STRATEGIES TO MANAGE THE IMPACT OF HIGH PHEV PENETRATION TO THE GRID

By

NURLIYANA BINTI BAHARIN

A dissertation submitted in partial fulfilment of the requirements for the award of the degree of Master of Electrical Engineering, College of Graduate Studies, Universiti Tenaga Nasional

AUGUST 2014
DEDICATION

I would like to dedicate this dissertation to my mother, my father, husband- Mohd Johari, my respected supervisor - Ir Dr Tuan Ab Rashid Bin Tuan Abdullah and co-supervisor - Puan Sharifah Azma Binti Syed Mustaffa for without their continuous support and prayers, I could not have completed this project. May Allah bless them all. Thank you very much!
ABSTRACT

Increasing awareness on environmental issues coupled with escalating prices of petroleum product has led to the development of greener electric vehicle in the last few decades. One of the most promising alternatives to reduce CO₂ emission and dependency on petroleum product in transportation market is the plug-in hybrid electric vehicle (PHEV). The battery of PHEV can be charged at home or other commercial locations through standard electrical power outlets. In Malaysia, the scenario of charging PHEVs at home is still new. The main objective of this project is to investigate the impact of introducing large amounts of charging activities in an existing residential area such as overloading of electrical network, undue stress due to inadequate line capacity and violation of voltage limits. The research used geographic information system (GIS) simulation software as a tool to investigate the impact of different penetration level of PHEV to the grid in selected residential networks in Malaysia. This software is used to model the PHEV charging load to the distribution grid and charging scenarios as an imitation of the Malaysian driving style. The electrical network was created on the real map using Xpower software. The PHEV charging load modelling were created based on the daily load usage and the selected PHEV charging load rated at 3.8kW. Then, the charging scenarios and the respective simulation cases were created to represent the Malaysian driving behaviour and lifestyle focusing on the working days or weekday. The residential network randomly tested by the entire house having the PHEV charging load is called uncontrolled charging or a base case. The uncontrolled charging strategy is obviously giving effect to the load demand on the transformer, voltage drop and power losses on the cable lines of the power system network. Hence, another strategy is planned to overcome this problem. By using controlled charging strategy and cable resizing strategy, the problem such increasing load demand, voltage drop and power losses of the lines are solved. Later, these simulation techniques of controlling charging strategy can be used as a guideline for the utility company.
ACKNOWLEDGEMENTS

Alhamdulillah was-salaat was-salaam 'ala Rasulillahi....

I would like to give my full appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) and Ministry of Higher Education Malaysia (MOHE) as giving me the opportunities and sponsored me to pursue the Master of Electrical Engineering study in Universiti Tenaga Nasional (UNITEN).

I would like to express my gratitude to my supervisor Ir Dr. Tuan Ab Rashid Bin Tuan Abdullah, whose invaluable guidance and support was very helpful throughout my research. A similar level of gratitude is due to my co-supervisor, Puan Sharifah Azma Binti Syed Mustaffa. It is unlikely that I would have reached completion without their encouragement and support.

Many thanks to the government of Malaysia for sponsoring and supporting this project under the fundamental research grant scheme (FRGS).

My appreciation also goes to the Manager of Tekla Corporation, Jari Malvela for providing me helpful information for the project. Last but not least, my family for their understanding, patience, encouragement and support. Thank you for all the support, comments and guidance.

Thank you so much. May Allah the Almighty return your good deeds.
DECLARATION

I hereby declare that this dissertation submitted to Universiti Tenaga Nasional (UNITEN) as partial fulfilment of the requirements for the award of the degree of Master of Electrical Engineering has not been submitted as an exercise for a similar degree at any other university. I also certify that the work described here is entirely my own except for excerpts and summaries whose sources are appropriately cited in the references.

This dissertation may be made available within the university, the library and may be photocopied or loaned to other libraries for the purposes of consultation and reference.

8th August 2014
Nurliyana Binti Baharin
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
<td>i</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>iv</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xii</td>
</tr>
</tbody>
</table>

## CHAPTER 1: INTRODUCTION

1.0 Introduction

1.1 Overview of the Study

1.1.1 World Fuel Consumption and Greener Transportation

1.1.2 Geographic Information System

1.1.3 Electric Vehicle Trend

1.2 Problem Statement

1.3 Objective

1.4 Scopes of Project

1.5 Statement of the Original Contribution

1.6 Dissertation Outline

## CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

2.1 Electric Vehicles Improves Mobility

2.2 Types of Electrical Vehicles

2.3 Types of Battery

2.3.1 Nickel Metal Hydride Battery

2.3.2 Lead-Acid Battery

2.3.3 Lithium-ion Battery

2.3.4 Lithium Polymer Battery

2.4 Vehicle Model Selection
### List of Figures

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Graph of global carbon dioxide (CO2) emissions from fossil-fuels from 1990 to 2030 [4].</td>
<td>4</td>
</tr>
<tr>
<td>1-3</td>
<td>Cumulative U.S Electric Vehicle Sales on 2012 [13].</td>
<td>5</td>
</tr>
<tr>
<td>2-1</td>
<td>Percentage of electric vehicle in 2012. (Total EV is 180,000 units)</td>
<td>11</td>
</tr>
<tr>
<td>2-2</td>
<td>EV and EVSE stocks in 2012.</td>
<td>12</td>
</tr>
<tr>
<td>2-3</td>
<td>The basic diagram of propulsion for conventional cars, PHEV, HEV and BEV [18]</td>
<td>13</td>
</tr>
<tr>
<td>2-4</td>
<td>Parallel hybrid system [21].</td>
<td>15</td>
</tr>
<tr>
<td>2-5</td>
<td>Series hybrid system [21].</td>
<td>15</td>
</tr>
<tr>
<td>2-6</td>
<td>Series parallel hybrid system [21].</td>
<td>16</td>
</tr>
<tr>
<td>2-7</td>
<td>Example of charging arrangement [40].</td>
<td>25</td>
</tr>
<tr>
<td>2-8</td>
<td>Electric vehicles charging equipment for typical AC supply [40].</td>
<td>25</td>
</tr>
<tr>
<td>2-9</td>
<td>Typical DC charging equipment [40].</td>
<td>26</td>
</tr>
<tr>
<td>2-10</td>
<td>System load curve for medium charge rate with randomly distributed charging of high penetration of PEV within shown time zone [43].</td>
<td>28</td>
</tr>
<tr>
<td>2-11</td>
<td>The transformer loads for CS1 with different type of cases [47].</td>
<td>30</td>
</tr>
<tr>
<td>2-12</td>
<td>The voltage drop at CS1 as a function of EV penetration [47].</td>
<td>32</td>
</tr>
<tr>
<td>2-13</td>
<td>Node voltages and line losses of daytime charging [48].</td>
<td>33</td>
</tr>
<tr>
<td>2-14</td>
<td>Node voltages and line losses in off-peak charging [48].</td>
<td>34</td>
</tr>
<tr>
<td>3-1</td>
<td>The flow chart for this project.</td>
<td>38</td>
</tr>
<tr>
<td>3-2</td>
<td>Daily load profile for one house.</td>
<td>43</td>
</tr>
<tr>
<td>3-3</td>
<td>Load modelling of low voltage connection load profiles [62].</td>
<td>44</td>
</tr>
<tr>
<td>3-4</td>
<td>Load modelling of medium or low voltage transformer load profiles [62].</td>
<td>45</td>
</tr>
<tr>
<td>3-5</td>
<td>Load modelling of medium feeder load profiles [62].</td>
<td>46</td>
</tr>
<tr>
<td>3-6</td>
<td>Load modelling of main transformer load profiles [62].</td>
<td>46</td>
</tr>
<tr>
<td>3-7</td>
<td>Left picture shows the empty workspace on the real map and on the right is the existing power system network.</td>
<td>48</td>
</tr>
<tr>
<td>3-8</td>
<td>Selected residential area: (a) Simulation area without circuit, (b) Simulation area with finished circuit.</td>
<td>48</td>
</tr>
</tbody>
</table>
3-9 Topology sketch for simulation works.
3-10 The example of consumption information for customer point.
3-11 Part of the consumption category available in Xpower software.
3-12 Programming code to create the household load and PHEV charging load.
3-13 Load modelling for normal house load and mobile load profiles.
3-14 The calculation options window one of the features in the Xpower software.
4-1 Daily load profile comparison between theory and simulation for 100 houses.
4-2 The comparison of the load profile with and without PHEV charging load.
4-3 The comparison of the load profile for different penetration level for PHEV uncontrolled charging.
4-4 The increasing of transformer load for uncontrolled charging strategy at 6.00pm
4-5 The increasing of transformer load for uncontrolled charging strategy at 9.00pm.
4-6 The category of voltage drop of the line in Xpower simulation.
4-7 The voltage drop percentage comparison for uncontrolled charging strategy.
4-8 The power losses percentage comparison for PHEV uncontrolled charging strategy.
4-9 The daily load profile for uncontrolled charging strategies.
4-10 The load profile for 100 houses for controlled charging strategy.
4-11 Transformer load for controlled charging strategy at 3.00pm.
4-12 Transformer load for controlled charging strategy at 6.00pm.
4-13 Transformer load for controlled charging strategy at 9.00pm.
4-14 Transformer load for controlled charging strategy at 12.00am.
4-15 Voltage drop of lines for controlled charging strategy.
4-16 Line losses for controlled charging strategy.
4-17 The line losses percentage for the cable resizing strategy.
4-18 The voltage drop of lines percentage for the cable resizing strategy.
4-19 Load demand comparison between different PHEV charging strategies. 78
4-20 Transformer load comparison of different PHEV charging strategies at 12.00 am. 79
4-21 Transformer load comparison of different PHEV charging strategies at 3.00 pm. 79
4-22 Transformer load comparison of different PHEV charging strategies at 6.00pm. 80
4-23 Transformer load comparison of different PHEV charging strategies at 9.00pm. 80
4-24 Comparison of Voltage Drop of Lines for Different PHEV Charging Strategies at 6.00 pm. 81
4-25 Comparison of Line Losses for Different PHEV Charging Strategies 6.00 pm. 82
<table>
<thead>
<tr>
<th>Table No.</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>The number of IC and EV vehicles in 2012.</td>
</tr>
<tr>
<td>2-2</td>
<td>Summary of the types of EVs.</td>
</tr>
<tr>
<td>2-3</td>
<td>The specification of the Toyota Prius plug-in hybrid [6]</td>
</tr>
<tr>
<td>2-4</td>
<td>The charging levels of the standard IEC 61851-1.</td>
</tr>
<tr>
<td>2-5</td>
<td>Summary of charging equipment arrangements. [40]</td>
</tr>
<tr>
<td>2-6</td>
<td>Different levels of charging modes [41]</td>
</tr>
<tr>
<td>2-7</td>
<td>Impacts of PEV charge rates, charging time periods and penetrations on the performance of a smart grid distribution system [43].</td>
</tr>
<tr>
<td>3-1</td>
<td>House Load Type</td>
</tr>
<tr>
<td>3-2</td>
<td>Load profile synthetising for simulation works.</td>
</tr>
<tr>
<td>3-3</td>
<td>The summary of customer point’s connection to the feeders and transformers.</td>
</tr>
<tr>
<td>3-4</td>
<td>The hourly load for base load and the two PHEV charging strategies.</td>
</tr>
<tr>
<td>3-5</td>
<td>The PHEV charging load category available in the Xpower software.</td>
</tr>
<tr>
<td>3-6</td>
<td>Uncontrolled charging strategy for 100 houses.</td>
</tr>
<tr>
<td>3-7</td>
<td>Controlled charging strategy for 100 houses.</td>
</tr>
<tr>
<td>4-1</td>
<td>The summary of results presentation.</td>
</tr>
<tr>
<td>4-2</td>
<td>Summary of the findings for this project.</td>
</tr>
</tbody>
</table>
# LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Items</th>
<th>Definition</th>
</tr>
</thead>
</table>
| BEV   | Battery Electric Vehicle  
An electric vehicle whose electricity is exclusively stored in batteries rather than a fuel cell or generator. |
| DF    | Diversity Factor  
The ratio of the sum of the non-coincident maximum demands of two or more loads to their coincident maximum demand for the same period. |
| EPA   | Environmental Protection Agency of US  
An independent federal agency established to coordinate programs aimed at reducing pollution and protecting the environment. |
| eREV  | Extended Range Electric Vehicle  
An electric vehicle with a rechargeable battery as well as an on-board gas powered generator to recharge the battery for extended mileage. |
| EV    | Electric Vehicle  
Usually referring to registered passenger vehicles, but can refer to any vehicle that is powered exclusively by an electric drive train. |
| EVSE  | Electric Vehicle Supply Equipment  
The charging equipment used to obtain a charge for an EV or BEV battery system. |
| GIS   | Geographic Information System  
An arrangement of computer hardware, software and geographic data that people interact with to integrate, analyse and visualize the data, identify relationships, pattern and trends, and find solutions to problems. The system is designed to capture, store, update, manipulate, analyse and display the geographic information. A GIS is typically used to represent maps as data layers that can be studied and used to perform analyses. |
| HEV   | Hybrid Electric Vehicle |
A vehicle that uses an electric motor and an internal combustion engine for propulsion.

HV

Hybrid Vehicle

A vehicle that uses two or more technologies for propulsion. To the content of the current automobile industry, the term hybrid usually refers to a vehicle combining an electric motor and an internal combustion engine.

ICE

Internal Combustion Engine

The standard way to power a vehicle, this part is removed when converting to an electric car.

PHEV

Plug-In Hybrid Electric Vehicle

A hybrid electric vehicle with substantial battery packs which is able to be charged by an external source other than its fossil fuel. Those vehicles often have the ability to travel in a pure electric mode without using any conventional fuels.

TCL

Total Connected Load

The sum of the continuous ratings or the capacities for a system, part of a system or a customer's electric power consuming apparatus.
Chapter 1

INTRODUCTION

1.0 Introduction

This chapter presents a background of study which encompasses three main topics including the world fuel consumption and greener transportation, geographic information system in general and the electrical vehicle trend. Besides, the problem statement, objective and scope of the project and the highlight on the original contribution in this project will be presented. Lastly, the outline of the dissertation covered in the description of the dissertation.

1.1 Overview of the Study

More than half of the fuel consumption in the world is used by the transportation sector. Concerned about this situation, countries like US, Western Europe, Japan and China became the countries that started to adopt the electric transportation such hybrid and plug-in hybrid. By choosing the hybrid and plug-in hybrids as a main transportation, the dependency to fuel will be decreased. Hence, reduce the harmful environmental emissions, health concerns, the soaring oil price and lastly the efficiency of this type of vehicle; it is essential to look for alternatives [1], [2], [3].
1.1.1 World Fuel Consumption and Greener Transportation

As the world fuel demand and the fuel price expected to increase around the world, causes some of the big countries to use the hybrid and electric transportation. Figure 1.1 shows the world fuel consumption growth from year 1986 to 2011 [4]. This shows how critical the fuel demand around the world. In the US, the government gave incentives to encourage their people to use electric vehicles. In addition, hybrid and plug-in hybrid have the advantages such as more energy efficient, power capability suited with the variable speed that produce greater torque at low speed. They also can operate in regenerative mode and makes these vehicles better than conventional vehicles in term of energy management.

Figure 1.1: World fuel consumption from year 1986 to 2011. [4]

Figure 1.2 illustrates the graph of global carbon dioxide (CO₂) emissions from fossil-fuels from 1990 to 2030. It shows that global carbon emissions from fossil fuels have significantly increased from 1900 to 2012 and expected to be increased until 2030 [4]. The greenhouse gas emission was contributed by many sectors such as energy
supply (26%), industry (19%), forestry (17%), transport (13%), agriculture (14%), residential and commercial building (8%) and waste/wastewater (3%) [5].

Figure 1-2: Graph of global carbon dioxide (CO2) emissions from fossil-fuels from 1990 to 2030 [4].

Car manufacturers such as Toyota, Nissan, Mitsubishi, and Chevrolet have recently begun the rollout Plug-in Hybrid Electric Vehicles (PHEVs) from their production line [6-10]. The current trend showed that more automotive company is expanding their market share in the PHEV. In the U.S., most of the automotive manufacturers either have or are in the process of developing Plug-in Electric Vehicles (PEVs), including Electric Vehicles (EVs) and Plug-in Hybrid Electric Vehicles (PHEVs) [11]. In Malaysia, Proton has done their fleet test which are Proton Saga Electric Vehicle (EV) and Proton Exora Range Extender Electric Vehicle (REEV).
1.1.2 Geographic Information System

Geographic Information System (GIS) is a powerful tool which can be defined as integrated sets of data, hardware, software and processes designed as a computer system for gathering, managing, mapping and analysing spatial data [12]. These software applications store and map a large amount of information about the utility's electric, gas and water systems. For maximum value, GIS needs to become one of the most integrated applications in the utility. In this project, the GIS has been used to analyse the impact of charging PHEV in residential areas.

1.1.3 Electric Vehicle Trend

It seems that the electric vehicle trend around the world is changing from time to time. Figure 1.3 shows the cumulative U.S electric vehicle sales on 2012 and 2013 [13]. The EV is accepted by people in US as shown in the graph that the increasing number of various types of EV from January 2012 until June 2013.
In 2012, sales of hybrid cars in the country had jumped 84% to 15,355 units (compared with 8,334 units in 2011), according to data from the Malaysian Automotive Association (MAA). The hybrid car sales came from four marques, namely, Toyota (5,653 units), Lexus (979 units), Honda (8,712 units) and Porsche (11 units). Honda has led the EV/PHEV in Malaysia, but with the tax exemption for hybrids ending in 2013, it could have a dampening effect on their take-up here [14].

1.2 Problem Statement

The PHEV is one of the electric vehicles that can give a longer driving range to the people because its power sources are a combination of electricity and fuel. The battery of these vehicles can be charged directly from the electric power from the grid and internal combustion engine. The increased usage of the PHEV will introduce a sizeable capacity increment to the power grid. This research study the impact of PHEV to the grid performance, such voltage profile, power losses, peak demand and transformer loading if a large number of PHEV were introduced onto the grid over a short period of time. The results of simulation work can be used to draw a guideline for a utility company.

1.3 Objective

The aim of this project is to create a modelling for the PHEV charging system using Xpower software. This project relates to the real life of Malaysia driving style and focused on the selected residential area in Malaysia.

Listed below are the objectives of this study:

i. To create models for the PHEV charging load using GIS software in order to manage the impact of the high penetration level of a PHEV

ii. To investigate the impact of charging of the PHEV to the power grid such impacts are increasing load demand, transformer loading, voltage drop and power losses of cable lines.
1.4 Scopes of Project

This project was formulated to cover four scopes as follow.

i. Plug-in hybrid electric vehicles (PHEV) were chosen as the type of the electric vehicle because of its performance and suitability to the market situation in Malaysia.

ii. The distribution network for this project is covered a residential area containing 100 houses and the analysis is limited to the low voltage level.

iii. The modelling of the PHEV charging load and the analysis of the impact of PHEV charging activity to the distribution network uses Xpower GIS. The analysis done are the impact of increasing load demand to the transformer loading profile, voltage drop and power losses in the electric cables.

iv. The charging time is assumed to be on weekday only and the charging is done randomly.

1.5 Statement of the Original Contribution

The main contribution of the work of this project are:

1. Knowledge to model PHEV charging from the grid using GIS software.

2. The impact of PHEV charging pattern can be used as a guideline for the utility company to mitigate the problem of network performance such as violation of the voltage drop limit, the network overload and higher energy losses. This thesis proposed the technical solution to mitigate the changes in the network performance.

3. Knowledge to visualize the impact of the PHEV charging such as load demand, transformer loading, power losses and voltage drop of lines using GIS Software.

4. The effectiveness of the impact of high PHEV penetration using the two proposed strategies. The strategies were controlled charging strategy and cable resizing strategies.
1.6 Dissertation Outline

This report is structured into five chapters. Chapter 1 discussed on the overview of study, including problem statement, objectives, scopes and contributions to knowledge. Chapter 2 discussed the theoretical background and summarised the related preceding studies. Meanwhile, Chapter 3 discussed the method used in modelling the PHEV charging using the GIS software. Chapter 4 presented the analytical findings, and discussion of the results. Finally, Chapter 5 summarised this dissertation and recommendation for future research.
Chapter 2

LITERATURE REVIEW

2.0 Introduction

This chapter presented a literature review of the electric vehicles and plug-in hybrid electric vehicle. These included the background of the electric cars, types of electric cars, types of electric car battery, PHEV charging system and charging specifications.

2.1 Electric Vehicles Improves Mobility

An electric car is an old invention. The history of electric vehicles can be divided into five major ages. The earliest electric vehicles are invented in Scotland and United States. In 1832 until 1839, Robert Anderson of Scotland builds the first prototype electric-power carriage. Thomas Davenport, of the United States invents and installs the first direct current electric motor in a car that operates on a circular electrified track in 1834. From 1851 until 1900 the electric vehicles start to enter the marketplace and find broad appeal. In 1921, the global electric vehicle stock reaches 30000 units until 1930s; the EVs become all extinct due to the predominance of internal combustion engine (ICE) vehicles and availability of cheap petrol. However, on 1966 the US Congress introduces legislation recommending electric vehicles as a means of reducing air pollution. Until now, the electric vehicle continues growing in the world automobile market with the main reasons are high oil prices and environmental pollution caused by the petrol-powered cars [15].
An electric vehicle is one of the promising pathways to increase energy security and reduced emissions of greenhouse gases and other pollutions. Hence, these vehicles become more popular and convenient around the world. By helping of the latest technologies of the battery, the electric vehicles can be used longer time and distance on the road. Many developing countries can be used as the benchmark in EV technologies because of the performance of the EV sales in their countries. Such countries are Europe (UK, France, Spain, Portugal, Denmark, Netherlands, Sweden, Finland, Germany and Italy), United States of America, China, India and Japan. The electric vehicle progress and development supported by the forum called as Electric Vehicle Initiative (EVI). EVI is a multi-government policy forum dedicated to the introduction and adoption EV worldwide. EVI is under Clean Energy Ministerial currently includes 15 members from Africa, Asia, Europe, North America and also joined by the International Energy Agency (IEA). According to (EVI), these countries have their own national policy initiatives in three main parts which are financial, infrastructure and research development and demonstration (RD&D) in order to encourage their people used EV. The financial support includes exemption from road taxes, reduce excise duties, gives purchase subsidiaries and giving the consumer incentive if buying EV. Most of these countries provide charging infrastructure either in term of financial or tax reduction includes the electric vehicle supply equipment (EVSE) and installation. Research and development also playing an important role to ensure that EV technologies have optimized operation, cost and gave a maximum safety to the consumers. Besides, by doing this R&D works, the latest technologies can be detected and some standards can be created so that can be referred by many other countries. For example, France allocates EUR 450 million in rebates to consumers that buying efficient vehicles, with 90% of that amount of fees on inefficient vehicles and remaining 10% is a direct subsidy. They are also allocated, EUR 50 million to cover 50% of EVSE cost, including charging equipment and installation and EUR 140 million budget provides to focus on the vehicle R&D. [16]

The data from the EVI shows that the EV sales more than doubled between 2011 and 2012. They stated that in 2011, the global EV approximate annual sales are 45,000
units and increasing to 113,000 units in 2012. Figure 2.1 shows the percentage of EV in EVI country members. Europe has the highest EV stock compared to other countries which is 40% of registered 180,000 units of the total EV stock worldwide [16].

![Percentage of EV in 2012](image)

**Figure 2.1:** Percentage of electric vehicle in 2012. (Total EV is 180,000 units)

Table 2.1 shows the number of internal combustion (IC) vehicles and EV vehicles for EVI countries member. The number of EV if compared to the IV vehicle is small. This is because, the EV still at progress level for all these countries [16], [17].

<table>
<thead>
<tr>
<th>Countries</th>
<th>IC Vehicle (Units)</th>
<th>EV Vehicle (Units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>10,288,238</td>
<td>47,724</td>
</tr>
<tr>
<td>China</td>
<td>15,495,240</td>
<td>11,573</td>
</tr>
<tr>
<td>India</td>
<td>2,781,919</td>
<td>1,428</td>
</tr>
<tr>
<td>Japan</td>
<td>4,572,333</td>
<td>44,727</td>
</tr>
<tr>
<td>US</td>
<td>7,241,900</td>
<td>71,174</td>
</tr>
</tbody>
</table>

Besides, the comparison between EV and EVSE stocks in 2012 also shown in Figure 2.2. The EVSE includes the public and residential charging infrastructures [16].