Hybrid Electric Vehicle Battery System

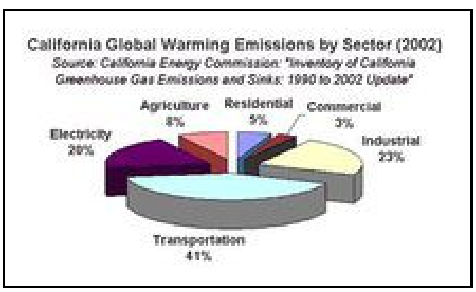
Contents

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.

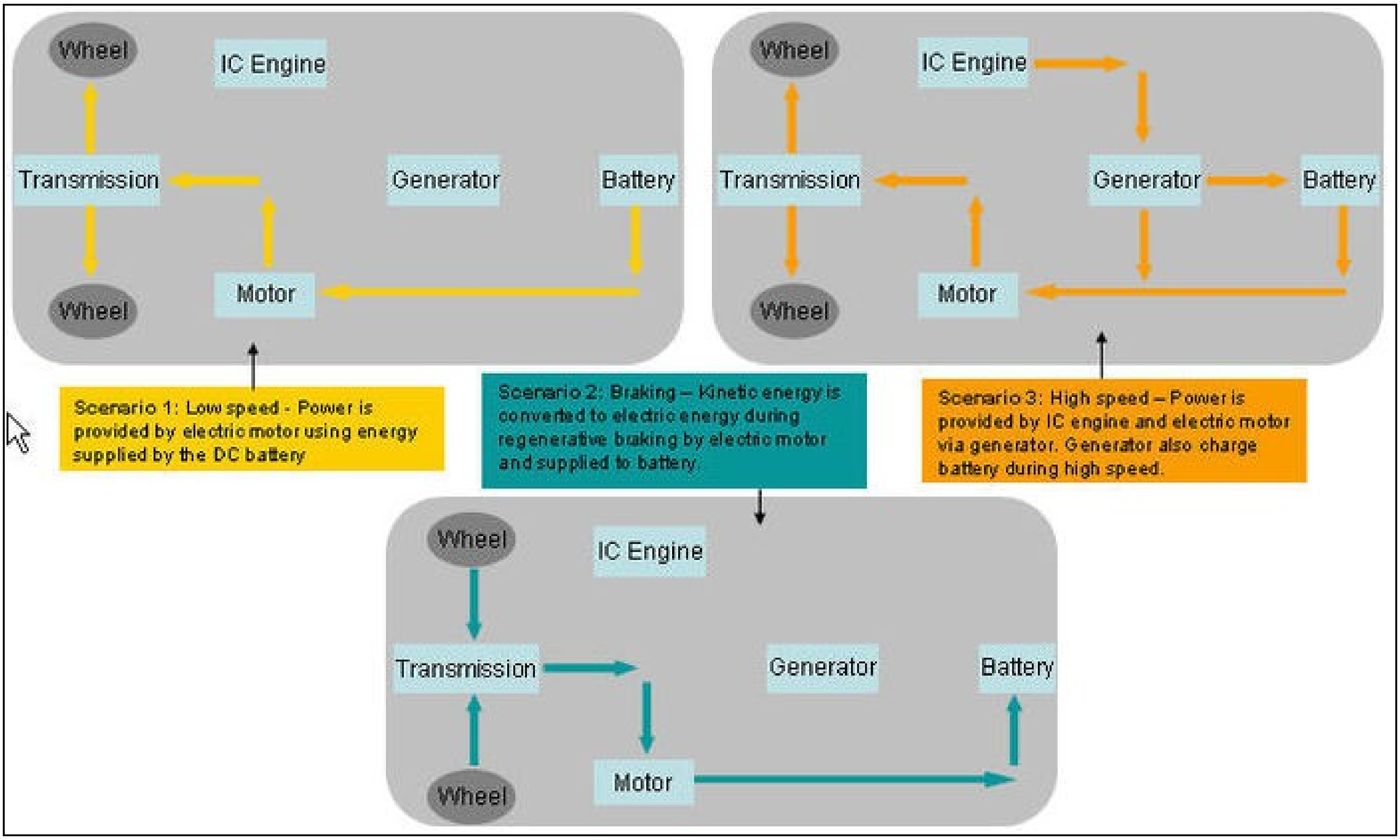
Advantages of HEV?s:

- 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		

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:

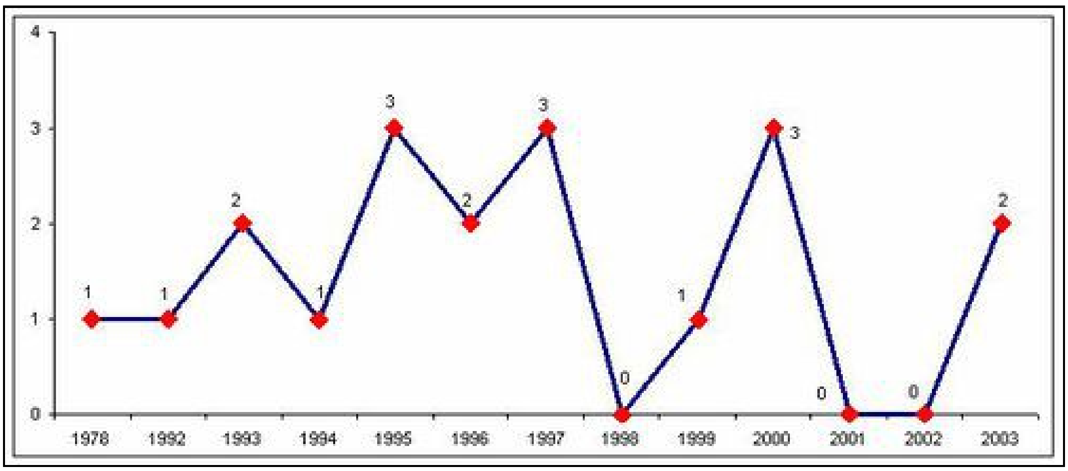
- Equivalent power range at low cost as conventional vehicle while reducing fuel costs and harmful emissions.
- Twice the travel distance of a conventional vehicle on the same amount of energy.

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

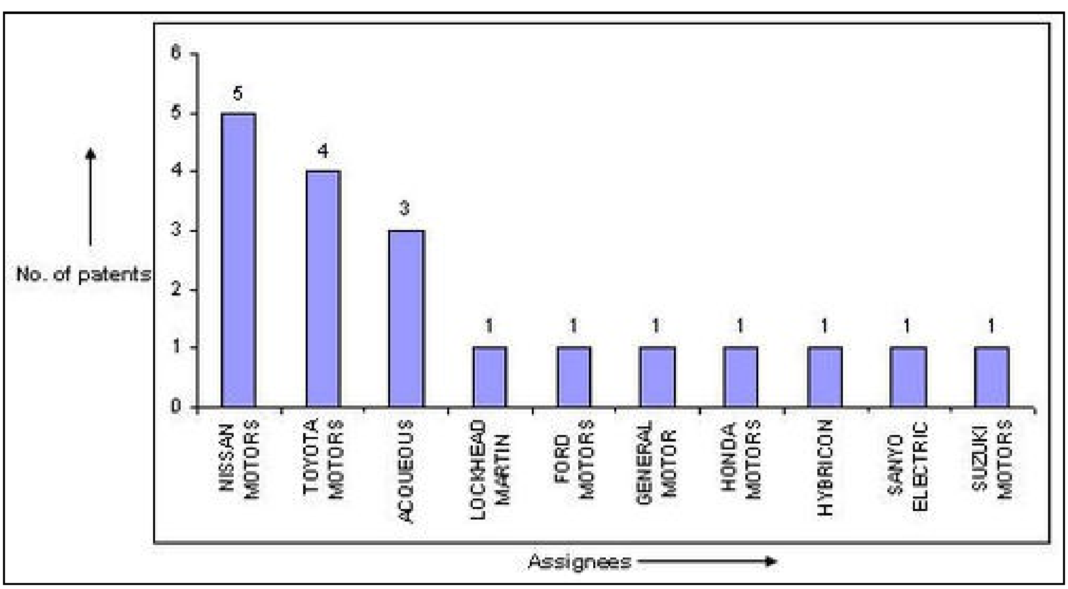
IP activity over the years



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).



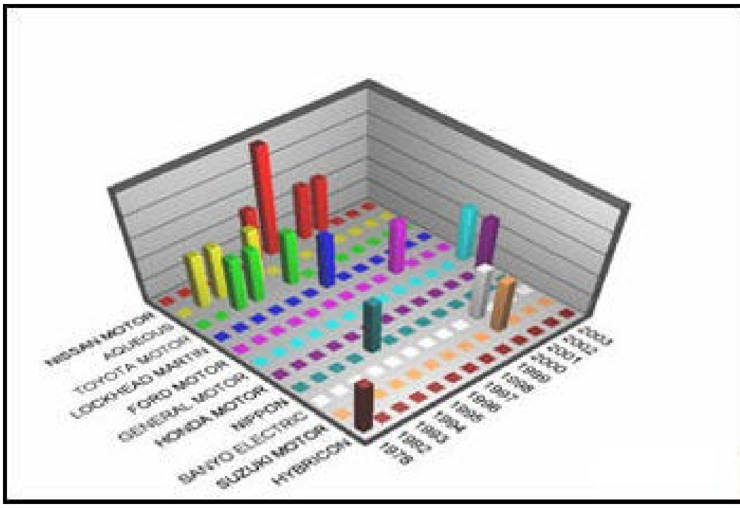
Assignee wise IP activity

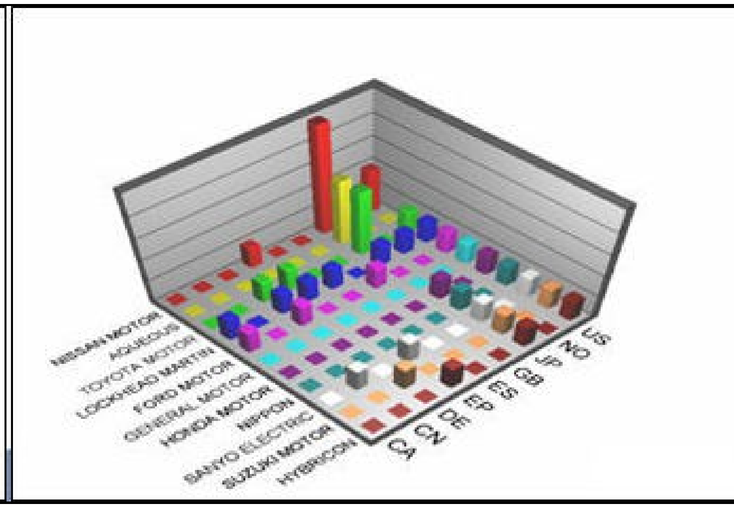
Competitor and Market Landscape

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.

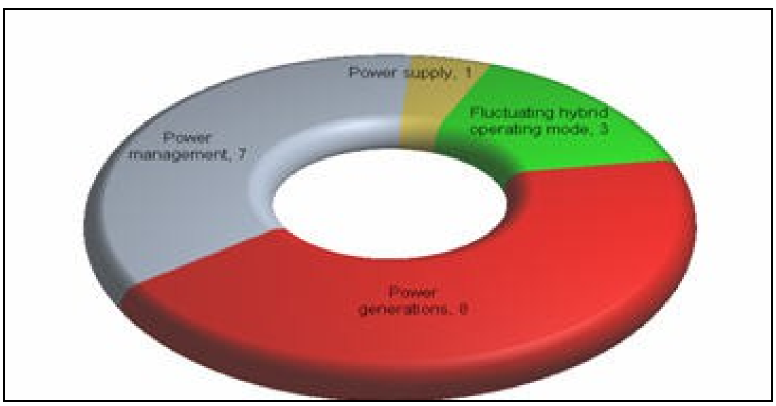
We will look into their technologies in competitor approaches section latter in the report.





Competitor and Market Landscape

Distribution of patents based on Technology focus



Distribution of patents based on Technology focus

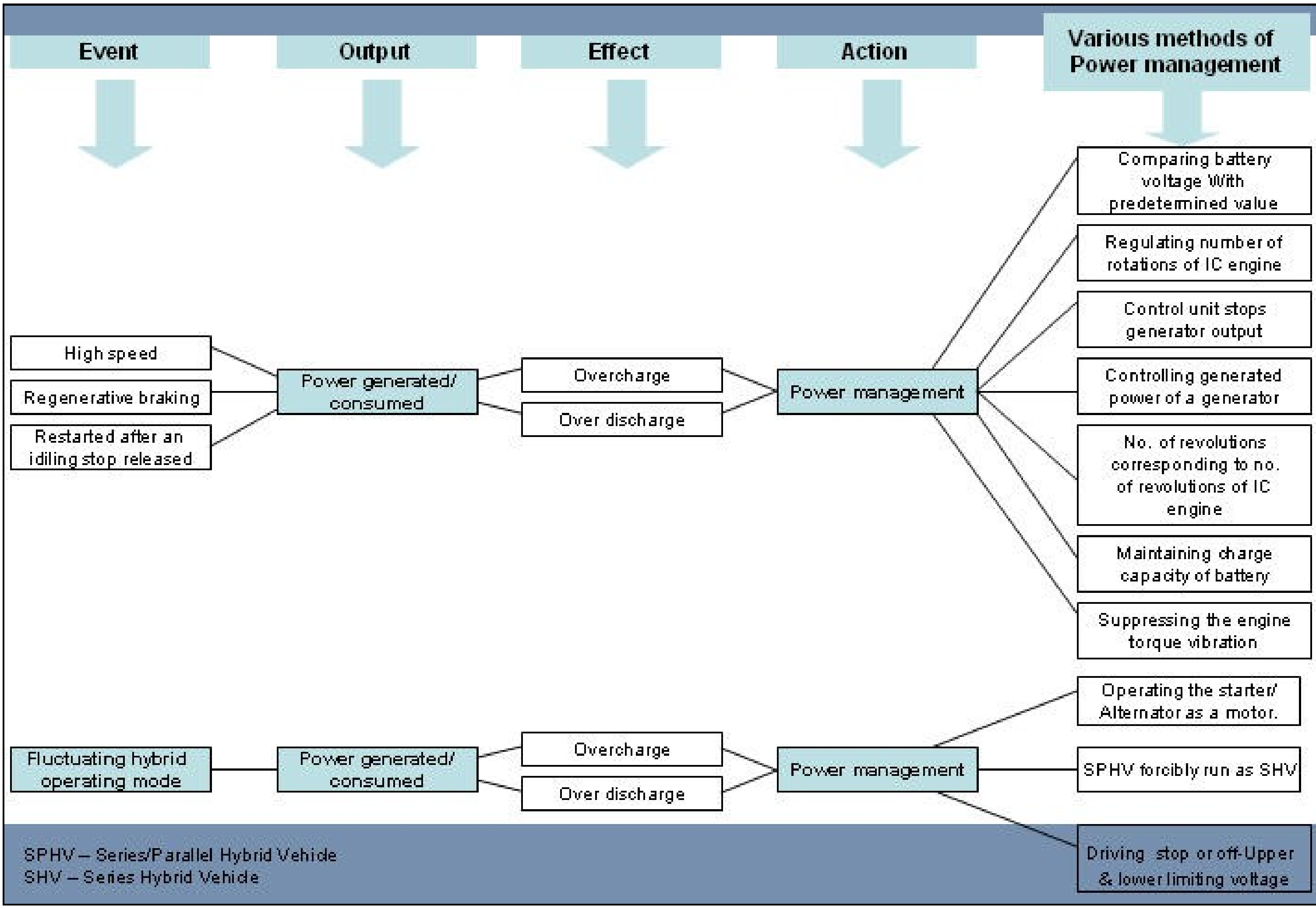
The above pie chart displaying various factors has effect on battery charge and discharge. The numbers indicating the distribution of patents in that area are from selected list of patents. The distribution of patents is based on technology focused in the patent.

- **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
JP06055941 (1997)	Regenerative braking	-	-	-	SPHV
JP10295045 (1997)	Regenerative barking	-	-	-	SHV
JP06319205 (1996)	Regenerative braking	-	-	-	SHV
JP2001268707 (1996)	Restarted after an idiling 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

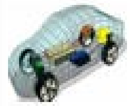
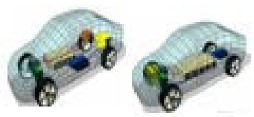
- Years in this activity
- Type of batteries used
- Battery charging system
- Types of HEV (Series (SHV)/Parallel (PHV)/Composite (SPHVS))
- Technological strength based on citation analysis
- Product Vs patent identification
- Battery management solutions proposed (i.e. current control/cut-off system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

technique)

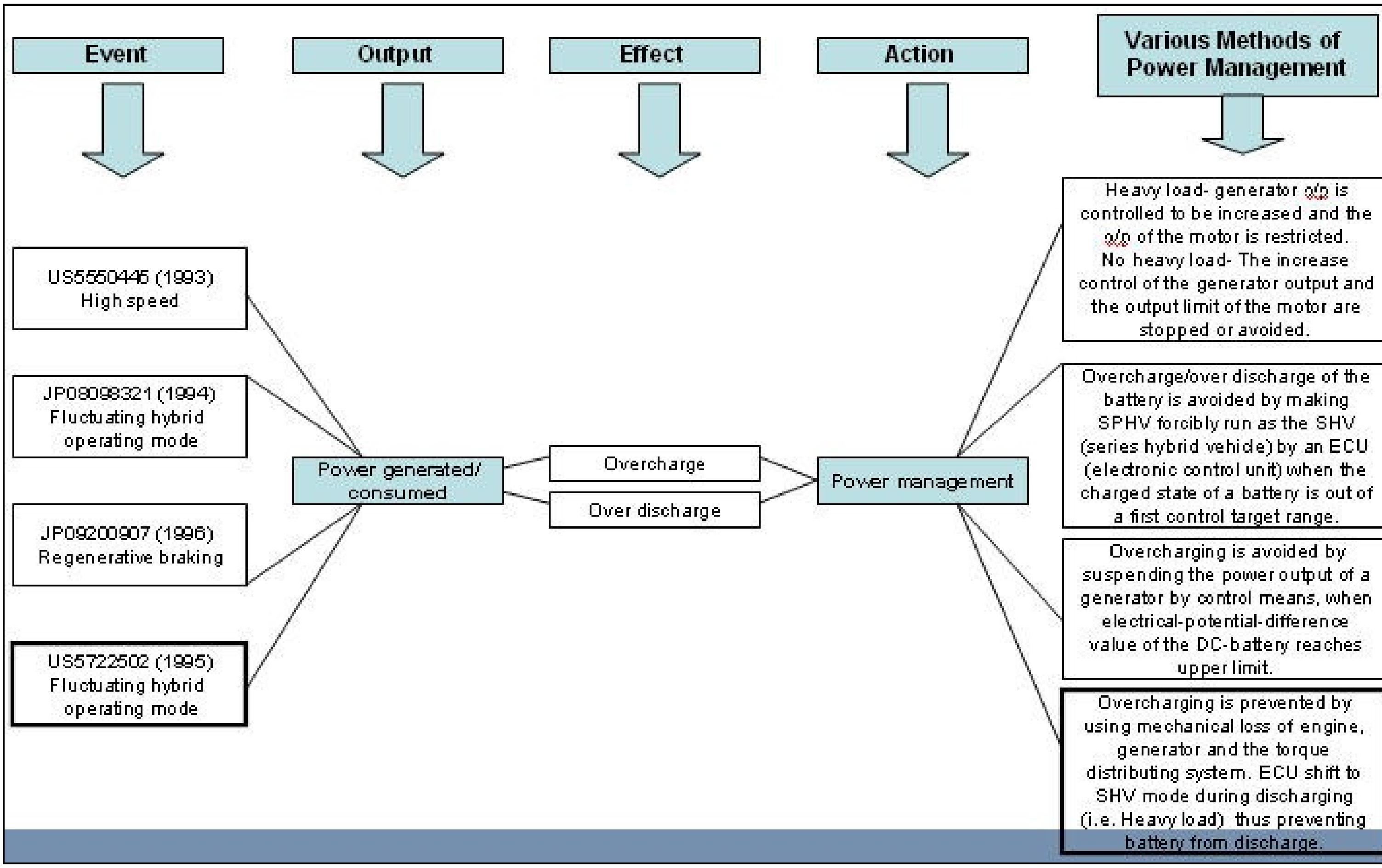
- Scientific literature and technology news to strengthen the report, since patent activity is a slow process.

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
 Series/parallel composite electric vehicle (SPHV)	US5550445 (1993) 	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.	Voltage sensor and an SOC senso voltage and an SOC of the battery a detected results to the controller.
	JP08098321 (1994) 	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.	The SOC sensor detects SOC of a voltage sensor detects the electric difference of a cell for the rotational f a motor.
	JP09200907 (1996) 	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.	SOC is controlled within proper limits. from a lower limit, a generator will be the maximum output, and if SOC upper limit, a generator will be opera minimum output.
	US5722502 (1995)  	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.	SOC sensor detects accumulator SO is maintained to the desired range by u mode control.

- **Second approach:**



Toyota Motors - Technology Approach2

- **Findings:**

Product	Patent
TOYOTA PRIUS	US5722502
TOYOTA HIGHLANDER	US6691809

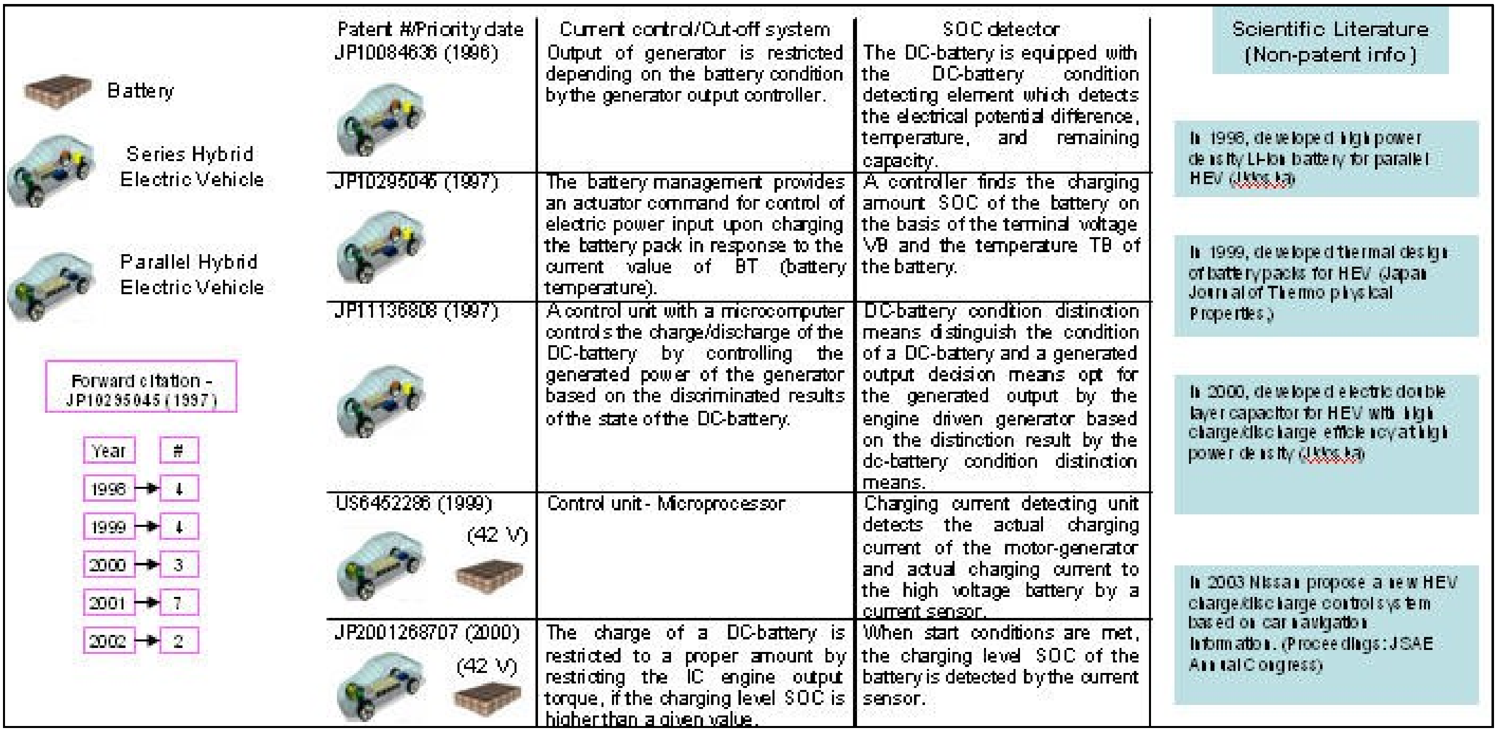
Findings

Nissan Motors

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

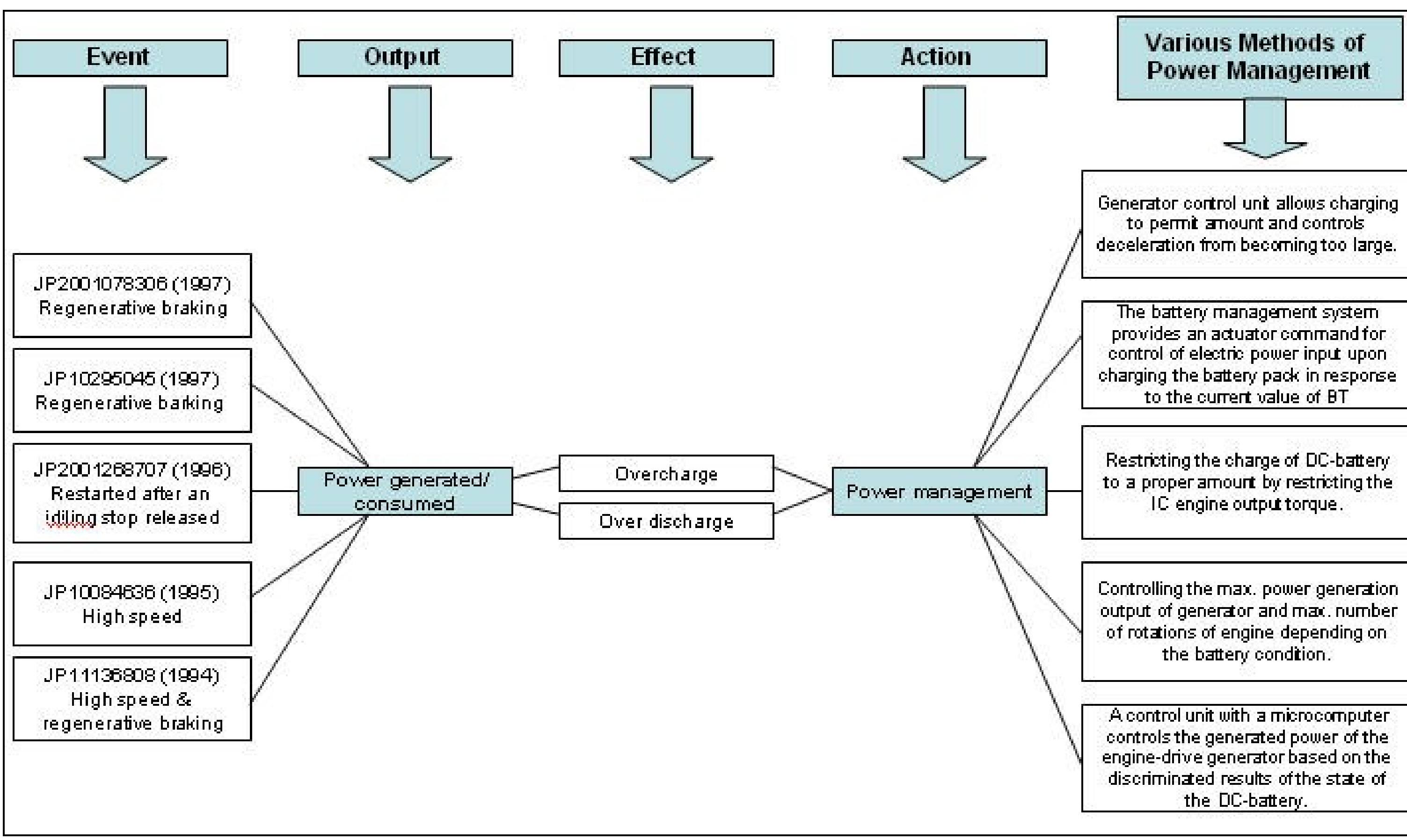
The battery is charged from the power generated by the generator and regeneration power from a motor.Electric motor functions as a generator to charge the battery when a hybrid vehicle is restarted after an idling stop released.

- **First approach:**



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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