IEEE STANDARDS ASSOCIATION

IEEE
SMART GRID
RESEARCH

IEEE SMART GRID VISION FOR VEHICULAR TECHNOLOGY: 2030 AND BEYOND





IEEE 3 Park Avenue New York, NY 10016-5997 USA

Documents
Document Sharing Hub

Full document details: IEEE Smart Grid Vision for Vehicular Technology: 2030 and Beyond (2011)

Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Documents
Document Sharing Hub

Full document details: IEEE Annual Conf. Intern. for Vehicular Technology - 2000 and Beyond, 2000 at
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

IEEE Smart Grid Vision for Vehicular Technology: 2030 and Beyond



Documents
Document Sharing Hub

Full document details: IEEE Smart Grid Vision for Vehicular Technology: 2030 and Beyond | 2014

Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Trademarks and Disclaimers

IEEE believes the information in this publication is accurate as of its publication date; such information is subject to change without notice. IEEE is not responsible for any inadvertent errors.

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2014 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published January 2014. Printed in the United States of America.

IEEE is a registered trademark in the U. S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-0-7381-8835-5 STDV98486
Print: ISBN 978-0-7381-8836-2 STDPDV98486

IEEE prohibits discrimination, harassment, and bullying. For more information, visit http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html.
No part of this publication may be reproduced in any form, in an electronic retrieval system, or otherwise, without the prior written permission of the publisher.

To order IEEE Press Publications, call 1-800-678-IEEE.

Find IEEE standards and standards-related product listings at:
http://standards.ieee.org/

Documents
Document Sharing Hub

Full document details: IEEE Smart Grid Vision for Vehicular Technology - 2030 and Beyond 2014

Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

IEEE Smart Grid Research has been obtained from sources believed to be reliable, and reviewed by credible members of IEEE Technical Societies, Standards Committees, and/or Working Groups, and/or relevant technical organizations. Neither IEEE nor its authors guarantee the accuracy or completeness of any information published herein, and neither IEEE nor its authors shall be responsible for any errors, omissions, or damages arising out of the use of this information.

Likewise, while the author and publisher believe that the information and guidance given in this work serve as an enhancement to users, all parties must rely upon their own skill and judgment when making use of it. Neither the author nor the publisher assumes any liability to anyone for any loss or damage caused by any error or omission in the work, whether such error or omission is the result of negligence or any other cause. Any and all such liability is disclaimed.

This work is published with the understanding that IEEE and its authors are supplying information through this publication, not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought. IEEE is not responsible for the statements and opinions advanced in the publication.

Review Policy

The information contained in IEEE Smart Grid Research publications is reviewed and evaluated by peer reviewers of relevant IEEE Technical Societies, Standards Committees and/or Working Groups, and/or relevant technical organizations. IEEE acknowledges with appreciation their dedication and contribution of time and effort on behalf of IEEE.

Documents
Document Sharing Hub

Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Full document details: IEEE Smart Grid Research for Vehicular Technology - 2010 and Beyond, 2010

Trademarks

Bluetooth is a registered trademark of Bluetooth SIG, Inc. (www.bluetooth.org/).

DeviceNet is a trademark of ODVA (www.odva.org/).

Fieldbus is a registered trademark of the Fieldbus Foundation (www.fieldbus.org/).

HART and WirelessHART are registered trademarks of the HART Communication Foundation (http://www.hartcomm.org/).

IEEE and 802 are registered trademarks of The Institute of Electrical and Electronics Engineers, Incorporated (www.ieee.org/).

IEEE standards designations are trademarks of The Institute of Electrical and Electronics Engineers, Incorporated (www.ieee.org/).

IrDA is a registered trademark of the Infrared Data Association (www.irda.org/).

PROFIBUS is a registered trademark of PROFIBUS Nutzerorganisation e. V (www.profibus.com/).

ZigBee Alliance is a trademark of the ZigBee Alliance (www.zigbee.org/).

All other trademarks belong to their respective owners.

Documents
Document Sharing Hub

Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Full document details: IEEE 2ma4-2012 - IEEE Draft Standard for Broadband Transmission Using Cable Television Channels

Dedication

To our families and friends

Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Acknowledgments

IEEE wishes to thank the following people for their outstanding contributions to the IEEE Smart Grid Vision for Vehicular Technology project:

- Liuqing Yang
- Joachim Taiber
- Russell Lefevre
- Hiroaki Nishi
- Philip Krein
- Koichi Inoue
- Iqbal Husain

Over the past year, these project leaders worked tirelessly outside of their own academic and professional endeavors to conceptualize and develop the framework of the vision and to oversee the writing and execution of this final document. As contributing editors to the document, they were instrumental in providing oversight, clarity, and overall direction to the men and women who authored this Smart Grid vehicle technology vision.

Documents
Document Sharing Hub

Full document details: IEEE Smart Grid Vision for Vehicular Technology - 2030 and Beyond, 2011

Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Authors

Xiang Cheng
Xiaoya Hu
Iqbal Husain
Koichi Inoue
Philip Krein
Russell Lefevre
Yaoyu Li
Hiroaki Nishi
Joachim Taiber
Feiyue Wang
Liuqing Yang
Murat Yilmaz

Documents
Document Sharing Hub

Full document details: IEEE Smart Grid Vision for Vehicular Technology - 2009 and Beyond, 2011

Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Documents
Document Sharing Hub

Full document details: IEEE Annual Conf. Intern. for Vehicular Technology - 2000 and Beyond, 2000 at
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Table of Contents

Executive Summary ..... **xii**

Chapter 1
Social, Economic, and Political Implications **1**

1.1 Vehicle electrification and Smart Grid 1
1.2 Vision for sustainable electrified transportation pathway 3
1.3 Societal implications 6
1.4 Evolution from Smart Grid to Smart City and its service 7
1.5 Citations 8

Chapter 2
Intelligent Vehicles and Grid Interaction **10**

2.1 Intelligent vehicles and grid interaction 10
2.2 Intelligent charging grid enhancements 12
2.3 Future expectations 13
2.4 Citations 14

Chapter 3
Infrastructure **18**

3.1 Introduction 18
3.2 Impact of transportation electrification and renewable energy 19
3.3 Impact of information and communication systems on transportation infrastructure 19
3.4 How to finance the transportation infrastructure of the future 20
3.5 The role of smart charging 21
3.6 Machine-to-machine system architectures as drivers of intelligent transportation infrastructure 21
3.7 Citations 22

Chapter 4
Travelers **24**

4.1 Introduction 24
4.2 The traditional role of the traveler 24
4.3 The new freedom of the future traveler 25
4.4 Public versus private traveler information 26

Chapter 5
Communications **27**

5.1 Introduction 27
5.2 Unique ITS-Smart Grid functions 28
5.2.1 Electronic and automatic transactions (EAT) 28
5.2.2 Optimum routing and charging (ORC) 28
5.2.3 Automatic parking and electricity leveling (APEL) 28

Documents
Document Sharing Hub

Full document details: IEEE Smart Grid Vision for Vehicular Technology - 2020 and Beyond, 2011

Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

5.2.4 Automatic driving coordination (ADC) 29
5.2.5 Connected travelers 29
5.3 ITS-Smart Grid communication infrastructure 29
5.3.1 Highly heterogeneous architecture 30
5.3.2 Hierarchically distributed quality-of-service (QoS)-oriented routing protocols 31
5.3.3 High-mobility high-fidelity 31
5.3.4 Extensive information sharing 32
5.4 Citations 34

Chapter 6
Systems, Operations, and Scenarios 35

6.1 Vision: Application scenario enabled by future SOS solutions 35
6.2 Paradigm shifts 37
6.2.1 Shift to EV-integrated building energy management system 37
6.2.2 Shift from complex visualization to simple visualization and operation 38
6.2.3 Shift from independent systems to integrated ITS and Smart Grid 38
6.2.4 Shift from cloud-oriented service to a hierarchically distributed cloud service 39
6.2.5 Shift from message-passing communication to contents-centric communication 40
6.2.6 Shift from Smart Grid to Smart Community 40
6.3 The future model of systems, operations, and services 41
6.4 Challenges and issues 43
6.5 Roadmap 43
6.6 Recommendations 43
6.7 Citations 43

Chapter 7
Conclusions 44

Documents
Document Sharing Hub
Full document details: IEEE Smart Grid: Vision for Vehicular Technology - 2030 and Beyond, 2014
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Documents
Document Sharing Hub

Full document details: IEEE Annual Conf. Intern. for Vehicular Technology - 2000 and Beyond, 2000 at
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Executive Summary

Vehicle electrification is envisioned to be a significant component of the forthcoming Smart Grid. In this document, a Smart Grid vision of electric vehicle technology for the next 30 years and beyond is presented from six different perspectives: 1) social, economic, and political implications, 2) intelligent vehicles and grid interaction, 3) infrastructure, 4) travelers, 5) communications, and 6) systems, operations, and scenarios.

From the social, economic, and political perspective (Chapter 1), a sustainable electrified transportation pathway that incorporates renewable energy generation is envisioned, which will provide energy production from renewable sources and bulk, distributed storage capabilities. In the grid infrastructure, bulk energy storage technology and secondary use of batteries will be essential. The combined capacity of numerous charging stations will also parallel the capacity of utility-scale energy storage. Available, suitable charging station infrastructure and standardize interfaces will be critical societal aspects of electrified transportation. The envisioned electrified transportation system will also be an integral part of the future Smart City as a business platform with an open architecture for third-party applications.

From the intelligent vehicles and grid interaction perspective (Chapter 2), the implication of intelligent vehicle charging is introduced. Such units offer both assurance for users and flexibility for the utility. The interactive energy storage to enable more advanced vehicle-to-grid systems, including unidirectional or bidirectional battery chargers, needs to be established. Compared with the unidirectional alternative, the bidirectional model will provide more flexibility in the long run. Mobile inductive charging might overcome the basic range-limitation of plug-in electric vehicles.

From the infrastructure perspective (Chapter 3), the future smart infrastructure and how the world is split in the future mature transportation market are described. The challenge is to ensure fully synchronized energy flow, transportation flow, and communication flow for existing infrastructure modernization and unification. Battery technology and its economics will be critical in the evolution of transportation electrification. Renewable energy sources will also play a significant role in low-density and remote locations with plentiful solar or wind energy. Future information exchange will require high-bandwidth, high-performance, and highly versatile cloud service platforms. Automated parking and automated or assisted driving will also help optimize charging infrastructures utilization.

From the perspective of the traveler (Chapter 4), this document describes how the traveler's role will evolve rapidly from the traditional picture. In the future, the traveler as a mobile node will be able to optimize its movement in a multidimensional grid, including energy, travel time, environmental impact, and data connectivity optimization. However, seamless system connectivity might lead to privacy issues.

From the communication perspective Chapter 5 discusses unique Smart Grid/intelligent transportation system (ITS) functions and the communication and networking infrastructure supporting the Smart Grid/ITS integration with unique functions. To support a broad array of new and extended Smart Grid/ITS functions, the envisioned communication and networking infrastructure is highly heterogeneous, with hierarchically distributed quality of service-oriented routing; high-mobility, high-fidelity connections; and extensive information sharing. It is also envisioned that high-mobility, high-fidelity communication technologies will be jointly developed and will benefit from nontraditional technologies such as wireless charging.

Documents
Document Sharing Hub
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.
Full document details: IEEE Smart Grid Vision for Vehicular Technology - 2030 and Beyond, 2014

From the systems, operations, and scenarios perspective (Chapter 6), a scenario of future electric vehicles, cities, and infrastructure is described, and a series of paradigm shifts are discussed. A future integrated model of systems, operations, and services is also presented. In this model, the main challenge is expected to be the commerce match and privacy control.

Following the chapters focusing on these distinct perspectives, conclusive remarks will overview the interconnections among all chapters. Discussions of key technologies dictating the real future of the evolution of vehicle electrification will also be included.

We hope that the joint efforts of the authors will serve the purpose of stimulating the reader's keen interest, as well as inspiring the reader's imagination in vehicle electrification and electrified vehicles as part of the Smart Grid.

Documents
Document Sharing Hub
Full document details: IEEE Smart Grid: Vision for Vehicular Technology, 2010 and Beyond, 2011
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Documents
Document Sharing Hub

Full document details: IEEE Annual Conf. Intern. for Vehicular Technology - 2000 and Beyond, 2000 at
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Acronyms and Abbreviations

ADC	automatic driving coordination
APEL	automatic parking and electricity leveling
API	application programming interface
BEMS	building energy management system
CEMS	community energy management system
DES	distributed energy storage
DBMS	database management system
DSRC	dedicated short-range communication
EAT	electronic and automatic transaction
EMS	energy management system
EPA	Environmental Protection Agency
ERP	enterprise resource planning
ETC	electronic toll collection
EV	electric vehicle
FTTH	fiber to the home
G2V	grid-to-vehicle
GHGRP	greenhouse gas reporting program
GPRS	general packet radio service
HEMS	home energy management system
ICE	internal combustion engine
ICT	information and communication technology
IoT	Internet of things
ITS	intelligent transportation system
M2M	machine-to-machine
NEZB	net-zero energy building
OEM	original equipment manufacturer
OLT	optical line terminal
ORC	optimum routing and charging
PDA	personal digital assistant
PEV	plug-in electric vehicle
PON	passive optical network

Documents
Document Sharing Hub
Full document details: IEEE Smart Grid Vision for Vehicular Technology - 2010 and Beyond 2014
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

PRT	personal rapid transit
PV	photovoltaic
QoS	quality-of-service
RPEV	roadway powered electric vehicle
UMTS	universal mobile telecommunications system
UWB	ultra-wideband
V2I	vehicle-to-infrastructure
V2G	vehicle-to-grid
V2V	vehicle-to-vehicle
VMT	vehicle miles travelled
WTP	willingness to pay
XML	extensible markup language

Documents
Document Sharing Hub
Full document details: IEEE Smart Grid Vision for Vehicular Technology - 2030 and Beyond, 2011
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Documents
Document Sharing Hub

Full document details: IEEE Transactions on Vehicular Technology, 2000 and Beyond, 2014
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.

Chapter 1

Social, Economic, and Political Implications

Iqbal Husain, *North Carolina State University*
Hiroaki Nishi, *Keio University*
Koichi Inoue, *National Institute of Informatics*

1.1 Vehicle electrification and Smart Grid

Electric power generation through conventional power plants and the dependence on fossil fuel as the sole source of energy for passenger and commercial vehicles has global economic, political, and environmental implications. Today's electric power systems are based on centralized generation transmitting bulk power with no intelligence appended to it, which leads to inefficient management of load, generation, and storage while exposing the system to greater security risks. Electric vehicles are tied at the distribution edge of the electrical grid system, which plays the dual role of demanding increased power from the grid system and simultaneously offering the potential for distributed energy storage. Electric vehicle sales are steadily increasing worldwide and the revolution in electrified transportation is opening doors for innovations and business opportunities that stimulate economic growth. The reported data in the power system and transportation sectors suggests that the drivers for both the smart electrical system and the electrified vehicles are environmental issues, energy security, and economic potentials.

In the US and elsewhere, the majority of power generation is derived from the burning of fossil fuels. According to the US Environmental Protection Agency (EPA) greenhouse gas reporting program (GHGRP) data, power plants accounted for about 40% of US carbon pollution and 67% of direct emissions in 2012 [10]. Power plants accounted for 2.09 billion metric tons CO_2e, which represents 67% of emissions reported to the GHGRP and 31% of total U.S. greenhouse gas emissions.

In the transportation sector, internal combustion engine vehicles are a major source of urban pollution, responsible for the greenhouse effect that causes environmental concerns [10, 11]. Transportation accounts for one-third of all energy use, and carbon emissions—primarily from personal vehicles—is one of the biggest challenges for reducing emissions of greenhouse gases [11]. According to the EPA [11], transportation is the largest end-use source of greenhouse gases (including direct emissions and emissions from electricity use) and accounts for 45% of the net

Documents
Document Sharing Hub
Full document details: IEEE Smart Grid Vision for Vehicular Technology, 2010 and Beyond, 2011
Authorized licensed use limited to: Stanford University. Downloaded on December 11,2014 at 09:42:13 UTC from IEEE Xplore. Restrictions apply.