

Hybrid Electric Vehicle Battery System

Contents

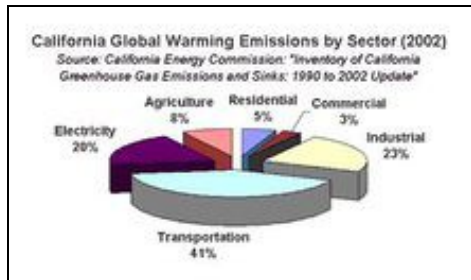
- 1 Introduction
- 2 Rationale
- 3 New Developments
 - ◆ 3.1 Sample visual interactive model
- 4 Hybrid Electric Vehicle (HEV)
- 5 Components of the HEV Battery System
- 6 HEV battery system design parameters
- 7 Comparison of top 3 batteries used in HEVs
- 8 Like this report?
- 9 HEV battery system concerns
- 10 Goal
 - ◆ 10.1 IP activity over the years
 - ◆ 10.2 Assignee wise IP activity
 - ◆ 10.3 Competitor and Market Landscape
 - ◆ 10.4 Distribution of patents based on Technology focus
 - ◆ 10.5 IPMap
- 11 Clustering - Technology focus
- 12 Technology approach
 - ◆ 12.1 Major Players
 - ◆ 12.2 Toyota Motors
 - ◆ 12.3 Nissan Motors
- 13 Like this report?
- 14 Contact Dolcera

Introduction

Transportation accounts for 41% of the sources of global warming. Electric vehicles can help dramatically reduce the production of greenhouse gases. Battery systems are the key to the success of electric vehicle technology.

This report describes the technology and patenting trends related to the battery systems used in hybrid vehicles. It also describes in detail the various technical challenges faced by designers of these batteries and the innovative solutions proposed for them. The report also covers the techniques used by Nissan and Toyota's vehicles in this domain.

Rationale



Global warming emissions by sector

- Automobiles are a source of considerable pollution at the global level, including a significant fraction of the total greenhouse gas emissions.
- On July 22, 2002 California Governor Gray Davis signed into law AB 1493 (commonly known as the "Pavley law") ? precedent-setting legislation to reduce global warming pollution from motor vehicles.
- This bill directs the California Air Resources Board (CARB) to develop and adopt regulations that achieve the maximum feasible and cost-effective reduction of greenhouse gas emissions (GHG) from passenger cars and light trucks sold in California.

New Developments

Sample visual interactive model

This is supposed to be a flash animation. You'll need the flash plugin and a browser that supports it to view it.

The new millennium is bringing a millennial change to the family car. A few years back, the key concerns were:

- Pollution,
- Nagging worries about global warming, and
- Oil shortages.

These concerns led to the development of Electric Vehicle (EV?s) powered by batteries. But current battery technology does not provide EV's with a range that is acceptable to consumers. **Limitations of EV?s:**

- An average commute to work is around 40 miles.
- EV's have a range of 80-100 miles using advanced battery technology.
- While batteries need frequent recharging, they are not the only way to power an electric car.

Hybrid Electric Vehicle (HEV)

The Hybrid Electric Vehicle (HEV) is just the first step in reducing the environmental impacts of automobile use without losing comfort, performance, storage room and extended driving range.

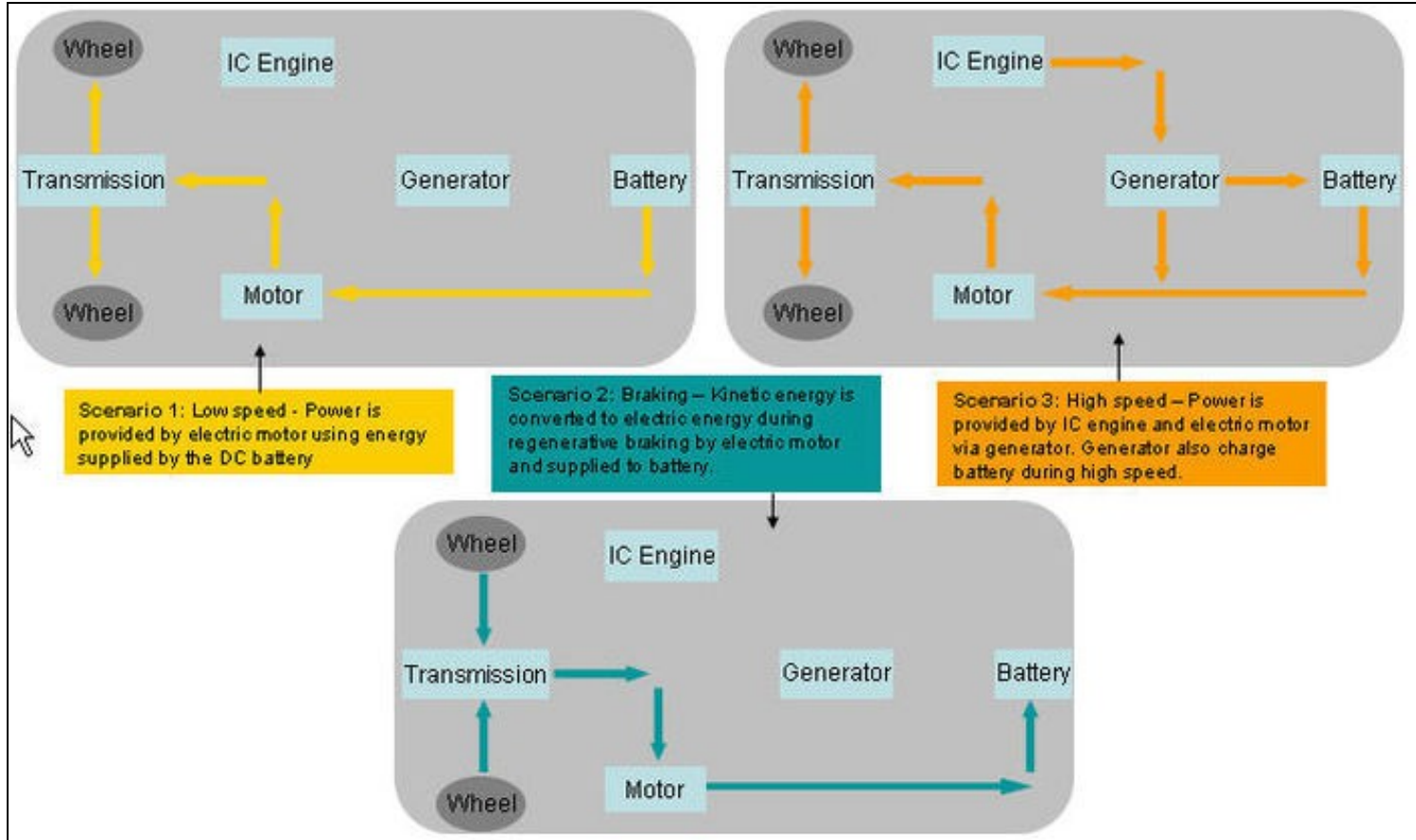
Advantages of HEV?s:

- The HEV contains parts of both gasoline and electric vehicles in an attempt to get the best of both worlds.
- It is able to operate nearly twice as efficiently as traditional internal combustion vehicles.
- It has equivalent power, range, cost and safety of a conventional vehicle while reducing fuel costs and harmful emissions.
- The battery is continuously recharged by a motor/generator driven by the Internal Combustion Engine (ICE) or by regenerative braking.

Components of the HEV Battery System

The battery in an HEV is the energy storage device for the electric motor. Unlike the gasoline in the fuel tank, which can only power the gasoline engine, the electric motor in a hybrid car can put energy into the battery as well as draw energy from it.

- **Battery:** Two or more electrochemical energy cells connected together to provide electrical energy.
- **Generator:** The generator is similar to an electric motor, but it acts only to produce electrical power.
- **Electric motor:** Advanced electronics allow it to act as a motor as well as a generator. For example, when it needs to, it can draw energy from the batteries to accelerate the car. But acting as a generator, it can slow the car down and return energy to the batteries.
- **SOC:** The State of Charge of a battery is its available capacity expressed as a percentage of its rated capacity



Components of the HEV Battery System

HEV battery system design parameters

Factors affecting battery performance:

- **Temperature:** Battery performance is highly dependent on temperature. Each type of battery works best within a limited range of temperatures.
- **Battery age/Shelf life:** Corrosion is the main culprit behind decreased performance in lead acid type batteries with age.
- **Depth of discharge:** Batteries are able to maintain their performance longer when they are not deeply discharged regularly.

Design parameters:

- How much space is available for the batteries?
- How much can they weigh?
- What is the desired range?
- What is the weight of the vehicle?
- What is the targeted vehicle cost?
- How will the batteries be recharged and
- What kind of drive system requirements is needed?

These questions are necessary because of the variety of battery types available and the differences between them. The chart below lists the characteristics of the most common types of batteries. (Source [1])

| Battery Type | Energy Density [Wh/kg] | Power Density [W/kg] | Cycle Life | Self Discharge Rate [% per month] | Current Cost [\$/kWh] | Future Cost [\$/kWh] | Vehicles Used_In | Other Notes |
|----------------------|------------------------|----------------------|--------------|-----------------------------------|-----------------------|----------------------|---|--|
| Lead-Acid | 25 to 35 | 75 to 130 | 200 to 400 | 2 to 3 | 100 to 125 | 75 | CARTA bus, Solectria E10 (sealed) | |
| Advanced Lead Acid | 35 to 42 | 240 to 412 | 500 to 800 | | | | Audi Duo, GM EV1 (VLRA), Solectria Force | Potential: 55 Wh/kg, 450 W/kg, and 2000 cycle life |
| Nickel-Metal Hydride | 50 to 80 | 150 to 250 | 600 to 1500 | | 525 to 540 | 115 to 300 | Toyota RAV4-EV, Toyota Prius, Chrysler Epic minivan, Honda EV, Chevy S-10 | Potential: 120 Wh/kg, and 2200 cycle life |
| Nickel-Cadmium | 35 to 57 | 50 to 200 | 1000 to 2000 | 10 to 20 | 300 to 600 | 110 | WWU Viking 23 | Potential: 2200 cycle life |
| Lithium-Ion | 100 to 150 | 300 | 400 to 1200 | | | | Nissan Altra EV | Potential: 1000 Wh/kg |
| Zinc-Bromide | 56 to 70 | 100 | 500 | | 300 | | | |
| Lithium Polymer | 100 to 155 | 100 to 315 | 400 to 600 | | | 100 | | |
| NaNiCl | 90 | 100 | | 400 | | | | |
| Zinc-Air | 110 to 200 | 100 | 240 to 450 | | 300 | 100 | | |
| Vanadium Redox | 50 | 110 | 400 | | 300 | | | |



Battery types by descending order of popularity

Comparison of top 3 batteries used in HEVs

During recharging, it is important to maintain the balance of battery. The balance of battery is maintained by controlling battery from overcharging and over discharging.

The battery is controlled by defining State of Charge (SOC) of the battery:

- Upper limit value ? overcharge and
- Lower limit value ? over discharge

When overcharge is detected, power generation is controlled/cut-off and when over discharge is detected, power supply to electric motor is stopped. Detection is achieved by appropriate sensors.

This report investigates various procedures available/adopted by various assignees in order to maintain balanced battery pack by avoiding overcharge and/or over discharge.

| Lead Acid | Advanced Lead Acid | Nickel-Metal Hydride |
|--|--|--|
| Low cost | Longer lifecycle than conventional lead acid | High cost |
| Low energy density | Valve regulated lead/acid (VRLA) batteries showing promise | Higher energy density than lead acid; not as susceptible to heat |
| Longer recharging time (6-8 hours) | | Shorter recharging time |
| Only fair cycle life | | |
| Can be ruined by completely discharging them | | |

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HEV battery system concerns

The ultimate goal of HEV can only be achieved with the balance battery pack since the main source of energy is batteries and recharging is carried out on board.

Advantages of balance battery pack:

- Balancing of battery SOC's increases battery life
- Automated balancing circuitry will decrease overcharging (and gassing) and decrease manual maintenance.

This, in turn, provides:

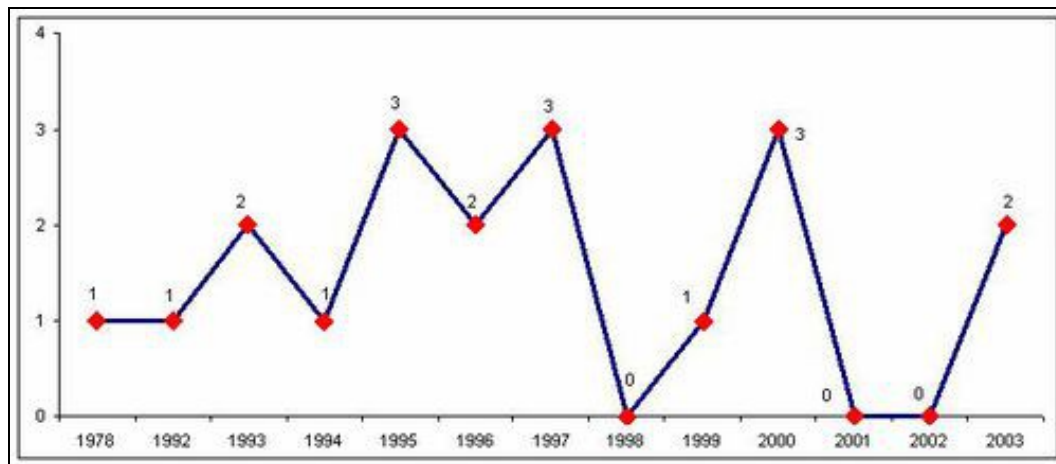
- Equivalent power range at low cost as conventional vehicle while reducing fuel costs and harmful emissions.
- Twice the travel distance of a conventional vehicle on the same amount of energy.

Goal

This report attempts to summarize various approaches involved in maintaining battery balance. We have selected a few patents, and will show:

- IP activity over the years
- Competitors
- Competitor and Market Landscape
- Technology map
- Technology approaches

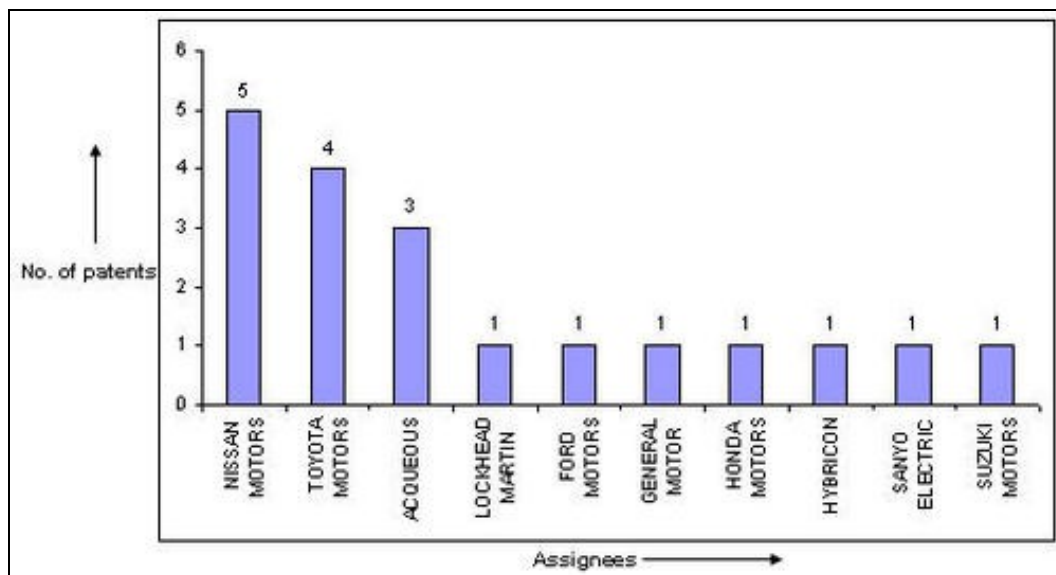
IP activity over the years



IP activity over the years

Assignee wise IP activity

Companies with many patents of HEV battery are arranged in decreasing order in the graph given below. Top three players are Nissan motors with (5) patent records to its credit, followed by Toyota with (4) and Acqueous (3).



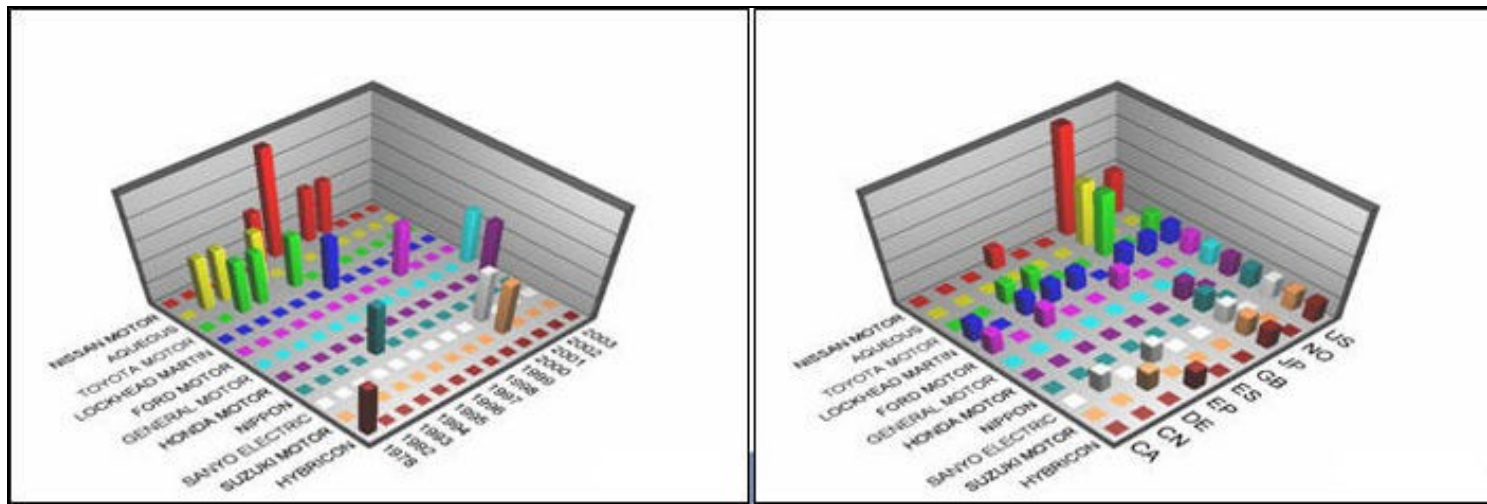
Assignee wise IP activity

Competitor and Market Landscape

The left graph given below displays the assignee wise IP activity over years, according to the present data the very first patent pertaining to HEV battery charging system was filed by HYBRICON in 1978 but is not in the race anymore. Though NISSAN, AQUEOUS and TOYOTA seems to be ahead in acquiring max. number of patent to their credits, but not active since 2000. GM and HONDA have bagged single-single patent of same age in 2003.

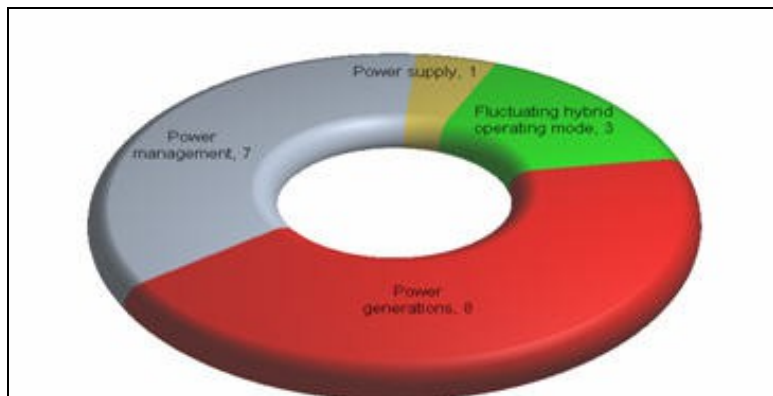
The right graph given below displays the market (countries) eyed by various competitors. The hot market place for most competitors is Japan (17) followed by United States (11) and Germany (04). According to the present data, Nissan seems to be having strong presence in Japan market that rests with 5 patents protected, followed by Aqueous and Toyota.

We will look into their technologies in competitor approaches section latter in the report.



Competitor and Market Landscape

Distribution of patents based on Technology focus



Distribution of patents based on Technology focus

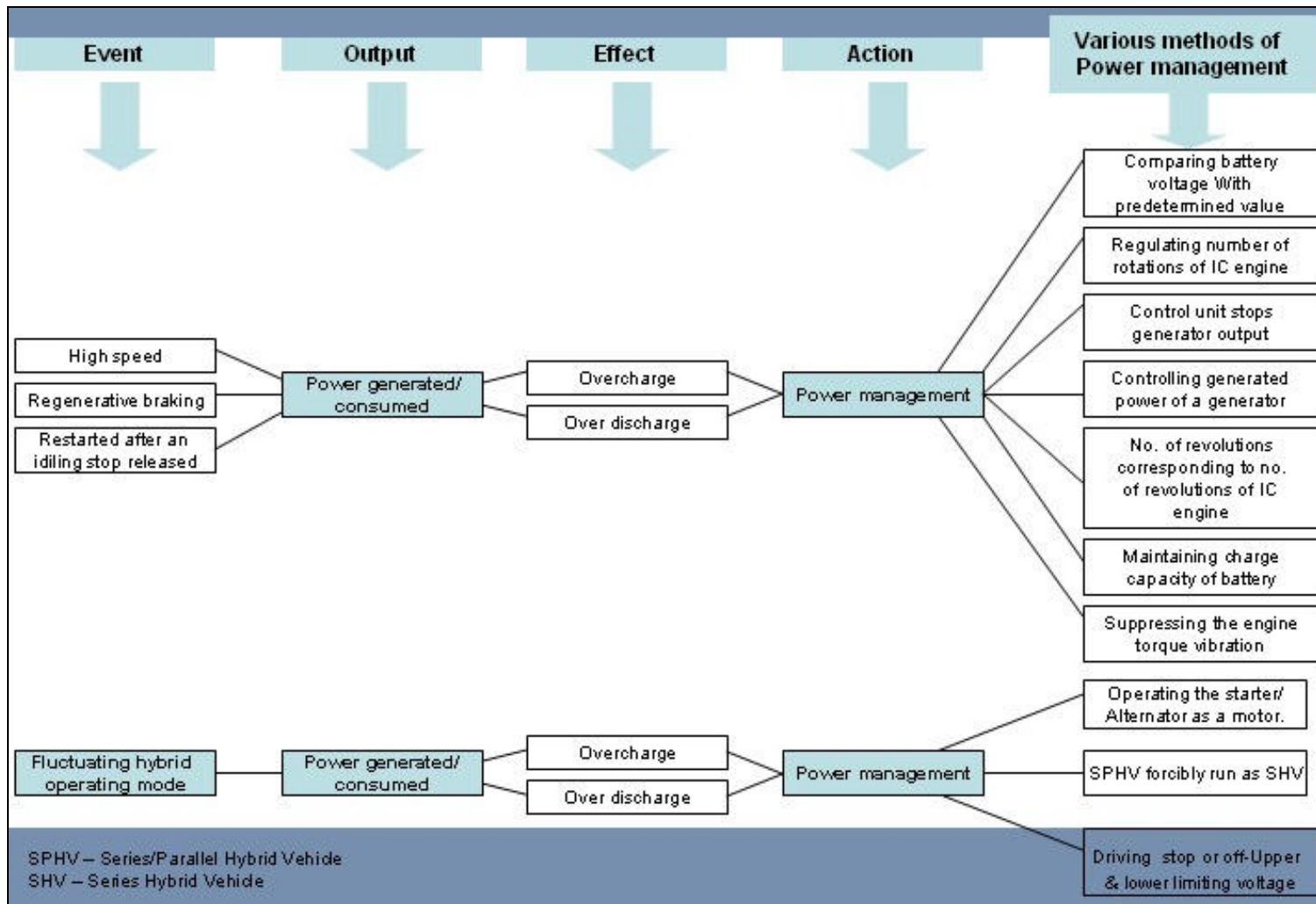
The above pie chart displaying various factors has effect on battery charge and discharge. The numbers indicating the distribution of patents in that area are from selected list of patents. The distribution of patents is based on technology focused in the patent.

- **Power generation:** Technologies disclosed in patents for modes of power generation in HEV for charging the battery and ways of handling them.
- **Power management:** Technologies disclosed in patents for managing the battery balance during power generating and/or consuming.
- **Fluctuating HEV operating mode:** Technologies disclosed in patents for managing battery balance during fluctuating operating modes, especially in composite HEV.
- **Power supply:** Technology disclosed in patent for starting engine with auxiliary battery current when main battery current is not sufficient to start engine

IPMap

| Patent number/ Priority year | Power Generation | Power management | Fluctuating hybrid operating mode | Power Supply | Series/parallel HEV |
|---------------------------------|--|---|--|---|------------------------|
| US6583599 (2003) | - | - | Operating the starter/ Alternator as a motor. | - | PHV |
| JP08098321 (2003) | - | - | SPHV forcibly run as SHV | - | PHV |
| US6504327 (2000) | - | - | Motor driving stop or off - Upper & lower limiting voltage | - | SHV |
| US5550445 (2000) | - | Comparing battery voltage With predetermined value | - | - | SHV |
| US6809501 (2000) | Idling in slow traffic | - | - | - | SHV |
| US5722502 (1995) | - | - | SHV mode or continuous-type PSHV mode is controlled by driver or based on the SOC of the accumulator. | - | PSHV |
| US4351405 (1999) | High speed | - | - | - | PHV |
| JP2001078306 (1997) | Regenerative braking | - | - | - | PHV |
| JP08055941 (1997) | Regenerative braking | - | - | - | SPHV |
| JP10295045 (1997) | Regenerative braking | - | - | - | SHV |
| JP08319205 (1996) | Regenerative braking | - | - | - | SHV |
| JP2001268707 (1996) | Restarted after an idling stop released | - | - | - | SHV |
| JP10084636 (1995) | - | Regulating number of rotations of IC engine | - | - | PHV |
| JP09200907 (1995) | - | Control unit stops generator output | - | - | PHV |
| JP11136808 (1994) | - | Controlling generated power of a generator | - | - | SHV |
| JP09117010 (1993) | - | Operates generator at number of revolution corresponding to number of revolutions of IC engine | - | - | PHV |
| US5828201 (1993) | - | Maintaining charge capacity of battery modules | - | - | SHV |
| US20050038576 (1992) | - | Suppressing the engine torque vibration | - | - | SPHV |
| US6392380 (1978) | - | - | - | Automotive elec. system battery is used to starts engine | SHV |

Clustering - Technology focus



Clustering - Technology focus

Technology approach

Major Players

In technology approach patent and non-patent literature is used to extract information about the technology profile of various assignees such as






- Years in this activity
- Type of batteries used
- Battery charging system
- Types of HEV (Series (SHV)/Parallel (PHV)/Composite (SPHVS))
- Technological strength based on citation analysis
- Product Vs patent identification
- Battery management solutions proposed (i.e. current control/cut-off system and SOC detection

technique)

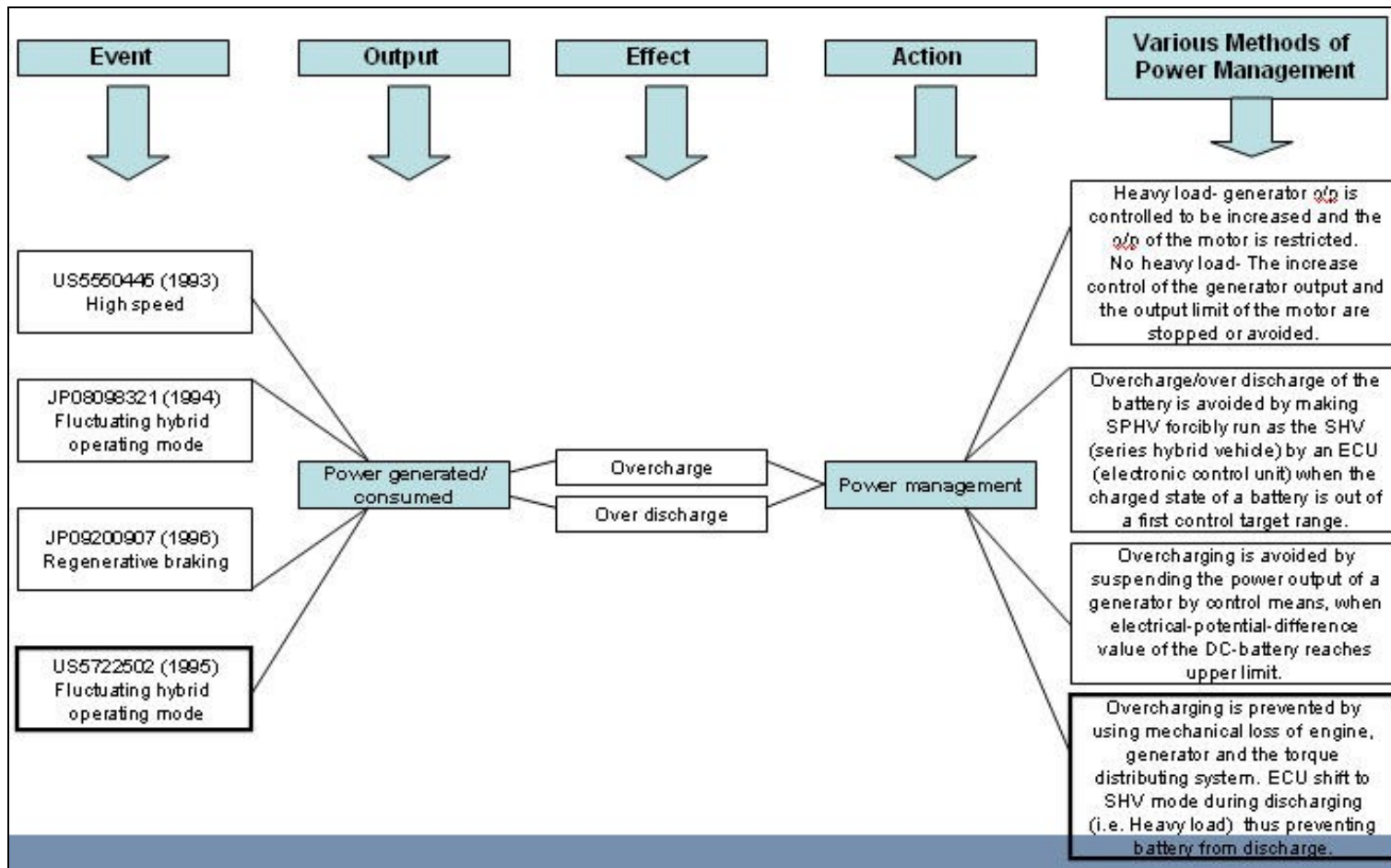
- Scientific literature and technology news to strengthen the report, since patent activity is a slow process.

Toyota Motors

- **Battery type:** Lead-Acid battery
- **Battery charging system:** The charge to the DC-battery is provided from the power generated by the generator and the regeneration power from the drive motor at the time of braking.
- **First approach:**

| | Patent #/Priority date | Current control/Cut-off system | SOC detector |
|--|--|---|--|
|  <p>Series/parallel composite electric vehicle (SPHV)</p> |  <p>US5550445 (1993)</p> | <p>During heavy load state, generator output is controlled to be increased and motor output is restricted. When heavy load is not detected, generator and motor output is stopped or avoided thus preventing battery overcharging.</p> | <p>Voltage sensor and an SOC sensor detect voltage and an SOC of the battery and detected results to the controller.</p> |
| |  <p>JP08098321 (1994)</p> | <p>When the charged state of a battery is out of a first control target range, the ECU makes the SPHV forcibly run as the SHV. With this constitution, even if the PHV running is continued for a long time, the charged state of the battery is controlled with a certain frequency, so that the overcharge or over discharge of the battery can be avoided.</p> | <p>The SOC sensor detects SOC of a battery, a voltage sensor detects the electrical potential difference of a cell for the rotational speed of a motor.</p> |
| |  <p>JP09200907 (1996)</p> | <p>The generation-of-electrical-energy output of a generator is suspended by the time it reaches the electrical-potential-difference upper limit limiting value of the DC-battery.</p> | <p>SOC is controlled within proper limits. When SOC falls from a lower limit, a generator will be operated to the maximum output, and if SOC reaches an upper limit, a generator will be operated to a minimum output.</p> |
| |  <p>US5722502 (1995)</p> | <p>Overcharging is prevented by using mechanical loss of engine, generator and the torque distributing system. ECU shift to SHV mode during discharging (i.e. Heavy load) is thus preventing battery from discharge.</p> | <p>SOC sensor detects accumulator SOC and SOC is maintained to the desired range by mode control.</p> |

• Second approach:



Toyota Motors - Technology Approach2

• Findings:




| Product | Patent |
|-------------------|-----------|
| TOYOTA PRIUS | US5722502 |
| TOYOTA HIGHLANDER | US6691809 |

Findings
Nissan Motors

- **Battery type:-** Lead-acid and/or Nickel-Hydrogen battery
- **Battery charging system:-**

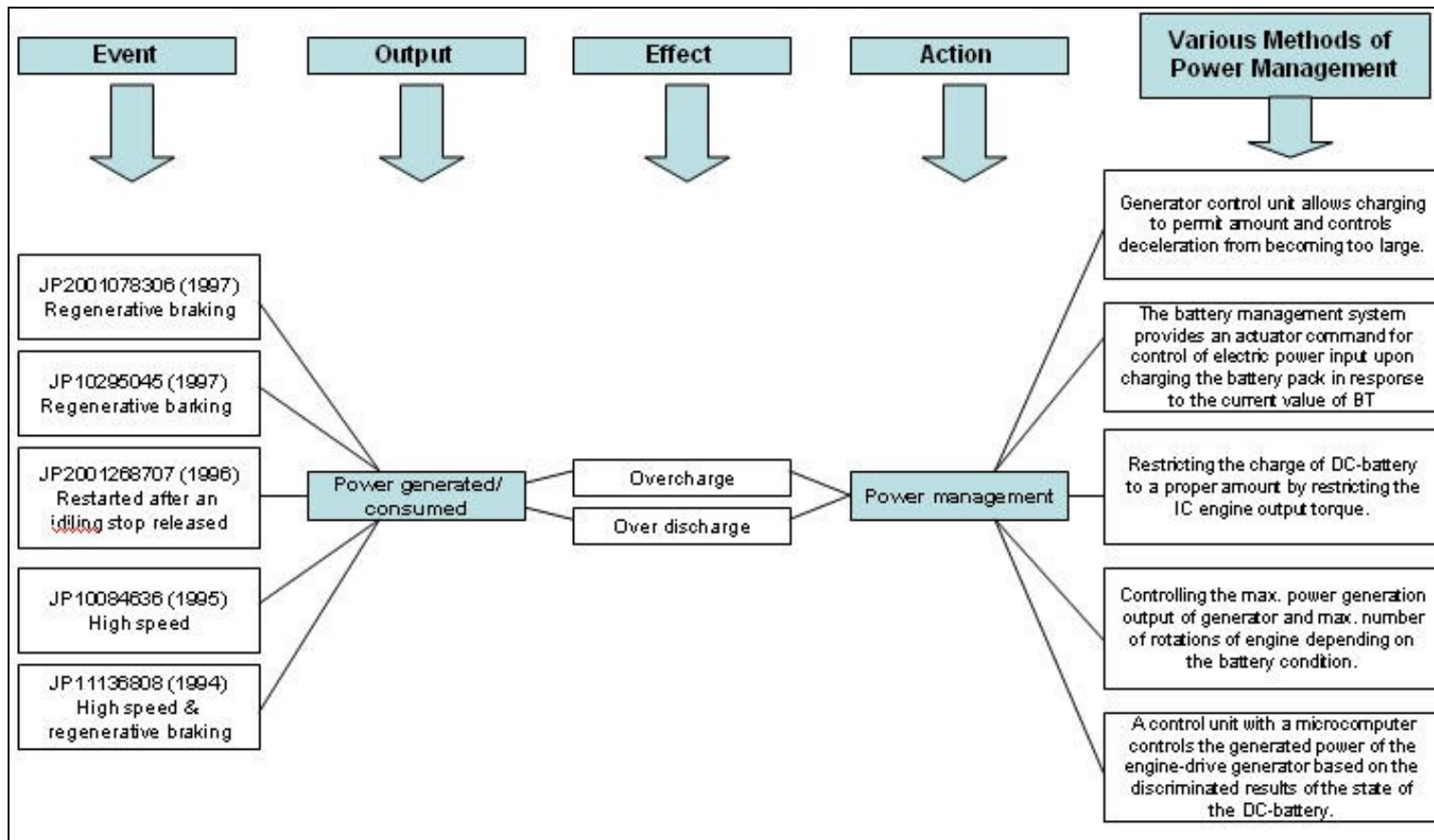
The battery is charged from the power generated by the generator and regeneration power from a motor. Electric motor functions as a generator to charge the battery when a hybrid vehicle is restarted after an idling stop released.

- **First approach:**

|  Battery  Series Hybrid Electric Vehicle  Parallel Hybrid Electric Vehicle <div style="border: 1px solid black; padding: 5px; margin-top: 10px;"> <p>Forward citation - JP10295045 (1997)</p> <table border="1"> <thead> <tr> <th>Year</th> <th>#</th> </tr> </thead> <tbody> <tr> <td>1998</td> <td>4</td> </tr> <tr> <td>1999</td> <td>4</td> </tr> <tr> <td>2000</td> <td>3</td> </tr> <tr> <td>2001</td> <td>7</td> </tr> <tr> <td>2002</td> <td>2</td> </tr> </tbody> </table> </div> | Year | # | 1998 | 4 | 1999 | 4 | 2000 | 3 | 2001 | 7 | 2002 | 2 | Patent #/Priority date JP10084636 (1996) | Current control/Out-off system Output of generator is restricted depending on the battery condition by the generator output controller. | SOC detector The DC-battery is equipped with the DC-battery condition detecting element which detects the electrical potential difference, temperature, and remaining capacity. | Scientific Literature (Non-patent info) In 1998, developed high power density Li-Ion battery for parallel HEV (US8,383) In 1999, developed thermal design of battery packs for HEV (Japan Journal of Thermophysical Properties) In 2000, developed electric double layer capacitor for HEV with high charge/discharge efficiency at high power density (US8,383) In 2003 Nissan propose a new HEV charge/discharge control system based on car navigation information. (Proceedings: JSAE Annual Congress) |
|---|--|---|------|---|------|---|------|---|------|---|------|---|---|---|---|---|
| | Year | # | | | | | | | | | | | | | | |
| | 1998 | 4 | | | | | | | | | | | | | | |
| | 1999 | 4 | | | | | | | | | | | | | | |
| | 2000 | 3 | | | | | | | | | | | | | | |
| | 2001 | 7 | | | | | | | | | | | | | | |
| 2002 | 2 | | | | | | | | | | | | | | | |
| JP10295045 (1997) | The battery management provides an actuator command for control of electric power input upon charging the battery pack in response to the current value of BT (battery temperature). | A controller finds the charging amount SOC of the battery on the basis of the terminal voltage VB and the temperature TB of the battery. | | | | | | | | | | | | | | |
| JP11136808 (1997) | A control unit with a microcomputer controls the charge/discharge of the DC-battery by controlling the generated power of the generator based on the discriminated results of the state of the DC-battery. | DC-battery condition distinction means distinguish the condition of a DC-battery and a generated output decision means opt for the generated output by the engine driven generator based on the distinction result by the do-battery condition distinction means. | | | | | | | | | | | | | | |
| US6452286 (1999) (42 V) | Control unit - Microprocessor | Charging current detecting unit detects the actual charging current of the motor-generator and actual charging current to the high voltage battery by a current sensor. | | | | | | | | | | | | | | |
| JP2001268707 (2000) (42 V) | The charge of a DC-battery is restricted to a proper amount by restricting the IC engine output torque, if the charging level SOC is higher than a given value. | When start conditions are met, the charging level SOC of the battery is detected by the current sensor. | | | | | | | | | | | | | | |

Nissan Motors - Technology Approach1

• Second approach:



Nissan Motors - Technology Approach2

• Findings:

- JP10295045 (1997):- Battery management system, received 21 forward citations from all big names in a span of 5 years and self-cited twice the same technology indicating strong technology strength and building on its own technology.

- Patent and non-patent information indicate that Nissan has focused much on circuit arrangements for charging or depolarizing batteries or for supplying loads from batteries (H02J 7/00).
- Jointly worked with Sony corp. (1998) developing high power density Li-ion battery for parallel HEV.
- Proposed a novel charge/discharge control system based on car navigation information.

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