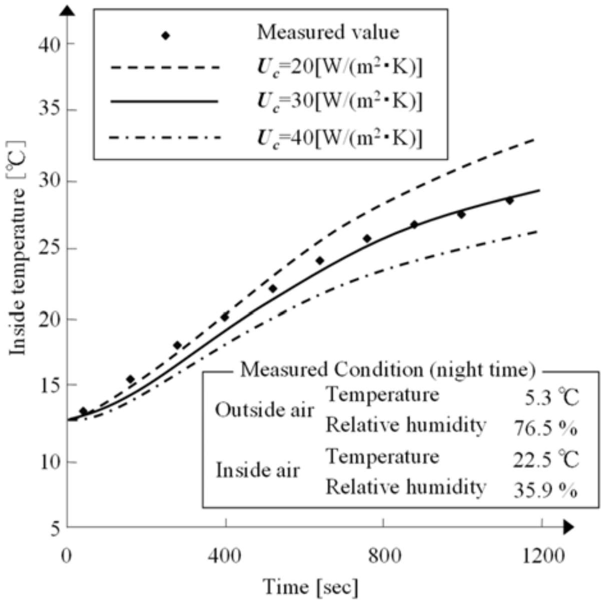

**Figure 6** A comparison result of a measure and calculation about total heat transfer coefficient $U_c$

From Figure 6, it is obtained that $U_c$ is 30 W / (m$^2$・K).

As the result, the required capacity of air-conditioner is able to calculate using Eq. (13). Eq. (13) is shown as cooling ($Q_0 > Q_1$). In the case of heating ($Q_0 < Q_1$), positive and negative signs are reversed. That is to say, the required capacity for cooling is calculated based on the capacity to cool outside air to a target condition of car inside through the use of an air-conditioner. For example, the outside condition has a temperature of 32[℃], relative humidity of 60[%] and solar radiation of 0.8 [kW/m$^2$]. The target condition has a temperature of 10[℃] and relative humidity of 100[%]. In this case, the the required capacity of air-conditioner for cooling is 6kW.

$$q_n = q_0 - q_1 \quad \cdots\cdots\cdots\cdots\cdots (13)$$

## 2-3. REQUIRED POWER OF A CAR AIR-CONDITIONER

The required compressor power of a car air-conditioner can be calculated based on the obtained air-conditioner capacity.

In this Study, it is necessary to evaluate the performance of an actual vehicle, so an air-conditioner which was mounted on 2000 model "Mira" was used. The refrigerating cycle of the air-conditioner is shown Figure 7. The performance of the air-conditioner is evaluated through the coefficient of Performance (hereinafter referred to as COP). The cooling COP is shown in Eq. (14) heating COP is shown in Eq. (15) [5].

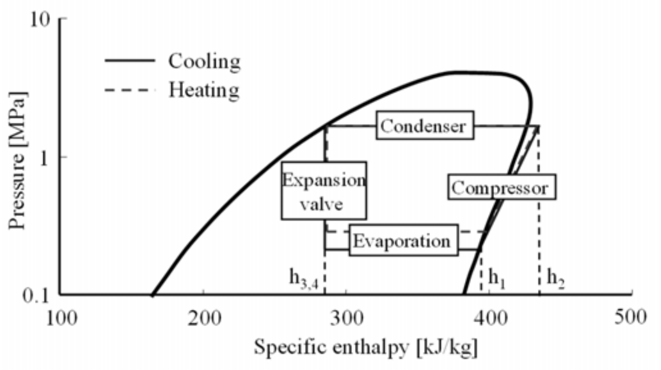

**Figure 7** Refrigerating cycle of Mira mounted air-conditioner

$$COP_C = \frac{h_1 - h_4}{h_2 - h_1}\eta_m \eta_p \quad \cdots\cdots\cdots\cdots\cdots (14)$$

$$COP_H = \frac{h_2 - h_3}{h_2 - h_1}\eta_m \eta_p \quad \cdots\cdots\cdots\cdots\cdots (15)$$

It is obtained that the cooling **$COP_C$** is 2.8 and the heating **$COP_H$** is 3.1 under the condition of Table 3. The required small-engine displacement to drive the air-conditioner compressor was calculated by **$COP_C$**, **$COP_H$**, the required capacity of air-conditioner and the engine output characteristics. Specifically, the engines output characteristics were used of EX13-premium (displacement of 126[cc]), EX17-premium (displacement of 169[cc]) and EX21-premium (displacement of 211[cc]) manufactured by FUJI Heavy Industries, Ltd. as general purpose. The result is shown in Figure 8.

**Table 3** The condition of measured air-conditioner capacity

| | | Outside condition | Output of air-conditioner |
|---|---|---|---|
| $COP_C$ | Temperature [℃] | 32.0 | 10.0 |
| | Relative humidity [%] | 60.0 | 100.0 |
| $COP_H$ | Temperature [℃] | 5.0 | 50.0 |
| | Relative humidity [%] | 80.0 | 5.6 |

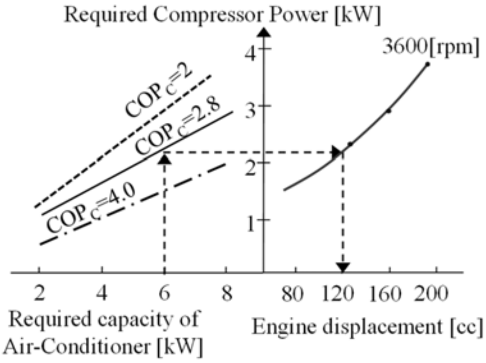

**Figure 8** Determination logic of the small-engine displacement mounted on AI-EV

Figure 8 is shown an example of the cooling case. As the result, it is clarified that the required engine output is obtained by the required capacity of air-conditioner and COP. And then, the engine displacement can be determined by the engines output characteristics. In this case, the required engine output is found 2.2kW and the engine displacement is found 120cc when the engine drives at 3600rpm.

## 3. EVALUATION OF SMART PV AND AI-EV SYSTEM

As the above results, it is clarified that the required engine displacement of AI-EV is less than one-fifth of that of conventional gasoline vehicles. However, AI-EV is concerned to increase $CO_2$ emissions which are compared with conventional EV, because AI-EV should consume fossil fuels in a small-engine. Accordingly, the value of the AI-EV has been evaluated for the reduction of $CO_2$ emissions and the level of economic efficiency in the Smart PV-EV System.

### 3-1. Evaluation of New Energy System (HEX model)

The evaluation was performed based on the simulation model of “HEX model” which is able to manage for the fuel, electric power, heat and renewable energy unitarily with measurement data. In the future energy system, which has been expected by authors, PV generated electricity in an arbitrary place and electricity is transported and stored by EV. Therefore, it is necessary to calculate the energy balance in each area. It is extremely difficult to evaluate by “Network Type Model”. For this reason, “HEX model” which is a novel simulation model shown as Figure 9 that has been developed refers to numerical analysis method of the flow analysis method and the heat transfer analysis using the control volume. [6]

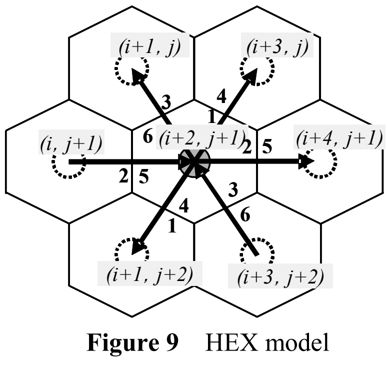

**Figure 9** HEX model

The energy balance of every HEX (hexagons) is a total of $\boldsymbol{EF_{ijmt}}$ (the energy variation of HEX with energy outflow and inflow such as EV) and $\boldsymbol{ES_{ijmt}}$ (The energy variation of HEX with generating energy, consumption and storage). Therefore, the total energy variation of HEX $(\boldsymbol{i}, \boldsymbol{j})$ at time $\boldsymbol{\gamma}$ is shown in Eqs. (16), (17). In addition, $\boldsymbol{C_m}$ as shown in Eq. (17) is the electrical conversion factors of each fuel. In the future, when the energy system will be designed within HEX as all energy consumption is substituted by electricity without using fuel, it is possible to calculate energy consumption with Eq. (17).

$$E_{ijm\gamma} = EF_{ijmt} + ES_{ijmt} \quad \cdots\cdots\cdots\cdots \ (16)$$

$$E_{ij\gamma} = \sum_{m=1}^{n1} C_m E_{ijm\gamma} \quad \cdots\cdots\cdots\cdots\cdots \ (17)$$

A wide area is shown as aggregate of continued plurality of HEX. And, the amount of energy variation with total of object area is shown in Eq. (18).

$$E_{Area\,\gamma} = \sum_{i=1}^{n2} \sum_{j=1}^{n3} E_{ij\gamma} \quad \cdots\cdots\cdots\cdots\cdots \ (18)$$

The basic restriction conditions of $\boldsymbol{E_{ij\gamma}}$ and $\boldsymbol{E_{Area\gamma}}$ are shown in Eq. (19). It is necessary to satisfy the balance of energy supply and demand within the object area at all times.

$$E_{ij\gamma} > 0, E_{Area\,\gamma} > 0 \quad \cdots\cdots\cdots\cdots\cdots \ (19)$$

## 3-2. CALCULARED CONDITION

In this case study, four different types of vehicle were simulated, a gasoline engine vehicle, a HV, an EV, an AI-EV. The vehicles were simulated driving for a commuting between a home and Okayama Prefectural University (hereinafter referred to as OPU) once a day for a year. The PV data is shown in Table 4.Amount of PV power generation is calculated based on an annual weather database which has hourly solar radiation data and reflected PV power fluctuations caused by the weather, the season and the time [7]. And, the AI-EV data is shown in Table 5.

**Table 4** PV date

| | |
|---|---|
| Output unit area | 190.0 W/m$^2$ |
| PV area | 12.5 m$^2$/unit |
| Total power | 2.4 kW |

**Table 5** AI-EV data

| | | |
|---|---|---|
| Electricity consumption（AI-EV） | 9.1 | km/kWh |
| Available capacity of the battery | 20%－80% | |
| The capacity of the battery | 24.0 | kWh/unit |
| Commuting distance | 28.0 | km/day |
| Commute day | 242.0 | day/year |
| Displacement of engine | 120.0 | cc |

AI-EV uses LPG to drive a small-engine. The average commuting distance of workers in OPU is 28km/day and the average running speed is 30km/h. Additionally, the $CO_2$ emission coefficient of gasoline is 2.62 kg-$CO_2$/ℓ, the $CO_2$ emission coefficient of electricity is 0.657 kg-$CO_2$/kWh (2011 The Chugoku Electric Power Company, Inc.), the $CO_2$ emission coefficient of LPG is 3.48 kg-$CO_2$/kg [8].

## 3-3. ANALYSIS RESULT

### 3-3-1. $CO_2$ EMISSIONS

A comparison result of the annual $CO_2$ emissions through the use of each vehicle in this system is shown in Figure 10. In Figure 10, in the Smart PV-EV System, AI-EV is expected to reduce $CO_2$ emissions of 20% compared with gasoline engine vehicle. The effect is almost the same as EV. The reduction value of $CO_2$ emissions is three times as the value of HV.

The reason is that the difference of energy conversion efficiency which is changed from fuels to using a car air-conditioning power. In the AI-EV, small-engine efficiency is $\eta$=30.0[%]. When it is considered that the driving and mechanical losses, the total efficiency from fuels to using a car air-conditioning power is 27.2%. On the other hand, EV has to be charged electricity from the conventional power system when the weather is bad such as rain. In the conventional power system, power generation efficiency is $\eta$=36.0[%] at receiving terminal (2010 result in JAPAN). When it is considered that the AC⇔DC conversion and charge⇔discharge losses, the total efficiency from fuels to using a car air-conditioning power is 26.0%. Therefore, the total reduction of $CO_2$ emissions in the Smart PV& AI-EV System is almost the same as the Smart PV& EV system.

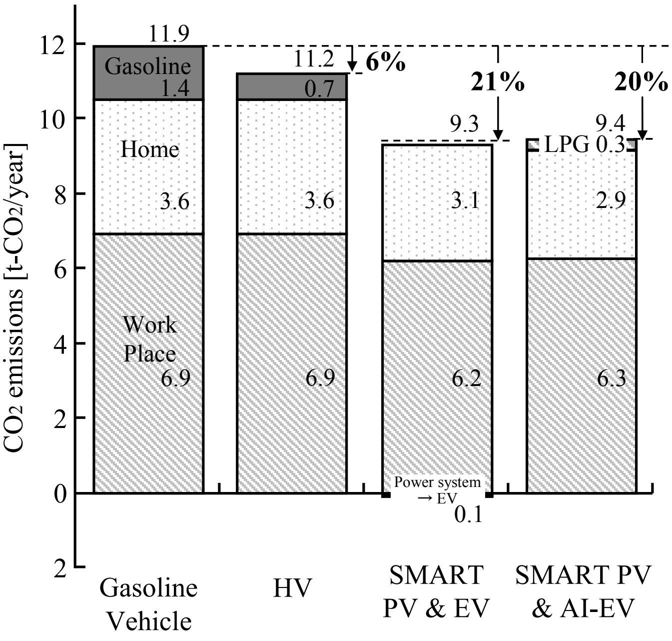

**Figure 10** A comparison of annual $CO_2$ emission

### 3-3-2. PERFORMANCE OF AI-EV AS A VEHICLE

The maximum cruising range of EV and AI-EV in summer season is shown in Figure 11. In Figure.11, the limit cruising range of EV is 100km in the case of driving in a city area (in other words, average speed 32km/h, 25miles/h) in the summer seasons. On the other hand, the maximum cruising range of AI-EV which is mounted a 120cc displacement engine is more than 200km under the same condition as above mentioned EV. Consequently, AI-EV is able to gain the maximum cruising range approximately twice as long as EV in a city area. The reason for this is that the AI-EV cruising range is extended by the effect of the hybrid system which drives the air-conditioning system and generates electric power in the case of a low air-conditioning load. As the results, it is clarified that AI-EV is able to solve the issues of conventional EV. Therefore, it is considered that the Smart PV & AI-EV system can be adapted for Europe and America that is long commuting distances of over 50 km for one way.

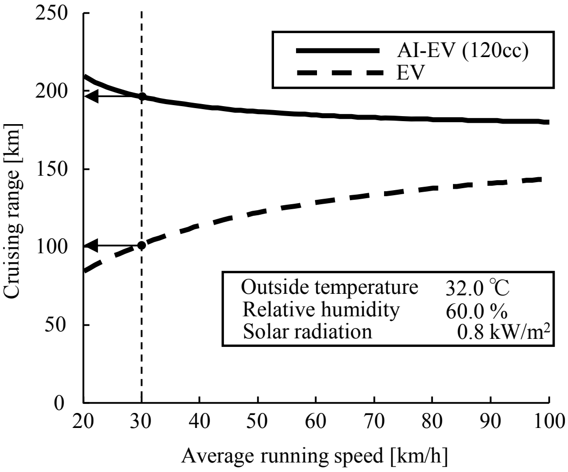

**Figure 11** Extend of the maximum cruising range

## 4. CONCLUSIONS

A car air-conditioner capacity is determined based on the heat transfer between inside and outside of the car. A mathematical simulation model which evaluates for the AI-EV energy consumption has been developed based on the thermodynamics that is the difference of the thermal efficiency between the power plant and the small-engine. And then, the value of the AI-EV is compared with conventional vehicles. In the comparison, the reduction of $CO_2$ emissions and the performance of a vehicle are evaluated in regards to total system which includes the home and workplace.

The result is as follows

- A novel concept car of AI-EV(Air-conditioner Integrated Electric Vehicle) has been proposed and verified the effects based on the heat transfer and thermodynamics.
- In the Smart PV & AI-EV System, AI-EV is expected to reduce $CO_2$ emissions of 20% which is compared with a gasoline vehicle. The effect is almost the same as EV.
- The performance of AI-EV as a vehicle in a city area, AI-EV is able to gain the maximum cruising range approximately twice as long as EV. Therefore, AI-EV can solve the issues of conventional EV.
- Therefore, it is considered that the Smart PV & AI-EV system can be adapted for Europe and America that is long commuting distances of over 50 km for one way.

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