Integration of PHEVs and EVs: Experience from Canada

G. Joos, *Fellow, IEEE*, and M. R. Dubois, *Member*, *IEEE*

***Abstract*—Plug-in hybrid vehicles (PHEVs) and Plug-in Electric Vehicles (PEV) are promoted in many jurisdictions worldwide as a way of reducing reliance on fossil fuels and reducing green house gases. In Canada, most utilities have initiatives in this area, with the aim to assess the impact on their electric grid of the wide scale deployment of these vehicles. There is also a significant interest on the part of international car manufacturers to supply vehicles to the local market, and on the part of equipment manufacturers to develop specialized components for this market. This paper summarizes the Canadian initiatives undertaken by utilities, in collaboration with car manufacturers, and by governments and government laboratories, and other stakeholders.**

***Index Terms*—Power systems, power industry, electric vehicles, battery storage, electric motors.**

I. Introduction

Plug-in Hybrid Electric Vehicles (PHEV) produce considerably less green house gases than conventional vehicles. They can also reduce the dependence of a country on imported fossil fuels. There is a renewed interest for plug-in electric (PEV) or all electric vehicles as a means of transportation in urban settings. Automotive manufacturers are therefore developing both the PHEV and the PEV vehicles and prototypes have recently become available. PHEV have the advantage of allowing longer driving ranges, while offering higher fuel efficiencies than conventional internal combustion engine vehicles.

A high penetration of PHEVs and PEVs into the electric distribution system requires careful assessment of the additional load on the distribution system (and possibly the additional generation required), the battery charging requirements, the charging system and charging stations, and communication and metering requirements. From the ancillary services viewpoint, the on-board PHEV battery may be considered and possibly used as a mobile distributed generation/storage unit, and support the integrating renewable energy by alleviating the variability.

The issues specifically associated with PHEVs were discussed extensively in Canada in a 2007 PHEV conference, sponsored by utilities, including Manitoba Hydro, federal and provincial government departments, including the Canadian federal government Natural Resources Canada and the Manitoba provincial government, and universities, including the University of Manitoba and the University of Winnipeg [2-5]. The conference featured an important representation of USA stakeholders, including representatives from the Electric Power Research Institute (EPRI). Significant developments have occurred in Canada since then, and representative results and initiatives were presented at the follow up 2009 PHEV conference [7-16], Montreal, organized by Electric Mobility Canada and sponsored by utilities and governments, among others.

Canada has, in general terms, followed the lead of the USA and capitalized on the expertise and initiatives in the USA, while developing made in Canada solutions to PHEV and PEV deployment.

This paper presents an overview of some of the initiatives in Canada related to the deployment of PHEVs and PEVs. The state of affairs evolves quickly and the information provided is based on the author's knowledge of the situation at the time of writing. In addition, it does not claim to be exhaustive in listing the projects in Canada, but attempts to offer a representative sample of the initiatives in different jurisdictions and by different stakeholders, including utilities, and government, with the support of key automobile manufacturers.

Details, additional information and updates of the state of the initiatives presented in this paper can be found on the Internet and obtained by typing into search engines the appropriate key words.

II. Canadian Stakeholders

A. Utilities

Most Canadian utilities are involved in initiatives related to PHEV deployment through demonstration projects, studies of the impact of the projected deployment on electric distribution systems and the development of implementation standards, including battery charging infrastructures.

The following utilities are among the more active in the area, and support demonstration and research initiatives, including university research:

- BC Hydro [7]
- Hydro-Québec [8]
- Hydro One Networks

This work was supported in part by the National Sciences and Engineering Research Council (NSERC) of Canada.

G. Joos is with McGill University, Montreal, Canada H3A 2A7 (e-mail: geza.joos@mcgill.ca).

M. R. Dubois is with Laval University, Quebec City, Canada G1K 7P4 (e-mail: maxime.dubois@gel.ulaval.ca).

978-1-4244-6551-4/10/$26.00 ©2010 IEEE

- Manitoba Hydro [9]

B. Government Entities

Canadian government departments and organizations involved in PHEV research and development include:

- Natural Resources Canada (NRCan) and its laboratories (including CANMET)
- National Research Council Canada (NRC)
- Transport Canada
- Provincial ministries

C. Industry

Car manufacturers are developing PHEV and PEV vehicles and making them available to utilities and other entities for testing. Some of the manufacturers and their models are mentioned below.

D. Utility Interest Groups

The following groups support the various initiatives associated with the deployment of PHEVs and PEVs:

- CEATI International and its Interest Groups
- Electric Mobility Canada

E. Universities

Many universities have activities in the area, including:

- University of Manitoba (associated with Manitoba Hydro and CEATI)
- University of Windsor (headquarters of the National Centre of Excellence AUTO 21)
- Laval University [10]
- University of Winnipeg
- Ontario Institute of Technology [15]

III. Issues Addressed

Issues of interest in demonstration projects and vehicle testing and research in Canada include:

- Vehicle battery charging – rate of charge and impact on the electric distribution and transmission grids – load flows
- Charging impact on existing utility infrastructure – lines and transformers
- Vehicle to grid interface – charger implementation issues – fast charging stations
- Near and long term impact of recharging on the grid
- Intelligent recharge, load management and communication
- Smart metering – billing and impact of deployment on the operation of the grid
- Battery life - developing test protocols for evaluating the deep cycle life
- Batteries – operation in cold climates
- Battery storage – capability to provide ancillary services
- Battery disposal – repurposing

IV. Utility Demonstration Projects

A. BC Hydro – PEV

The British Columbia Hydro and Power Authority (BC Hydro) has joined forces with the Renault–Nissan Alliance, the Province of British Columbia and the City of Vancouver to launch Nissan's Canadian zero emission transportation program. British Columbia is scheduled to receive the Nissan LEAF, Nissan's first all-electric production vehicle in 2011, in advance of global distribution in 2012. Also included in the agreement is a plan to develop a charging infrastructure pilot program planned by the same stakeholders, and for which federal funding is sought under Clean Technology funding.

BC Hydro has also announced an agreement with Mitsubishi to acquire and test the fully electric iMiev in the near future.

B. Hydro-Quebec – PHEV and PEV

Hydro-Quebec is involved in two demonstration projects, in collaboration with car manufacturers Ford (plug-in hybrid, PHEV) and Mitsubishi (all electric, PEV)

1) Ford Escape Hybrid – PHEV

Hydro-Québec has signed an agreement with Ford Motor Company and EPRI, which will consist in testing a prototype of the hybrid rechargeable Ford Escape. Tests are carried out under normal operating conditions, to allow analysis of the different recharging modes and their impact on the electric distribution grid.

The characteristics of the power train include an operation in the all electric mode at low speed, with regenerative electric braking. The gasoline consumption is expected to be reduced by two thirds. Other fuels can also be used, as an option. The battery is a 10 kWh Li-Ion, rechargeable in 6 to 8 hours on a 120 V circuit.

2) Mitsubishi – PEV

Hydro-Quebec, in collaboration with the town of Boucherville (near Montreal), will be testing 50 all electric Mitsubishi i-MiEV under various operating conditions, particularly winter conditions. The vehicles will be integrated into the fleets of local utilities, municipalities and local companies. The project will also evaluate the driving experience and the driver satisfaction.

C. Manitoba Hydro – PHEV

The demonstration program concerns 12 Hymotion Toyota Prius PHEV conversions, installed and tested. The chargers are plugged into ordinary block heater outlets.

The PHEV has an additional battery, allowing an electric range of 50 km. Driving options are pure electric under 55 km/h for the first 50 km, or operation at a higher speed with a reduced gasoline consumption for the first 80 km. It then operates as a normal PHEV. Using a standard 120 V plug, the battery can be fully charged in about 6 to 8 hours, for example overnight. Charging time will vary depending on the size and type of the battery, the distance traveled, and the charger used. It is expected that newer batteries can be recharged in 1 to 15 minutes, allowing the deployment of fast charging stations, similar to gasoline stations.

Issues of interest and under investigation include:
- Power quality issues
- Studies of charging profiles and their impact of power generation and supply requirements
- Studies in adoption scenarios

V. Other Demonstration Projects

A. Universities – Laval University – PHEV Deployment

The university has set up a PHEV Québec test program which aims to examine PHEV market potential and market viability by conducting real-world field tests. The project takes into account design and engineering requirements, vehicle to grid issues, and environmental and economical concerns [10]. The experimental studies are carried out on a PHEV fleet owned by real users on the Université Laval campus, in Québec City. The campus is in a central position, serves 35 000 people, manages an independent electrical grid, and is exposed to large temperature variations and gradients, and weather variations. The tests are managed by a team of engineers and financial analysts with industrial partners (ModEnergy, a manufacturer of modular energy devices and Bell Canada, a communications company) and financial partners (Desjardins, a banking entity).

The project is built around a fleet of 50 PHEVs, to be acquired over 5 years, and modified from existing HEV platforms (including the Toyota Prius).

The following results are sought:
- Identifying optimal trade-offs, considering different battery technologies and various battery pack sizes
- Evaluating the impact of the climate on PHEV performance
- Studying driver-PHEV interactions
- Identifying driving trends and optimal PHEV systems
- Obtaining performance comparisons between experimental PHEVs and a non-converted HEV vehicles (Toyota Prius)

The project makes use of data logging systems installed in vehicles (CANBus, battery current/voltage, GPS, vehicle fuel consumption). Fuel consumption and battery energy use are monitored for different driving profiles, including urban, mixed, highway and snowy conditions and low temperatures.

B. Manitoba Hydro – PHEV Battery Repurposing

Manitoba Hydro has embarked on a PHEV related project, PHEV battery repurposing research, as part of a utility-scale Li-ion battery storage project [11]. The idea is to re-use automotive propulsion battery for electric energy storage in substations, thus extending battery life and alleviating the problem of battery disposal or recycling. The Repurposing Research partners of Manitoba Hydro also include Hydro One Networks, Toronto Hydro-Electric System, Verdant Power Canada and Ryerson University.

VI. Integration and Deployment Studies

A. Hydro-Quebec – PHEV integration studies

Hydro-Quebec is involved in a study, in collaboration with EPRI, of the impacts on the distribution system of a wide deployment of PHEVs, including the following issues, related to operation and asset management [8]:
- Transformer and distribution line thermal loading
- Voltage regulation, voltage imbalance, and voltage harmonics
- Distribution losses
- Transformer loss of life

These studies are based on PHEV and PEV assumed characteristics including: type and range, deployment and market share, charge profile and power level, customer charging behavior.

The system impacts are based on a micro level analysis of PHEV impact as an additional load on the distribution grid and take into account the following: a full electrical model of specific feeders, a sequential power flow throughout a complete year, and the sensitivity of PHEV spatial/temporal variations.

Specific results expected from the study, to be used in distribution system planning and operation, include: the impacts on specific feeders and circuits, the implications on specific system design, planning and operational practices. In addition, the potential use of rules of thumbs based on circuit characteristics will be evaluated. The general questions addressed are the nature of system impacts likely to occur, the level of penetration that would necessitate feeder/asset upgrades, and the management of the new load created by PHEVs.

The preliminary conclusions of the study are the following: the feeder impacts are very low whether evaluated on a deterministic or a preliminary stochastic analysis; the impact on distribution system assets is not significant; clustering may cause some problems, which can be addressed on a case by case basis. In addition, it is concluded that more stochastic scenarios need to be examined, and that the impacts on underground feeders and the transmission networks need to be more precisely assessed.

B. BC Hydro – Deployment Guidelines

BC Hydro manages a project on the development of an Electric Vehicle Charging Infrastructure Deployment Guidelines, sponsored by Natural Resources Canada [12]. Also involved are the following entities, mentioned to indicate the typical stakeholders in many PHEV et PEV projects: Office of Energy R&D, Natural Resources Canada; Emerging Energy Systems, Manitoba Hydro; the Sustainability Group, City of Vancouver; Electric Mobility Canada; the Vancouver Electric Vehicle Association; Straightforward BC, Ministry of Small Business, Technology & Economic Development (STED); the Government of British Columbia; Hydro-Quebec, IndusTech; GM Canada; Mitsubishi Motor Sales Canada.

The guidelines being developed set the charge power, the connectors/inlets, the accessibility. It considers the PEV Technology used (vehicle configurations, types, batteries), the charging applications (single family, multi-family, commercial, public installations), the utility integration context (demand response, Vehicle-to-Grid interface and exchanges), planning and deployment considerations (power, communications, internet exchanges) and cost estimation

issues. The guidelines build on and make reference to national and regional codes and standards (CSA, Building Code, and Regulatory Agencies).

VII. Government Initiatives

A. Federal Government – Natural Resources Canada

Natural Resources Canada (NRCan) supports a number of initiatives aimed at helping and supporting the deployment of electric vehicles [13]. In particular, it has

- Aided the formation of Electric Mobility Canada
- Supported a National Electric Drive Transportation Initiative
- Supported the formation of an the Interdepartmental Working Group on Electric Mobility

NRCan has been involved in a Canada-US Collaboration on Automotive Clean Energy R&D, which addresses issues including:

- Hybrid power trains and vehicle systems
- Lighter weight and/or sustainable materials
- Advanced power trains
- Energy storage
- Application of alternative fuels, including biofuels
- Power electronics and electrical machines
- Intelligent transportation systems

B. Consortium – Electric Mobility Canada

Electric Mobility Canada is a national organization dedicated to the promotion of electric mobility as a readily available and important solution to Canada's emerging energy and environmental issues. Membership includes: private sector companies engaged in the sale or distribution of vehicles or components or the delivery of professional services; providers of electric energy at the provincial and local levels; managers of fleets from private sector companies, governments agencies and others; related associations, societies, research centres and labor organizations; government agencies and individual supporters.

It has developed the Electric Vehicle Technology Roadmap for Canada (evTRM), as a result of a Canada wide consultative process held during 2008 and 2009. The roadmap deals with personal and commercial vehicles that rely exclusively or primarily on electric traction, namely PEVs and PHEVs. It recommends that efforts be focused on a number of initiatives including technology (storage), codes, standards and regulations, studies and assessments, and education and outreach.

The R&D Program, funded in part by NRCan, focuses on four main areas:

- Energy storage (batteries)
- Electric drive components (lighter weight motors, control systems, smart chargers)
- Power train optimization (simulation)
- Development of regulations for emissions and fuel/energy efficiency

C. International Involvement – International Energy Agency

NRCan is involved in the International Energy Agency (IEA) Implementing Agreement on Hybrid and Electric Vehicles (IA-HEV). Annex XV was initiated by Canada (2008). The objectives include: identifying and undertaking key activities where Canadian research and development can be brought to bear on issues currently limiting the development and adoption of PHEVs in Canada, and strengthening the scientific basis for policy and regulatory decisions affecting the adoption of PHEV technology in Canada [13].

The IA-HEV is a working group of 14 governments interested in advanced vehicle technologies (Austria, Belgium, Canada, Denmark, Finland, France, Italy, Netherlands, Spain, Sweden, Switzerland, Turkey, United Kingdom, USA), initiated in 1994.

In Annex XV, Subtask 4 (Utilities and the Grid, led by Canada's CEATI) focuses on issues related to the widespread connection of PHEVs to the electrical distribution grid and their impacts on the electricity sector (power production and distribution utilities). Areas to be addressed by this group will focus principally on (but not limited to): impacts of PHEV deployment on power generation, ancillary service opportunities from PHEV deployment, and commercial aspects of PHEV deployment to be addressed by utilities.

Subtask 1 (Advanced Battery Technologies, led by Canada's National Research Centre NRC), explores issues related to battery life, battery power and energy density, their use in extreme climates, safety, recycling and also their disposal. It concentrates its efforts on lithium based batteries, as these are the most important contenders for PHEV applications,

D. Other NRCan Involvements

NRCan provided funding to BC Hydro help and led the development of the Electric Vehicle Charging Infrastructure Deployment Guidelines project (see above).

NRCan and BC Hydro have made arrangements for CEATI International to coordinate the receipt of comments on the guidelines from other utilities, municipalities, car manufacturers, and other stakeholders.

VIII. Other Initiatives

A. Electric Power Systems Research

The Electric Power Systems Research (EPRI, USA) is involved in a number of projects with Canadian utilities, including BC Hydro, Hydro Quebec and Manitoba Hydro on a distribution system impact project. Other USA participants include Con Edison (NY), American Electric Power, Tennessee Valley Authority, and Dominion Power.

B. Research - Utilities

Many research projects are carried out by universities, government and utility laboratories. Hydro Quebec among others continues to develop new materials for safe batteries, including Li-Ion batteries [14].

C. Other Deployment Initiatives

Other PHEV deployments are under way, as in the case of a joint project between a regional entity and a utility [15], a project that is tied into the Ontario Smart Grid initiative, sponsored by Hydro One Networks (Ontario) and the provincial government.

IX. Acknowledgment

The author gratefully acknowledges the contributions of all the people, graduate students and colleagues, and sources from which the information was drawn, including technical and public meetings and conferences, and which may not have been specifically mentioned.

X. References

[1] Natural Resources Canada, "Situation Analysis for the Current State of Electric Vehicle Technology", June 2008.
[2] J. Tomic, "Beyond Hybrids – HTUF Process and Pathway for Plug-in Hybrids", PHEV 2007 Conference Winnipeg, November 2007.
[3] K. Parks, P. Denholm and T.Markel, "Costs and Emissions Associated with Plug-In Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory", NREL, May 2007.
[4] M. Walters, T. Outlaw, "Plug-In Hybrid Electric Vehicle Impact Study for the Progress Energy Carolinas Territory", PHEV 2007 Conference Winnipeg, November 2007.
[5] M. Duvall, "Plug-In Hybrid Vehicles – EPRI & Utility Perspective", March 2007.
[6] M. Kitner-Meyer, K. Schneider and R. Pratt, "Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S Power Grids - Part1: Technical Analysis", November 2007.
[7] A. Tsang, "Identifying PEV Early Adopters and Their Needs", PHEV'09 Conference, Montreal, Sept 2009.
[8] A. Giumento, A. Maitra and W. Kook, "Evaluation of PEV Loading Characteristics on Hydro-Québec's Distribution System Operations, PHEV'09 Conference, Montreal, Sept 2009.
[9] E. Innes, "PHEV Adoption", PHEV'09 Conference, Montreal, Sept 2009.
[10] M. Dubois, "PHEV-Québec Test Program: A Real-World Test Study on Financial, Technological and Social Aspects of PHEVs", PHEV'09 Conference, Montreal, Sept 2009.
[11] E. Bibeau, "Repurposing PEV batteries Supporting renewables meet the drivers", PHEV'09 Conference, Montreal, Sept 2009.
[12] S. Schey, "Electric Vehicle Charging Infrastructure Deployment Guidelines British Columbia", PHEV'09 Conference, Montreal, Sept 2009.
[13] C. Burelle, "Federal Activities to Enable PEV Uptake", Plug'n Drive Ontario Meeting November 9, 2009, Toronto, Ontario.
[14] K. Zaghib, et al, "HQ Safe Li-ion Technologies for Green Transportation", PHEV'09 Conference, Montreal, Sept 2009.
[15] M. Angemeer, "Oshawa and the Region of Durham's drive to deploy, research, and build electric vehicles; and Ontario's Smart Grid", PHEV'09 Conference, Montreal, Sept 2009.
[16] T. Reddoch, "Successful Integration of Plug-in Electric (PEV) Transportation Systems", PHEV'09 Conference, Montreal, Sept 2009.
[17] W. Short and P. Denholm, "A Preliminary Assessment of Plug-In Hybrid Electric Vehicles on Wind Energy Markets", NREL, April 2006.
[18] T. Molinski and E. Innes, "Effectiveness of Utilizing Renewable Energy for PHEVs", Renewable Energy Use in Transportation Conference, Winnipeg, June 20 2005.

XI. Biographies

Géza Joós (M'82, SM'89, F'06) graduated from McGill University, Montreal, Canada, with an M.Eng. and Ph.D.

He has been a Professor with McGill University since 2001, and holds a Canada Research Chair in power electronics applied to power systems. He is involved in fundamental and applied research related to the application of high-power electronics to power conversion, including the integration of distributed generation and wind energy, and to power systems compensation. He was previously with ABB, the Ecole de technologie supérieure and Concordia University. He has consulting experience in power electronics and power systems. He is active in a number of IEEE Power Engineering Society working groups, and in CIGRE working groups.

He is a Fellow of the Canadian Academy of Engineering and of the Engineering Institute of Canada.

Maxime R. Dubois (M'99) obtained his B. Sc. and M. Sc. in Electrical Engineering from the Université Laval, in 1991 and 1993.

Between 1993 and 1999 he has worked in the industry as an electronic designer. He obtained a PhD cum laude from Delft University of Technology in The Netherlands in 2004. Since 2004, he has been Associate Professor at the department of Electrical & Computer Engineering at the Université Laval. His interests are the electromechanical conversion, the optimization of electrical machines, the design of magnetic actuators and power electronics applied mainly to the field of wind energy and electric vehicles.