# OPERATION OF NET-ZERO CARBON CHARGING STATIONS WITH RENEWABLE ENERGY INTEGRATION

by

Fei Sun

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Committee Members:

Tongdan Jin, Chair

Clara M. Novoa

Jesus Jimenez

Vedaraman Sriraman

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## LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| BEV | Battery Electric Vehicle |
| BMS | Battery Managements Systems |
| CDF | Cumulative Density Distribution |
| CPV | Concentrating Photovoltaic |
| CRP | Capital Recovery Factor |
| DG | Distributed generation |
| EV | Electric Vehicle |
| EVSE | Electric Vehicle Supply Equipment |
| FCV | Fuel Cell Vehicle |
| GD | Grid Distributed |
| GW | Giga Watts |
| HAWT | Horizontal Axis Wind Turbine |
| HEV | Hybrid Electric Vehicle |
| ICE | Internal Combustion Engine |
| O&M | Operation & Maintenance |
| PDF | Probability Density Function |
| PHEV | Plug-in Hybrid Electric Vehicle |
| PV | Solar Photovoltaic Panel |

| | |
|---|---|
| VAWT | Vertical Axis Wind Turbine |
| WT | Wind Turbine |

## ABSTRACT

The goal of this project is to develop a quantitative approach for designing and operating charging stations using intermittent renewable energy. In particular wind turbines (WT) and solar photovoltaic panels (PV) are integrated into charging stations in order to displace fossil fuel based energy and reduce carbon emissions. This study performs a feasibility analysis of implementing a cost-effective and environmentally-benign charge station for electric vehicles.

The grid-connected distributed generation system consists of WT, solar PV, battery storage packs and a net metering system. The capacity of WT, solar PV panels, and the battery system are decision variables which will be optimized. Due to the intermittency of wind and solar generation, the output power of WT and PV is not guaranteed. Quantitative decision models are formulated and allow for simulating the output of wind and solar generation hour-by-hour during the course of a year. The optimal size or capacity of WT, PV and battery is determined to minimize the annualized charge station cost.

Ten candidate cities where charging station will be constructed are chosen from different areas of world, representing the variation and diversity of wind speed and weather conditions. Even if the cost parameters in the optimization model are identical, the optimal decision on the capacity of WT, PV and battery could be different due to the diversity of climatic profiles. Our numerical results show that charging stations can attain

net-zero carbon emission with onsite renewable energy resources in regions where medium wind speed or sunny weather prevails.

Keywords: onsite generation, decision variable, charging station, cost-effective.

# CHAPTER I

# INTRODUCTION

Nowadays, the air pollution and climate change due to burning of excessive fossil fuels (i.e. coal, oil and natural gas) are becoming grave concerns of the general public and policy makers. Decreasing carbon emissions, mitigating air pollutants, and searching for clean and sustainable energy sources have become the consensus among the people in the world. To attain a sustainable future of the world, clean and renewable energy resources are becoming the emerging technologies for substituting fossil fuels in residential, commercial, manufacturing, and transportation sectors. According to IEA, 26% of global energy consumption is used for the transport sector in 2004. In the U.S., American consumption of fuel in transportation accounts for over 70% of total national oil consumption (American Energy Independence 2014). More than 65% of that amount is driven by personal or family vehicles (American Energy Independence 2014). This proportion is continuously rising now due to the growth of vehicle fleet. The number of vehicles registered in the U. S. has increased from 193,057,380 to 253,639,390 between 1990 and 2012 (Statista 2015), increase of 31% in 22 years.

Humans have to search for new types of vehicle technologies to substitute the traditional vehicles in order to reduce the heavy dependence of petroleum. Electric Vehicles (EVs) have been around for more than 100 years since 1912 (Matulka 2014). The EV is the new transportation tool that is propelled by an electric motor powered by rechargeable battery packs. Electric motors have several advantages over internal combustion engines (ICEs), such as high energy efficiency, environmental protection, and less dependence on fossil fuels. However EVs also have some challenging issues deterring the wide adoption of this technology. For example, an EV has significantly longer charging time than conventional vehicles and it also possesses limited driving range due to batteries have a lower energy density than gasoline. The specific energy of Lithium ion battery has over 140 Wh/Kg (Ivanovic 2012). However the current technology only achieves a drive range between 70-300 miles on a single charge.

Governments worldwide announced sets of new policies for EVs that would encourage more people to purchase and drive EVs. In the U.S., depending on the size of the battery pack, credits range from $2,500 to $7,500 for EV and plug-in hybrid passenger cars. The minimum pack size is 4 kilowatt-hours (KWh), and the scale varies from 4 KWh to 24 KWh (or more). If a customer buys an EV in which the capacity of battery package is over 16 KWh, the customer can get the $7,500 federal tax credits. More than 236,000 electric vehicles are estimated to be produced in the U.S in 2015 from forecast of Electric Car Production 2015 at (Statista 2014). President Obama in his 2011 State of the Union address prospects putting one million electric vehicles on the road by 2015 (Obama 2011).

New enabling technologies are under development to enhance the advancement of EVs industry. The auto industry has surged with manufacturers beginning to introduce new generations of EVs. The travel distance increases as the battery technology advances. In late 2010, Nissan introduced the Leaf, a 86 miles driving range that incorporates an advanced lithium-ion battery as its sole power source (Nissan-Global Technology 2014) Besides focusing on improving the capabilities of the battery, building suitable and reasonable amount of charging infrastructures is another solution to compensate this fatal disadvantage. All of the big auto companies also invest heavily in researching the large charger facility and setting up easy-to-access charging stations. The most popular fast charger technology, based on association of Japan's EV charging standard, can provide 50 KW power. For an EV car with battery capacity of 25 KWh, it takes only 30 minutes to complete the full charge while the normal charge level may requires 5-10 hours. Tesla supercharger is exploring pushing the 150 KW units in the future and will soon charge the model S at a rate of 370 miles per hour (Tesla Supercharger 2015)

Though EV can significantly reduce the carbon footprints and improve the environmental performance. The ultimate solution to environmental sustainability relies on the integration of renewable energy into the charge stations. The goal of this thesis is to investigate the economic and environmental benefits by integrating onsite wind and solar generating units into local charge stations. To that end, fifteen cities possessing charge stations are chosen from different areas of world, representing the variation and diversity of wind speed and weather conditions. Even if the optimization model parameters are identical, the optimal decision on the capacity of wind turbine (WT), solar photovoltaic panels (PV), and battery storage could be different. Our experiment results show that charging stations can attain net-zero carbon emissions through onsite renewable energy resources. If a location has the more wind resources, the cost to building a charging station would be lower and the profit would be higher. This result is shown in the chapter 4.

Under these policies and new technologies stimulus, the number of EVs in the world sharply prompts 400,000 until now (Gordon-Bloomfield 2014). The power of EVs produced by traditional fuel fired electricity does not do real achieve environmental protection purpose. According to Taylor, only 2.5% of the renewable energy is utilized in the transport compared with traditional energy in the world (Taylor 2013). For these reasons, one promising solution is to build the charging station powered by the renewable energy, namely based on wind, solar, and other environment-friendly generation. For instance, solar PV panels can be easily installed on the roof or on the wall of convenience store in a charging station and other open space of a charging station. The canopy and the wind turbine can be installed in the yard or open space behind the section of charging station.

Public and workplace charging stations are available today at public parking lots, retail chains (e.g. Walgreens), business centers, and airports. The Google Company provides free charging for employees when they park their cars in the garage during working time. Google's installation represents the largest workplace charging installation for EVs in the U.S. and the supply of power of chargers is coming from the utility grid and the onsite solar generators. In October 2013, there were more than 64,000 public chargers installed globally, and this number is expected to expand over the next several years (Martin 2013). Most of electricity for chargers is from the utility grid. In this paper, the goal is to establish charging stations powered by totally renewable energy and strives for the zero-carbon emission performance.

The design of a renewable energy charging station is influenced by the facility scale, the geographical location, the meteorological conditions, the electric vehicle supply equipment (EVSE), and operation and maintenance (O&M). The research also aims to assist the owner of the charging station in planning a grid-connected renewable distributed generation (DG) system to achieve net-zero carbon emission performance while maximizing the annual profit to the facility owner. The DG system includes WT, solar PV, battery storage packs, and a net metering system. The capacity of WT, solar PV panels, and the battery system are the decision variables. Due to intermittency of wind and solar generation, the output power of WT and solar PV is not guaranteed. A mathematical model is developed to simulate the output of wind and solar generation hour by hour across the 20 years, and then decide the best suitable capacity of WT, PV, and battery so that the annualized charge station cost is minimized.

The goal of this project is to develop a quantitative approach for designing and operating charging stations using intermittent renewable energy. Particularly, WT and solar PV should be integrated to in the charging station in order to replace fossil fuel-based energy and reduce the environmental impacts. This study performs a feasibility analysis of implementing a cost-effective and environmentally benign charge station for electric vehicles.

There are multiple issues that need to be considered in the future, such as maximizing the renewable energy penetration or fully using alternative energy (e.g. wind and solar power) for charging EV fleet, improving the reliability of the renewable energy supply, and continuously reducing O&M cost of the facility. The will also consider the development in the future that can expand the number of charge points in commercial settings as more EVs are running on the road. EVs will prosper dramatically in the coming decade with the rapid deployment of charging infrastructure. The charging station should achieve net-zero carbon emission goals with the technology development of wind and solar generation and large-scale of storage technology.

The objective of this research is twofold. First, a mathematical model is developed to estimate the total costs that include the installation, the maintenance and operation, and the utility bills and the incentives that include the carbon credit, selling electricity to main grid and EV owners. Second, Monte Carlo methods are employed to simulate intermittent power output of WT and solar PV generators at several representative areas according to the historic wind speed and climate records. To make a fair comparison in different regions of the world, all the charging stations are assumed to use the same type of WT, solar PV and battery storage packs in this study.

The mathematical models intend to answer these following questions:

(1) Estimating the output of renewable energy generation at each location.

(2) Determining the optimal sizing of wind turbine, PV and battery in order to realize zero-carbon emission while maximizing profit of the charge station owner

(3) Simulating three conditions of the income per KWh. Only wind generation, wind combine solar generations and wind, solar generation and the storage batteries

The simulation result in this paper comes from these assumptions:

(1) Wind speed follows Weibull or normal distribution. Yet the model in this paper can be adopting Weibull distribution due to no negative the wind speed value.

(2) The daily weather condition is mutually independent. However, using linear regression model to simulate the weather condition, the weather condition becomes dependent.

(3) The paper will not consider the factor of price fluctuation, I assume utility, maintenance and operation cost per Wh are fixed within 20 years.

(4) Two options are to design a fully renewable powered charging station: islanding operation or grid- connected DG system that contains two decision variables for capacity of WT and PV. The capacity of WT and PV generators in option one must higher than option two, however the total cost of option one will lower than the option one.

The research provides a solution to building charging stations with competitiveness, profitability, and the least impact on the main grid. The charging station can make the maximum profit and the minimum emission of greenhouse gas emissions. The chargers using renewable energy save the usage amount of crude oil, but there is no real solution for the owners of electric vehicles who need to travel long distances. The driving range of EVs is still limited. So finding a cost effective solution and building charging station model along the highways between cities would be my research goal.

# CHAPTER II

# RENEWABLE ENERGY RESOURCE

With science and technology in current state of development, the potential of renewable energy can be fully exploited to benefit the mankind. Renewable energy sources include solar energy, wind energy, biomass energy, tidal and geothermal energy and so on. In this paper the wind and solar generation are chosen as the emphasized key technology, with the highest potential becoming power supply for the charging station of the growing electric vehicle fleet. The reason for that is because of their widespread and almost limitless nature. Wind and solar energy can be obtained on a reserve covering a relatively small area and using infrastructure that is relatively easy to construct.

Government policies have been essential to the adoption and growth in renewable energy technology. More than 70 countries are expected to deploy renewable energy technologies in the power sector by 2017 (IEA 2012).

Sustainable future of the world needs clean and renewable energy resources for substituting fossil fuel based electricity in residential, commercial, manufacturing, and transportation sectors. The development and utilization of renewable energy is most significant in our society. Some encouraging results have been obtained. It is estimated that electric capacity is added 194 gigawatts(GW)  globally and about 50% of capacity is from the renewable energy increasing during 2010. Existing renewable power capacity worldwide reached 1.32 GW in 2010 approximately, up almost 8% from 2009 (Janet and Eric 2011). A report released by the Global Wind Energy Council states that worldwide wind power capacity grew by 20% over 2012, pushing its production to a total of 282.482

GW. Meanwhile, European Photovoltaic Industry Association declares that the capacity of solar panels has reached up to 100 GW (Yirka 2013).

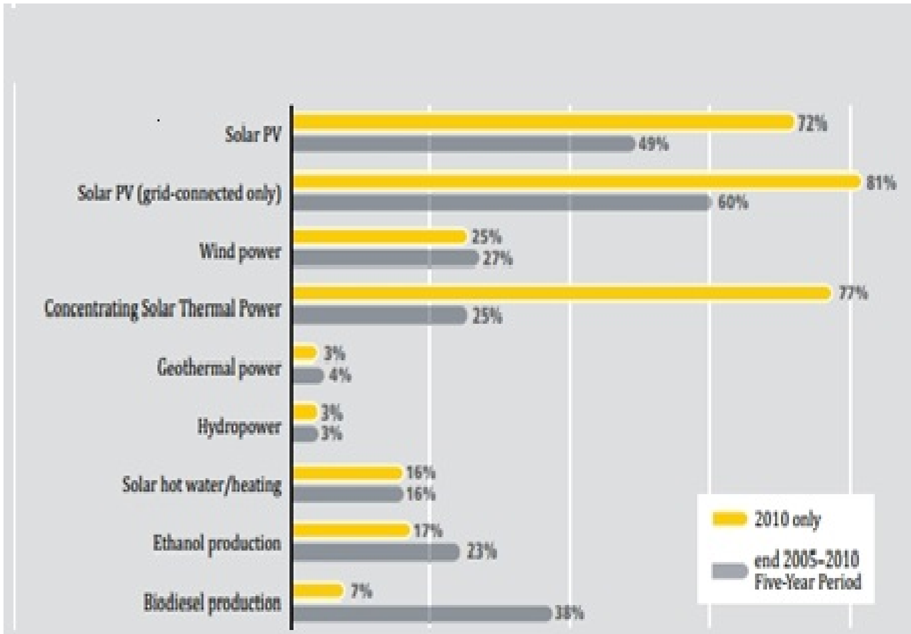


Fig 1: Average Annual Growth Rate of Renewable Energy Capacity (REN21 2011)

2.1 Wind Generator

Wind turbines convert the kinetic energy of the air flow into mechanical power. In ancient, wind turbines were used for grinding grain, pumping water, and irrigating farm land. Nowadays, this kind of mechanical power can be used for making electrical energy through modern wind turbines. The wind rotates the blades that spin a shaft, and the shaft connects to an electricity generator.

2.1.1 The Types of Wind Turbines

- Vertical and Horizontal Axis Wind Turbine

According to axis direction, wind turbine technologies are divided into two categories- horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). Horizontal axis has its blades rotating on an axis parallel to the ground and vertical axis wind turbine, dominating the majority of the wind industry, has its blades rotating on an axis perpendicular to the ground and is more available and cost-effective than vertical wind turbines. Nevertheless, HAWT is more effective to produce electricity than VAWT in a certain amount of wind, such as the efficiency of a horizontal axis with propeller blades is about 60%. However VAWT, applied in small wind project and residential conditions, can work well when the wind comes from any direction.

- Up-wind turbine and down-wind turbine

Most wind turbines are designed as up-wind turbines. When the rotor is installed in the front of the unit, it is called upwind turbine. On the contrary, if the rotor is positioned in the back, it is called down-wind turbine. Up-wind turbine is the most ordinary type of turbines operating. A yaw mechanism such as a tail vane is needed to keep turbine oriented towards the wind.

- The number of the blades

Wind turbine is designed to have one, two, and multiple blades. The ability to transfer the wind energy into electricity is decided by the number of blades. Considering the cost and installation, the number of blades of wind turbine is no more than three in general.

(1). Single blade wind turbine

Single blade wind turbines must move more rapidly to acquire the same amount of wind in a high speed rotation. This specialty will produce more noise and impact on wildlife. The capacity of energy capture is 10% less than that of the two blades.

(2). Two blades wind turbines

Two blades wind turbines have the similar feature with single blade. The capacity of captures is 5% less than the energy of the three blades design.

(3). Three blades wind turbines

The number of blades depends on many factors. Those factors include maximizing total energy captured, minimizing total mass, minimizing downstream turbulence and limiting cross section when the blades are deliberately stalled. According to above parameters, the three blades wind turbine is one of the best optimized structure designs (Meyers 2013).

2.1.2 Working Principle

Wind turbines are quite simple in design and operate on a simple principle. The energy in the wind turns two or three propellers - like blades around a rotor. The blades catch the wind and help rotate shaft. The rotor is connected to the main shaft, which spins a generator to produce electricity. A generator normally consists of magnets and a conductor such as coiled copper wire. The array of magnets is connected to the shaft and surrounded the coil of wire. When magnets rotate around the copper windings, it produces a difference in electrical potential which can create voltage and an electric current. This process is called induction and all types of wind turbines use the same principle to generate electricity despite the variations of the gearboxes and drivetrains.

Modern wind turbines are mounted on a tower to capture the most wind energy. A wind energy plant normally consists of many wind turbines that are 30 to 50 m long each. Most of wind farms are located in high altitudes to propel the turbines much faster. The electricity produced by wind turbines can be connected to an electricity grid for more widespread electricity distribution and use.

2.1.3 Wind Power Curve

Wind speed is the essential means influencing the power output of a wind turbine. The power output of a wind turbine is characterized by the so-called power curve (Jangamshetti and Rau 2001).

$$P_w(y_t) = \begin{cases} 0 & 0 < y_t < v_c, or\ y_t > v_s \\ \gamma y_t^3 & v_c \le y_t \le v_r \\ P_m & v_r \le y_t \le v_s \end{cases} \tag{2.1}$$

Where,

$P_m$ is the rated power or the WT capacity, and $\gamma = P_m/v_r^3$. Note that $v_c$ is the cut-in speed, $v_r$ is the rated speed, and $v_s$ is the cut-off speed, respectively. In this paper, the parameters of wind turbine have the cut-in speed $v_c$ =2.5 m/s, the rate speed $v_r$= 10 m/s, cut-off speed $v_s$=25 m/s. Figure 1 shows a typical wind power curve comprised of four operating phases as defined in Equation (2.1)

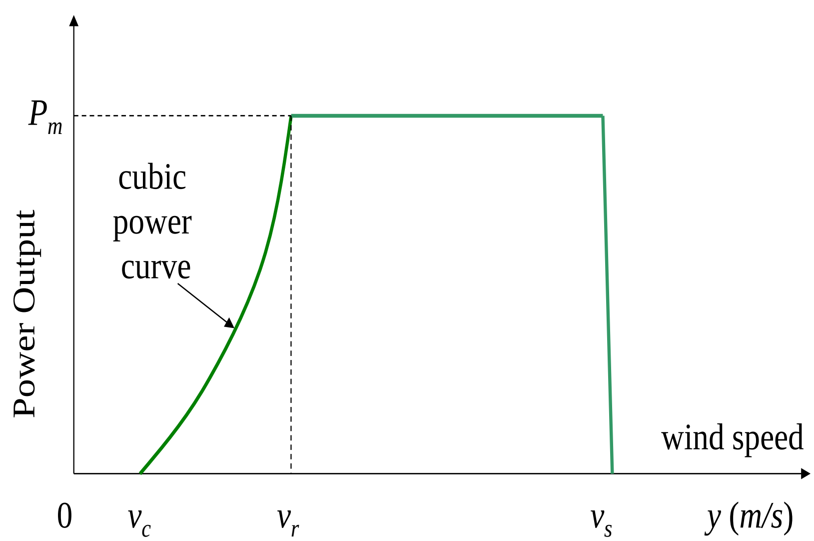


Fig 2: A Typical Wind Turbine Power Curve

2.1.4 The Profile

Table 1: The Comparison Table of Wind Power

| **Category** | **Advantage** | **Disadvantage** |
|---|---|---|
| Technology | 1. Wind energy is a plentiful, widely distributed, clean, and renewable resource<br>2.The capacity of capture wind is sharp improvement<br>3. Wind power potential is much higher than current estimates | 1. The working capacity depends on the wind resource, not constant<br>2. Wind farms located in far away from the city and residential area<br>3. Wind turbines need more land than traditional energy resource to produce the same amount of energy |
| Cost | 1. Wind turbines have significant economies of scale and one of the most economical alternative energy<br>2. The costs for a utility scale wind turbine in 2012 range from about $1.3 million to $2.2 million per MW<br>The cost per unit of energy produced is similar to the cost for new coal and natural gas installations | 1.It has higher initial investment<br>2. the cost of installation and maintenance is high<br>3.It needs more substantial environment cost |
| Other | 1.Environment friendly<br>2.Create employment opportunities | 1. Noise and killing birds and bats<br>2. Removal vegetation, disturbance, and compaction of soil, soil erosion, and changes in hydrologic features<br>3. Should consider foot print |

2.1.5. Current Capacities

Wind energy is the fastest development alternative source in the world. Wind power is ten times bigger than the amount of water energy development and utilization on earth (James2012). Most country makes efforts to help wind power development from technology, policy, and budget. More than 44,900 MW of new capacity were installed worldwide in 2012. World wind power capacity grew to approximately 285.7 GW, an increase of 18.6 % in the total wind power installation base (Saidur et al 2010). Some countries deployed detail scenarios in the several decades, in order to help the development of wind power from government policy. The wind energy policy could help increasing wind power generation as well as stimulating the energy industry. China is one of the main fastest development and usage countries which installed at 18,000 MW in 2011. China now has 75,564 MW of wind power installed (Xia and Song 2009).

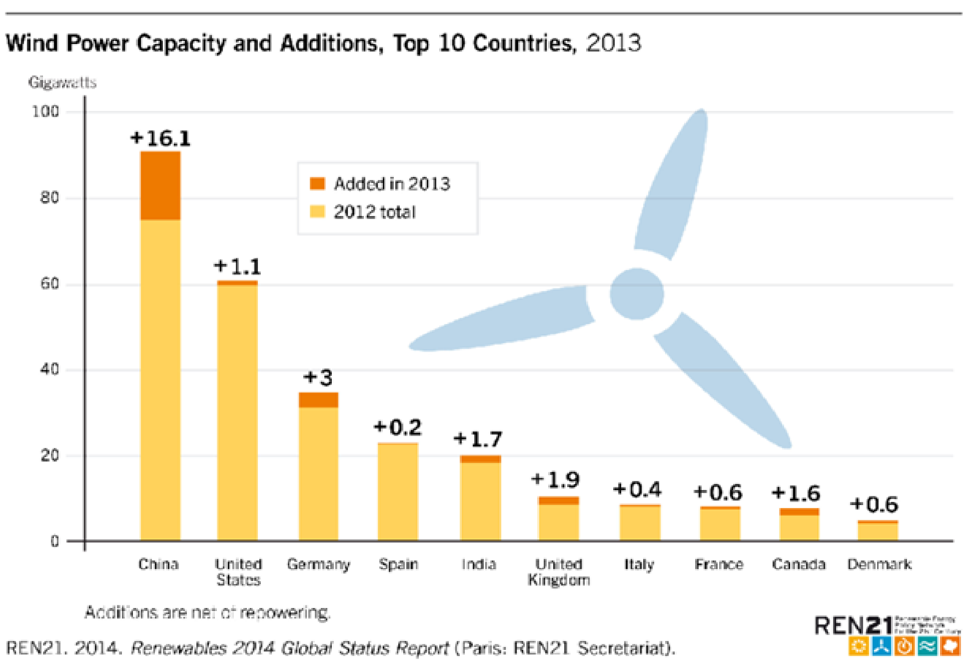


Fig 3: World-Wide Wind Power Installation by Nations (REN21 2014)

2.2 Solar Energy Generation

The solar is one of the most important sources of sustainable renewable energy. The sun provides energy for earth through radiant light and heat. All living creatures on earth depend on the sun's energy to exist. The amount of the energy that the earth obtains from the sun per hour is more than the amount of entire year's energy that human consume. Solar photovoltaic (PV) is a technology that harnesses the sun's radiation energy and convert it into electric power. However, the solar PV generation has its limitation. It heavily depends on the weather condition, and it is only available in the daytime.

2.2.1 The Principle of Silicon-based Solar Cells

The working principle of solar cells is basic same. Semiconductor has p-type and n-type layers where they join at the p-n junction. Electrons and holes diffuse to create the charge-free depletion zone. Moreover, the junction creates a slope in the resulting energy bands. Now, when a photon promotes an electron to the conduction band, it can subsequently "roll down" through the depletion zone into a lower energy band rather than instantly re-combine with a hole. This forms the photo current.

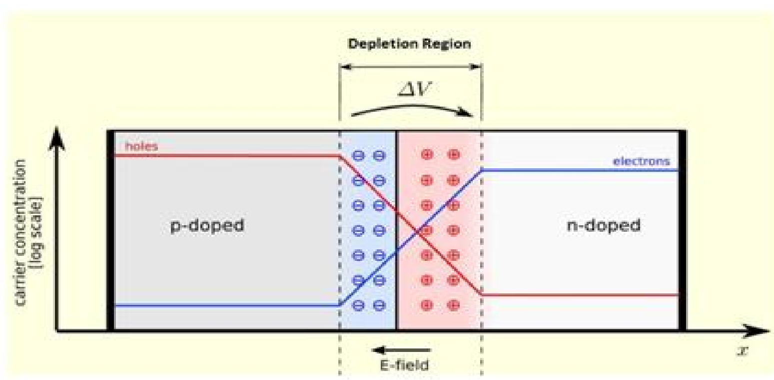


Fig 4.The Working Principle of the Solar Cells (Center for Solar Energy Research and Applications 2014)

2.2.2 CPV

Concentrating photovoltaic (CPV) modules work in the same way as regular photovoltaic (RPV) modules, except that they use optics to concentrate the sun onto solar cells that do not cover the entire module area. A large area of sunlight is focused onto the solar cell using multiple mirrors and lenses. By concentrating sunlight onto a small area, its efficiency can reach as high as 40-50%, or 2-3 times higher than RPV. Nevertheless, high operating temperature and thermal stresses on the cell is the key challenge that is confronted by this type of technology.

Fig 5: Concentrated Solar Photovoltaic (Defense Industry Daily 2006).

2.2.3. The Profile of the Solar Cell

Solar energy technology is rapidly advancing in this year. These advancements make it more affordable than ever to add new applications for solar energy use. The cost of a system in 2013 is only a third of around $12 per watt in 1998 (Pernick et al 2011). Solar technologies are also still expensive and require a lot of land area to collect the sun's energy. Despite the drawbacks, solar energy use has surged at about 20 % a year over the past 15 years because rapidly decrease of prices and increase in transfer efficiency.

2.2.4 Current Capacities

Many countries focus on developing and researching solar energy technology, so the solar photovoltaic is growing rapidly. The capacity of global is 102,156 MW at the end of 2012. Japan, Germany, and the United States are major markets for solar cells. With tax incentives, solar electricity can often pay for itself in 5-10 years.

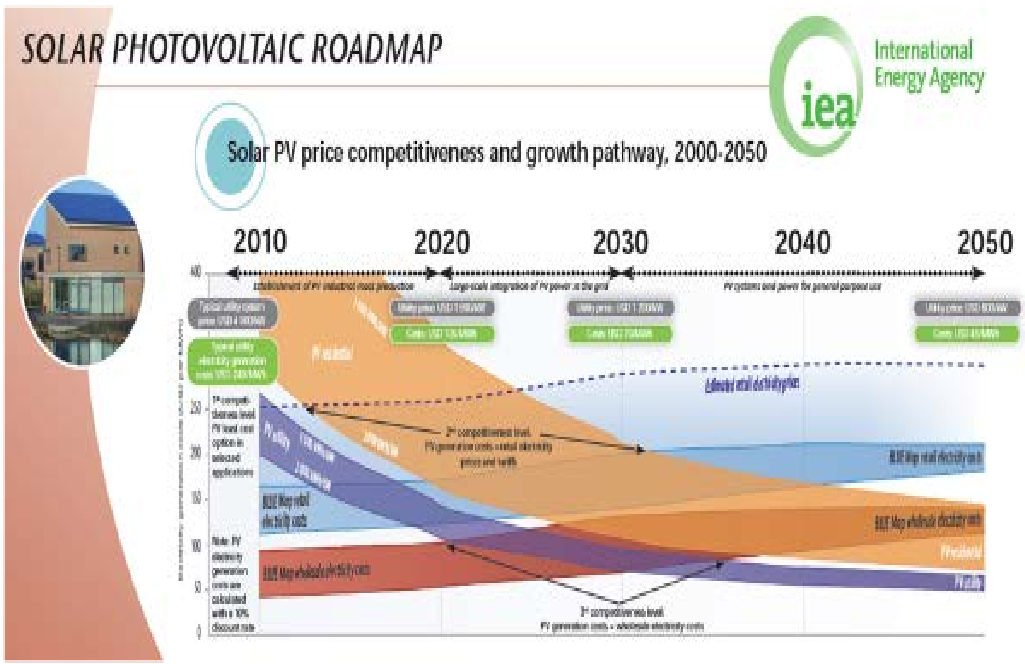


Fig 6: Solar PV Roadmap (IEA 2010)

2.3 Biomass

Biomass is biological material derived from living or dead organisms. Biomass energy is one of humanity’s earliest energy sources. Biomass has been directly used in combustion to produce thermal energy for heating and cooking for thousands of years. Nowadays, biomass can be converted into gas or liquid forms of biomass fuels through chemical processes. They can be indirectly used in industry or civil. In fact, biomass energy is used to meet a variety of energy needs, including generating electricity, heating homes, powering vehicles and providing process heat for industrial facilities. The ratio of the conversion is continually improved and the material that can be adopted as feedstock is not limited only on crops. Feedstocks become widely available and sustainable such as agricultural wastes, crop residues, wood pecks, wood waste and organic waste. Conversion of biomass into biofuels can be achieved by thermal, chemical, and biochemical methods

Biofuel energy resources become the most important and economic alternative energy resource in the future because biofuels can be used in existing petroleum engine and transportation system and become substitute of petroleum productions (Lynd 1996).

### 2.3.1 Biomass Energy Technology Applications

Unlike other renewable energy sources, the forms of biofuels are various. Biofuels can be stored and used as liquid, gaseous, and solid forms. Liquid or gaseous biofuel can be directly used in petrol engine and current equipment (i.e. cars, trucks, buses, airplanes, and trains) for transportation needs. The two most common types of biofuel energy resources are bioethanol and biodiesel which are separately blended with gasoline or petrol diesel in scale is most widely used. These two types of biofuels decrease the usage of petrol productions and reduce the amount of carbon dioxide emissions at the same time.

(1) Biofuels: Converting biomass into liquid or gaseous fuels for transportation.

(2) Biopower: Burning biomass directly, or converting it into a gaseous or oil fuel, to generate electricity and heat.

(3) Bioproducts: Converting biomass into chemicals for making products that typically are made from petroleum (Bioenergy 2007).

2.3.2 The Profile of the Biofuel

This part will introduce the advantages and disadvantages using biofuel in the technology, cost, and other effect aspects.

2.3.2.1 Advantage of Using Biofuel

Although biofuels cannot entirely replace petroleum, there are still many advantages to encourage us to develop it:

(1) It provides a change for utilizing excess production of vegetable oils and animal fats;

(2) It decreases the country's dependence on import petroleum. A greater diversification of energy supply;

(3) Biodiesel is a renewable energy resource. Feedstock is sustainable. Biofuels are made from plants that can be re-cultivated each year.

(4) Biofuels are considered as no contribution to global warming because the total amount of carbon is balanced between burning biofuel and the carbon consumed by the plants. A life cycle analysis of biodiesel shows that overall CO2 emissions could be reduced by 78% compared with petroleum based diesel fuel (Sheehan et al. 1998).

(5) It can also be mixed with other energy resources to use;

2.3.2.2 Disadvantages of Biofuels

(1) It is about one and a half times more expensive than petroleum. The cost will be limited by the region and weather;

(2) It will consume many resources to ensure the supply of feedstock. Using water, fertilizer, and land;

(3) It will cause monoculture. Most lands are grown crops that can be converted into biofuel;

(4) The quality of biofuel is various that depend on the condition of feedstocks;

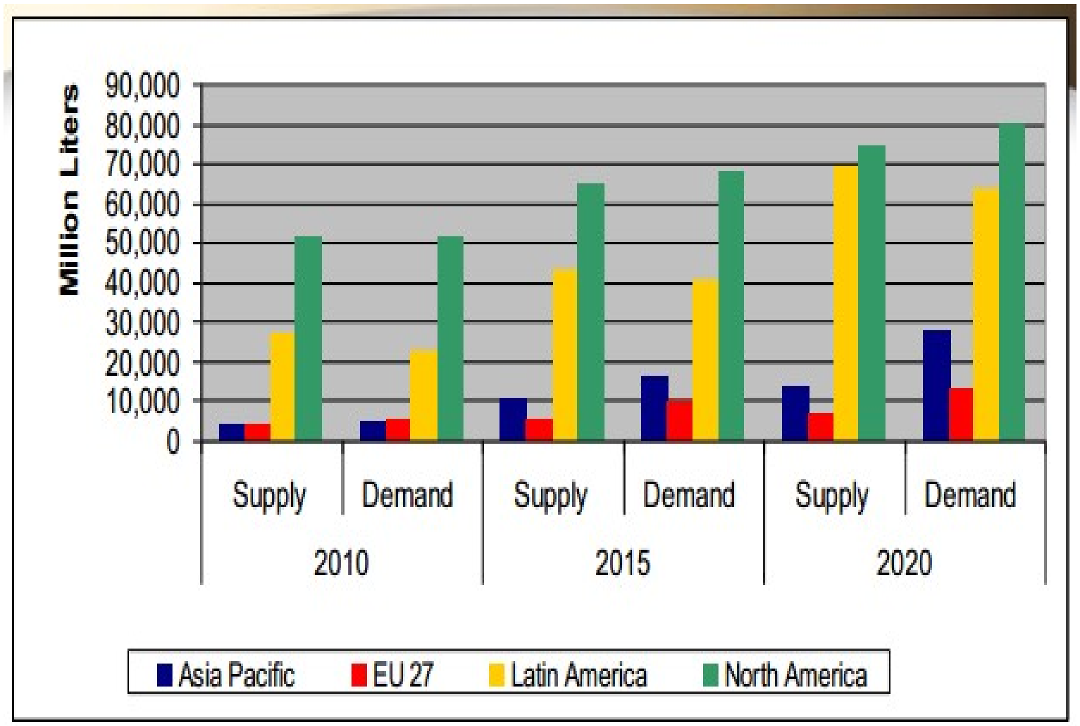


Fig 7: Bioethanol Growth by Region, 2010-2020 (Pinto 2011).

2.3.3. Evaluation Forecast

The productions of biofuel will rapidly grow in the next decade. The reports coming from the international energy agency and Navigant show the tendency of using and the producing of the biofuel. According to the International Energy Agency document, biofuel capacity must more than double growth by 2020 to meet the two degree Celsius scenario (2DC) targets.

2.4 Geothermal Energy

Geothermal energy is thermal energy generated and stored in the Earth

In early 2014, the United States' installed geothermal power capacity is about 3,442 megawatts (MW) (American Council on Renewable Energy 2014). The geothermal electricity installed capacity is approaching the 10,000 GM (Bertani 2007).

Profile of Geothermal Generation as follow:

2.4.1 Advantage

(1) It runs continuously day and night with an uptime typically exceeding 95%. The output is not influenced by weather condition.

(2) Geothermal power stations are relatively small and have little impact on the environment.

2.4.2 Disadvantage

(1) Geothermal heat is extracted from deep within the earth's surface which results in disadvantage concerning finding a suitable build location

(2) Some geothermal stations have created geological instability, even causing earth quakes strong enough to damage buildings

(3) It extracts small amounts of minerals such as sulfur

(4) The initial cost of design and installation is high

(5) Open-loop systems require a large supply of clean water in order to be cost-effective (Bull 2001).

2.5 Tidal Energy

Tidal energy is environment friendly energy and does not emit greenhouse gases during operation. Tides are the waves caused due to the gravitation interaction between the moon and the sun. It is meant that we could harness tidal power as long as moon and sun exist. While 71% of Earth's surface is covered by ocean, it is on large scale.

Efficiency of tidal power is far greater as compared to coal, solar or wind energy. Its efficiency is around 80% (Khaligh and Onar 2009).

The working principle of tidal energy device has the same theory with wind turbine. The blades are driven by water.

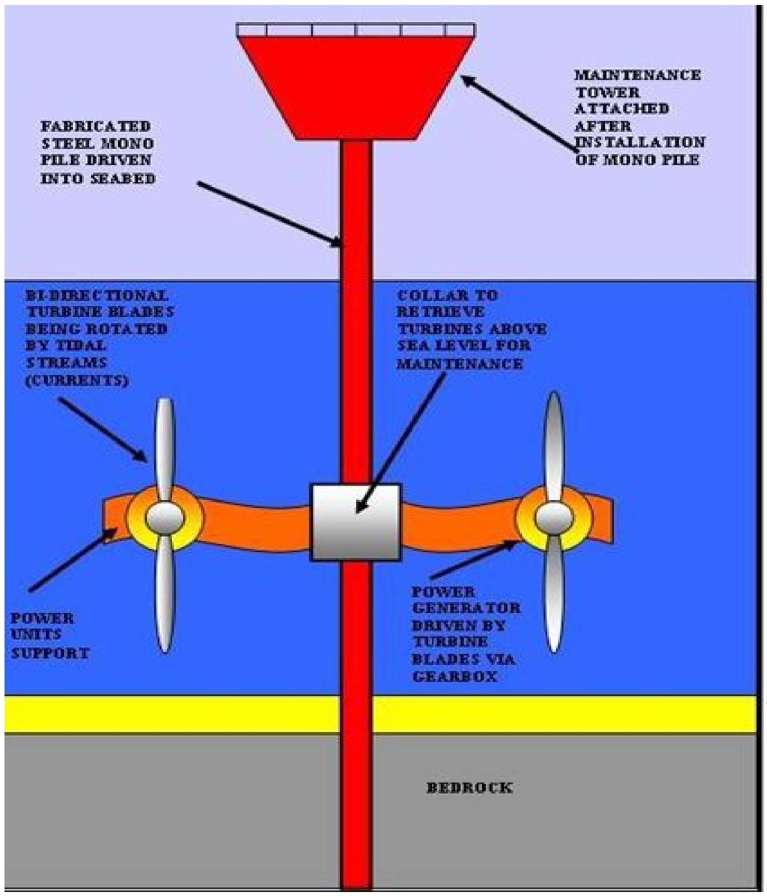


Fig 8: Marine Tidal Energy Extraction Devices Working Principle (Scott 2011).

# CHAPTER III

# MODELING RENEWABLE ENERGY PRODUCTION

Renewable energy resources including sunlight, wind, tides, biomass and geothermal heat are considered as an alternative to replace conventional coal, gas and oil. In particular, both the wind power and solar energy are among the two main alternative energy resources. They have been applied broadly worldwide in the last 20 years in order to meet the growing needs of energy.

In this chapter, we model and forecast wind speed and solar radiation at every location before designing or building charging stations using wind and solar energy due to the variable nature of the wind and solar resources. We need to develop the mathematical models to manage the cost-effectiveness and the environmental benefits if the solar irradiation and wind variation can be predicted. This would help us to determine the optimal capacity of WT and solar PV, and battery size in a particular charging station. The load is considered as a variable parameter due to the variation of EV being charged. In order to match the load, it is necessary to simulate and predict the wind speed and the weather conditions according the historical weather records.

## 3.1 Modeling Output of Wind Turbine

### 3.1.1 Wind Data

The project collects the weather data of Dallas (Texas), Phoenix (Arizona), Toronto(Canada), Hohhot(China), Delhi(India), London(England) and other worldwide cities (see Table 3-1) over past 2 years (2012 and 2013). They are total fifteen cities. The data obtained from the national climate data center includes average temperature, average length of day, average daily solar radiation and the average wind speed. The weather conditions in these locations have the representativeness and uniqueness in terms of wind speed and sunny days. Dallas has relatively high wind speed and the number of sunny days in Brisbane is the highest compares the figures in Table 3-1 and Table 3-3.

Table 2: The Annual Weather Record of Locations (Weather underground 2015).

| No | Location | Country | Average Temperature (F) | Average Length of Day (hrs) | Average Wind Speed (m/h) | Average Daily Solar Radiation (KWh/m$^2$) | Latitude (degree) |
|---|---|---|---|---|---|---|---|
| 1 | Dallas | USA | 66.19 | 11.87 | 10.54 | 4.54 | 32.78 |
| 2 | Phoenix | USA | 74.99 | 12.63 | 6.08 | 5.47 | 33.45 |
| 3 | Hohhot | China | 44.08 | 12.66 | 9.00 | 4.48 | 40.82 |
| 4 | Kunming | China | 60.33 | 12.64 | 11.67 | 3.72 | 35.68 |
| 5 | Seoul | Korea | 54.50 | 21.70 | 5.83 | 3.86 | 37.56 |
| 6 | Singapore | Sigapore | 82.5 | 12.42 | 6.83 | 4.49 | 1.3 |
| 7 | Delhi | Indian | 77.30 | 12.58 | 6.08 | 5.30 | 28.61 |
| 8 | Brisbane | Queensla nd | 69.25 | 12.53 | 7.92 | 5.15 | 27.47 |
| 9 | Munich | Germany | 46.92 | 12.83 | 11.50 | 3.18 | 48.13 |
| 10 | London | UK | 50.44 | 12.89 | 6.65 | 2.82 | 51.51 |
| 11 | Santiago | Chile | 58.41 | 12.54 | 6.25 | 5.53 | 33.45 |
| 12 | San Francisco | USA | 57.87 | 12.86 | 8.91 | 5.35 | 37.78 |
| 13 | Des Moines | USA | 50.80 | 12.71 | 9.94 | 3.89 | 41.59 |
| 14 | Toronto | Canada | 41.68 | 12.74 | 8.98 | 3.38 | 44.38 |
| 15 | São Paulo | Brazil | 69 | 12.52 | 7.83 | 4.65 | 23.55 |

Even if the demands for electricity are the same, due to different weather conditions of world, the capacity size of wind turbines and PV panels will be different in different locations. All the climate data in Table 3-1 allows us to deduce the output power of WT and PV in the entire year. Stimulating each day of solar and wind output will be shown below.

3.1.2 Wind Speed Statistics

The random behavior of wind speed can be characterized by normal or Weibull distributions (Villarreal et al. 2013). If the random wind speed, denoted as Y, follows the Weibull distribution, the probability density function (PDF), $f(y)$, and its cumulative density distribution (CDF) (Novoa 2011), $F(y)$, are given as

$$f(y) = \left(\frac{k}{c}\right)\left(\frac{y}{c}\right)^{k-1} e^{-(y/c)^k} \tag{3.1}$$

$$F(y) = 1 - e^{-(y/c)^k} \tag{3.2}$$

From function (3), I get the equation 3.3 to calculate the wind speed at t hour.

$$y = C * \sqrt[K]{-(In(1-F(y)))} \tag{3.3}$$

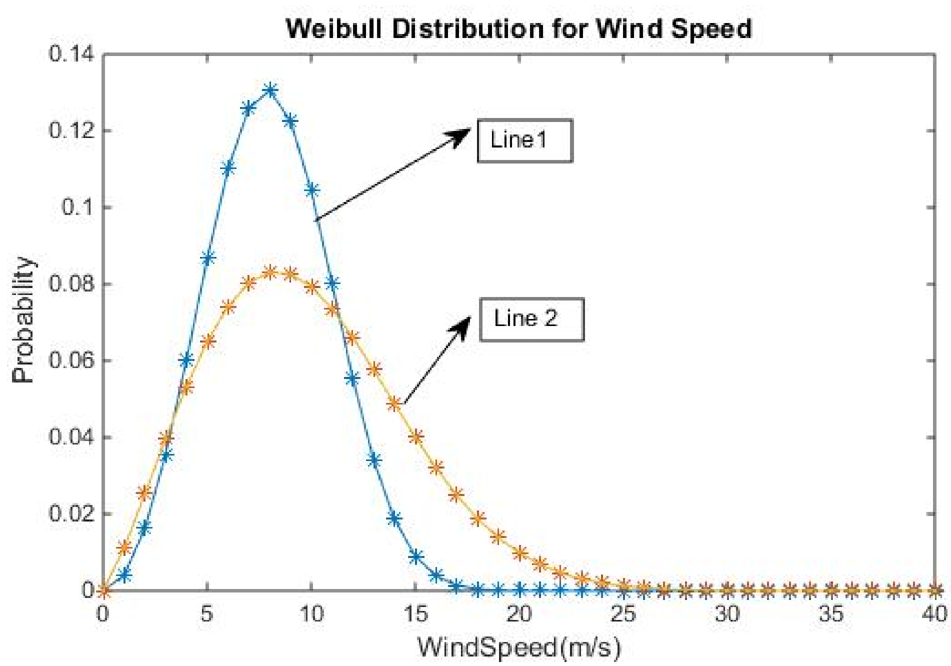


Fig 9: Weibull Wind Speed

Line1 $c$=9.45/s and $k$=3.23; Line2 $c$=11.32 m/s and $k$=2.2.The $c$ and $k$ are called scale and shape parameter, respectively, in the Weibull distribution. The larger shape parameter pushes the Weibull distribution toward into normal distribution. The mean $\mu_y$ and the variance $\sigma_y^2$ can be estimated by through the gamma function, $\Gamma(\cdot)$.Respectively(Jin and Tian 2010);

$$\mu_y = c\Gamma(1+\frac{1}{k}) \tag{3.4}$$

$$\sigma_y^2 = c^2\Gamma(1+\frac{2}{k}) - \mu_y^2 \tag{3.5}$$

The Weibull distribution does not have negative value that is an important advantage in modeling and simulating the stochastic wind speed.

3.1.3 Calculate the Weibull Parameter *c* and *k*

Assuming the wind speed follows the Weibull distribution. This section estimates the parameter *c* and *k* of 15 locations based on the weather records of wind speed.

The functions to calculate *C*, *K* values (Chen et al. 2011)

$$k = (\frac{\sigma}{\mu})^{-1.086} \tag{3.6}$$

$$c = \frac{\mu}{\Gamma(1+\frac{1}{k})}; \qquad \Gamma(1+\frac{1}{k}) = (0.568+\frac{0.434}{k})^{\frac{1}{k}} \tag{3.7}$$

(3.8)

Table 3: The *c* and *k* Value of 15 Locations

| **month average wind speed** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **Mean** | **STDEVA** | ***c*** | ***k*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dallas Texas | 11 | 11 | 12 | 12 | 11 | 10 | 10 | 9 | 9 | 10 | 11 | 11 | 10.542 | 1.134 | 11.02 | 11.259 |
| Phoenix Arizona | 5 | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 6 | 6 | 5 | 5 | 6.083 | 0.840 | 6.433 | 8.589 |
| Hohhot China | 10 | 10 | 10 | 10 | 9 | 9 | 8 | 6 | 8 | 8 | 10 | 10 | 9 | 1.279 | 9.532 | 8.321 |
| Kuming China | 10 | 11 | 11 | 10 | 8 | 7 | 6 | 5 | 6 | 6 | 8 | 9 | 8.083 | 2.109 | 8.875 | 4.303 |
| Seoul South Korea | 8 | 8 | 8 | 8 | 8 | 6 | 4 | 4 | 4 | 3 | 3 | 6 | 5.833 | 2.125 | 6.531 | 2.994 |
| Singapore Singapore | 11 | 10 | 9 | 6 | 6 | 6 | 6 | 8 | 6 | 5 | 4 | 5 | 6.833 | 2.167 | 7.594 | 3.480 |
| Delhi India | 6 | 8 | 8 | 8 | 8 | 8 | 4 | 4 | 6 | 4 | 4 | 5 | 6.083 | 1.832 | 6.739 | 3.682 |
| Brisbane Queensland | 11 | 11 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 11 | 11 | 10 | 7.917 | 2.575 | 8.810 | 3.387 |
| Munich Germany | 16 | 13 | 13 | 11 | 8 | 10 | 10 | 9 | 10 | 11 | 13 | 14 | 11.5 | 2.316 | 12.423 | 5.699 |
| London England | 8 | 8 | 9 | 6 | 7 | 6 | 5 | 7 | 5 | 6 | 6 | 7 | 6.65 | 1.133 | 7.113 | 6.832 |
| Santiago Chile | 6 | 8 | 6 | 6 | 5 | 5 | 4 | 5 | 6 | 8 | 8 | 8 | 6.25 | 1.422 | 6.803 | 4.991 |
| San Francisco USA | 2 | 3 | 5 | 6 | 7 | 8 | 8 | 7 | 6 | 4 | 3 | 2 | 5.092 | 2.232 | 5.741 | 2.449 |
| Des Moines Iowa | 11 | 11 | 11 | 12 | 10 | 9 | 8 | 8 | 9 | 10 | 11 | 10 | 9.942 | 1.113 | 10.411 | 10.782 |
| Toronto Canada | 10 | 11 | 10 | 9 | 8 | 7 | 7 | 7 | 8 | 9 | 10 | 11 | 8.975 | 1.590 | 9.621 | 6.549 |
| São Paulo Brazil | 8 | 8 | 8 | 8 | 6 | 6 | 6 | 8 | 9 | 9 | 9 | 9 | 7.833 | 1.193 | 8.327 | 7.717 |

3.1.4 Simulate the Output of Wind Turbine

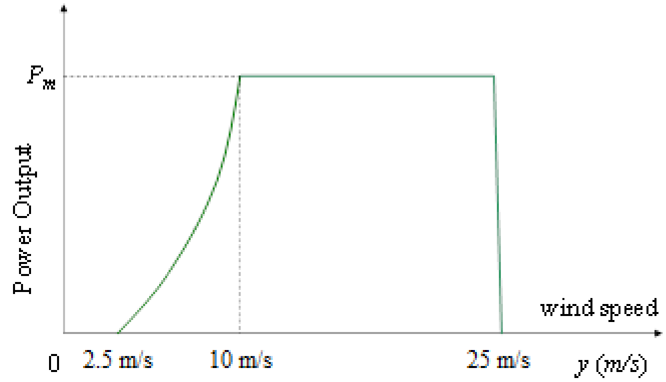


Fig 10: The Wind Power Curve

The relationship of the output power and the wind speed is regarded as a non-linear function when the turbine operates between wind speed and. Cubic power curve model is developed based on the kinetic theory of the air flow dynamics (Jangamshetti and Rau 2001).

$$P_w(y_t) = \begin{cases} 0 & 0 < y_t < v_c, or\ y_t > v_s \\ \gamma y_t^3 & v_c \le y_t \le v_r \\ P_m & v_r \le y_t \le v_s \end{cases} \quad (3.9)$$

$P_m$ is the rated power or the WT capacity, and $\gamma$ =$P_m$/vr$^3$. Note that $v_c$ is the cut-in speed, $v_r$ is the rated speed, and $v_s$ is the cut-off speed, respectively. In this paper, the parameters of wind turbine have the cut-in speed $v_c$ =2.5m/s, the rate speed $v_r$= 10m/s, cut-off speed $v_s$=25m/s.

3.2 Modeling Output of Solar PV

Solar photovoltaic is a technology that harnesses the sun's radiation energy and converts it into electric power. In this part, we develop simulation programs to emulate the whole year output power of a solar PV panel at the specific locations. The output power of a PV system is determined by multiple factors, including panel size, operating temperature, the PV orientation, the panel tilt angle, the calendar date, the solar irradiance incident and instantaneous electric current on the PV (Taboada et al. 2012).

Table 3-3 lists all the main factors that influence the output of a PV system.

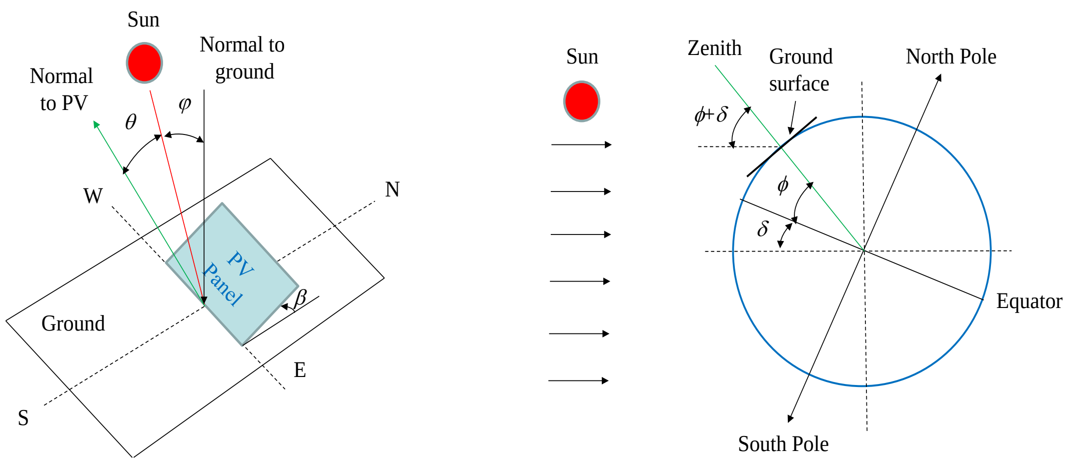


Fig 11: Working Principle of Solar PV during Daytime

### 3.2.1 Modeling Formula

A three-step procedure to calculate the PV energy production is presented below. It is worth mentioning that the unit for angles is radian (rad) unless stated.

Step 1: Compute the sunrise and sunset time for day $d \in \{1, 2, \ldots, 365\}$

$$\cos(-\omega_{rise}) = \cos(\omega_{set}) = \tan(\phi - \beta) \tan \delta \tag{3.10}$$

with

$$\delta = 0.40928 \sin\left(\frac{2\pi(d + 284)}{365}\right) \tag{3.11}$$

Where, $\delta$ is the declination angle, $\omega_{rise}$ and $\omega_{set}$ are the sunrise and the sunset angles in day $d$ perceived from the PV panel. There is no power output when $\omega < \omega_{rise}$ or $\omega > \omega_{set}$, i.e. before sunrise and after subset.

Step 2*:* Computing the total amount of solar irradiance incident on the PV surface at time $t$ in day$d$, that is

$$s_t = 1370\left(0.7^{(\cos\varphi)^{-0.678}}\right)\left(1 + 0.034\cos\left(\frac{2\pi(d-4)}{365}\right)\right) \times \left(\cos\theta + 0.1\left(1 - \frac{\beta}{\pi}\right)\right) \qquad (3.12)$$

With

$$\cos\varphi = \cos\delta\cos\phi\cos\omega + \sin\delta\sin\phi \qquad (3.13)$$

$$\begin{aligned}\cos\theta = &\sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\alpha \\ &+ \cos\delta\cos\phi\cos\beta\cos\omega \\ &+ \cos\delta\sin\phi\sin\beta\cos\alpha\cos\omega + \cos\delta\sin\alpha\sin\omega\sin\beta\end{aligned} \qquad (3.14)$$

Where, $s_t$ is the solar irradiance (W/m$^2$) received by the PV at time $t$ during date $d$, and $\varphi$ is the solar zenith angle which is given by equation (2.4). $\omega$ is the solar hour angle determined by the local time. For instance $\omega$=-π/2 at 6:00AM in the morning, and it increases 15$^o$ every hour until reaching $\omega$=π/2 at 6:00PM in the evening. To maximize the energy yield, the PV panel shall be oriented towards the south (i.e. $\alpha$=0), then equation (3.10) can be simplified as

$$\cos\theta = \sin\delta\sin(\phi - \beta) + \cos\delta\cos(\phi - \beta)\cos\omega \qquad (3.15)$$

Step 3*:* The actual power output of a PV system considering the weather condition can be estimated by

$$P_t(s_t) = W_t\eta A s_t\left[1 - 0.005(T_o - 25)\right] \qquad (3.16)$$

Where

$P_t(S_t)$ = the DC output power of the PV system;

$S_t$= the solar irradiance incident on the PV surface at time $t$ for $t$=1, 2, …, 24 hours on day $d$ for $d$=1, 2, …, 365.);

$P_s$ = the instantaneous PV output power; $\eta$= conversion efficiency (10-15%);

$A$= the PV area ($m^2$); $T_o$= the PV operating temperature ($^oC$);

$W$= a random variable representing the weather pattern. For instance, 0.9, 0.7 and 0.3, respectively (Lave and Kleissl 2011).), can characterize PV system in a clear day, a partly cloudy day, and a cloudy day.

Table 4: Key Factors of PV Power Generation

| **No.** | **Factor** | **Symbol** | **Explanation** |
|---|---|---|---|
| 1 | weather condition | $W_t$ | random variable |
| 2 | PV size ($m^2$) | $A$ | PV module area |
| 3 | PV  efficiency | $\eta$ | between 10-20% |
| 4 | date | $d$ | $d$=1,2,3….365 |
| 5 | solar hour (rad) | $\omega$ | related to the local time |
| 6 | PV temperature ($^oC$) | $T_o$ | operating temperature |
| 7 | latitude (rad) | $\phi$ | depends on location |
| 8 | PV azimuth angle (rad) | $\alpha$ | if facing south, $\alpha$=0 |
| 9 | PV tilt angle (rad) | $\beta$ | between PV and ground |
| 10 | local hours | $h$ | $h$=1, 2, …, 24 |

### 3.2.2 Climatic Data

The climatic data capture the detailed wind speed and weather conditions of 15 locations. The percentage of sunny day decides the output of the solar generation. Kunming, Hohhot and Brisbane have the remarkable sunny day.

Table 5: The Annual Weather Record of Locations (Weatherbase 2015).

| **No** | **City** | **Country Region** | **Latitude (degree)** | **Sunny (days)** | **Partly cloudy (days)** | **Overcast (days)** | **Sunny (%)** | **Partly cloudy (%)** | **Overcast (%)** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Dallas | USA | 32.78 | 135 | 97 | 133 | 0.37 | 0.266 | 0.364 |
| 2 | Phoenix | USA | 33.45 | 211 | 85 | 70 | 0.578 | 0.233 | 0.192 |
| 3 | Hohhot | China | 40.82 | 270 | 6 | 89 | 0.74 | 0.016 | 0.244 |
| 4 | Kunming | China | 35.68 | 276 | 0 | 89 | 0.756 | 0 | 0.244 |
| 5 | Seoul | South Korea | 37.56 | 168 | 0 | 197 | 0.46 | 0 | 0.54 |
| 6 | Singapore | Singapore | 1.3 | 1 | 105 | 260 | 0.003 | 0.288 | 0.712 |
| 7 | Delhi | India | 28.61 | 255 | 0 | 110 | 0.699 | 0 | 0.301 |
| 8 | Brisbane | Queensland | 27.47 | 334 | 0 | 31 | 0.915 | 0 | 0.085 |
| 9 | Munich | Germany | 48.13 | 195 | 65 | 105 | 0.534 | 0.178 | 0.288 |
| 10 | London | England | 51.51 | 10 | 119 | 236 | 0.027 | 0.326 | 0.647 |
| 11 | Santiago | Chile | 33.45 | 126 | 125 | 114 | 0.345 | 0.342 | 0.312 |
| 12 | San Francisco | USA | 37.78 | 43 | 160 | 162 | 0.118 | 0.438 | 0.444 |
| 13 | Des Moines | Iowa | 41.59 | 24 | 160 | 181 | 0.066 | 0.438 | 0.496 |
| 14 | Toronto | Canada | 44.38 | 1 | 134 | 230 | 0.003 | 0.367 | 0.63 |
| 15 | São Paulo | Brazil | 23.55 | 259 | 87 | 19 | 0.71 | 0.238 | 0.052 |

## 3.3 Time Series Forecasting Models for Wind Speed and Solar Radiation

There are many distinctive models for forecasting global solar radiation and wind speed, such as time series methods. For instance, developing a line-method to forecast next 5 hours weather could be used in real-time wind farm power management systems. Below a class of parametric time series models, namely Autoregressive and moving average (ARMA) processes, is introduced by Box and Jenkins (1994).

Table 6: Parameters (AR=Autoregressive, MA=Moving Average)

| No. | Factor | Symbol |
|---|---|---|
| **1** | The observation at hour *t* | $OW_t$ |
| **2** | The mean observation at hour *t* | $\mu_t$ |
| **3** | The standard deviation of the observation at hour *t* | $\sigma_t$ |
| **4** | The mean of all the observed data | $\mu$ |
| **5** | The standard deviation obtained from all the observed data | $\sigma$ |
| **6** | The simulated at hour *t* | $SW_t$ |
| **7** | the seasonal AR polynomial of order *n* | $\emptyset_n$ |
| **8** | the seasonal MA polynomial of order *m* | $\Theta_m$ |

Auto-Regressive and moving average ARMA(*n*, *m*) time series model (Billinton et al.1996).

$$\begin{aligned} y_t &= \phi_1 y_{t-1} + \phi_2 y_{t-2} + \phi_3 y_{t-3} + \phi_4 y_{t-4} \cdots + \phi_n y_{t-n} \\ &+ \alpha_t - \theta_1 \alpha_{t-1} - \theta_2 \alpha_{t-3} - \theta_3 \alpha_{t-3} \cdots - \theta_m \alpha_{t-m} \end{aligned} \quad (3.17)$$

$$y_t = \mu - \sum_{i=1}^{n} \phi_i y_{t-i} - \sum_{j=1}^{m} \theta_j \alpha_{t-j} + \alpha_t \quad (3.18)$$

Simulated wind speed $SW_t$ can be calculated as follows:

$$SW_t = \mu_t + \sigma_t y_t \tag{3.19}$$

3.4 Simulating Wind Speed and Weather Condition

Table 7: Hourly Wind Speed Record of Dallas on Dec 2015 (National Weather Service2015)

| **Dec-15** | **Hrs** | **Wind Speed m/h** | **Dec-15** | **Hrs** | **Wind Speed m/h** | **Dec-15** | **Hrs** | **Wind Speed m/h** |
|---|---|---|---|---|---|---|---|---|
| 13 | 1 | 13 | 14 | 1 | 14 | 15 | 1 | 12 |
| 13 | 2 | 9 | 14 | 2 | 18 | 15 | 2 | 8 |
| 13 | 3 | 12 | 14 | 3 | 15 | 15 | 3 | 7 |
| 13 | 4 | 12 | 14 | 4 | 13 | 15 | 4 | 7 |
| 13 | 5 | 12 | 14 | 5 | 14 | 15 | 5 | 9 |
| 13 | 6 | 10 | 14 | 6 | 13 | 15 | 6 | 10 |
| 13 | 7 | 10 | 14 | 7 | 14 | 15 | 7 | 10 |
| 13 | 8 | 7 | 14 | 8 | 15 | 15 | 8 | 7 |
| 13 | 9 | 8 | 14 | 9 | 14 | 15 | 9 | 10 |
| 13 | 10 | 9 | 14 | 10 | 14 | 15 | 10 | 17 |
| 13 | 11 | 13 | 14 | 11 | 18 | 15 | 11 | 16 |
| 13 | 12 | 12 | 14 | 12 | 13 | 15 | 12 | 10 |
| 13 | 13 | 13 | 14 | 13 | 15 | 15 | 13 | 15 |
| 13 | 14 | 15 | 14 | 14 | 15 | 15 | 14 | 15 |
| 13 | 15 | 14 | 14 | 15 | 10 | 15 | 15 | 15 |
| 13 | 16 | 16 | 14 | 16 | 21 | 15 | 16 | 14 |
| 13 | 17 | 16 | 14 | 17 | 16 | 15 | 17 | 17 |
| 13 | 18 | 12 | 14 | 18 | 13 | 15 | 18 | 14 |
| 13 | 19 | 14 | 14 | 19 | 9 | 15 | 19 | 12 |
| 13 | 20 | 15 | 14 | 20 | 7 | 15 | 20 | 9 |
| 13 | 21 | 13 | 14 | 21 | 6 | 15 | 21 | 5 |
| 13 | 22 | 17 | 14 | 22 | 5 | 15 | 22 | 5 |
| 13 | 23 | 23 | 14 | 23 | 8 | 15 | 23 | 13 |
| 13 | 24 | 17 | 14 | 24 | 8 | 15 | 24 | 13 |

Note, Unit: m/h=mile/hour.

Table 8: Hohhot Weather Condition Record on 2012, 2013 and 2014 (Weather underground 2015).

| **Hohhot, China** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Mon** | **S** | **PC** | **OC** | **Year** | **Mon** | **S** | **P C** | **OC** | **Year** | **Mon** | **S** | **P C** | **OC** |
| 12 | 1 | 30 | 0 | 1 | 13 | 1 | 29 | 0 | 2 | 14 | 1 | 27 | 0 | 4 |
| | 2 | 29 | 0 | 0 | | 2 | 28 | 0 | 0 | | 2 | 27 | 0 | 1 |
| | 3 | 21 | 2 | 8 | | 3 | 30 | 0 | 1 | | 3 | 30 | 0 | 1 |
| | 4 | 27 | 0 | 3 | | 4 | 25 | 0 | 5 | | 4 | 25 | 0 | 5 |
| | 5 | 20 | 0 | 11 | | 5 | 24 | 1 | 6 | | 5 | 24 | 1 | 6 |
| | 6 | 13 | 1 | 16 | | 6 | 9 | 0 | 21 | | 6 | 9 | 0 | 21 |
| | 7 | 18 | 0 | 13 | | 7 | 12 | 0 | 19 | | 7 | 14 | 0 | 17 |
| | 8 | 17 | 0 | 14 | | 8 | 19 | 0 | 12 | | 8 | 16 | 0 | 15 |
| | 9 | 17 | 0 | 13 | | 9 | 22 | 8 | 0 | | 9 | 22 | 8 | 0 |
| | 10 | 24 | 0 | 7 | | 10 | 28 | 0 | 3 | | 10 | 27 | 0 | 4 |
| | 11 | 23 | 0 | 7 | | 11 | 25 | 0 | 5 | | 11 | 24 | 0 | 6 |
| | 12 | 21 | 1 | 9 | | 12 | 29 | 0 | 2 | | 12 | 29 | 0 | 2 |

Note, S=Sunny

PC= Partly Cloud

OC= Overcast Cloud

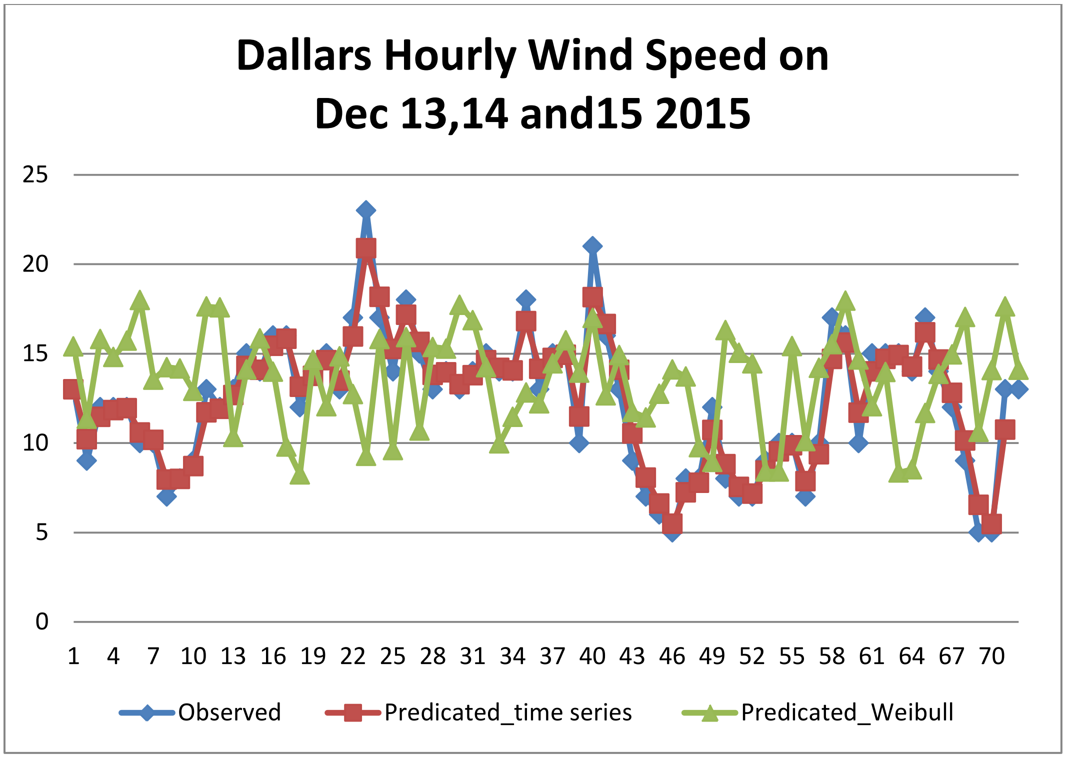


Fig 12: Observed and Simulated Wind Speed of Dallas.

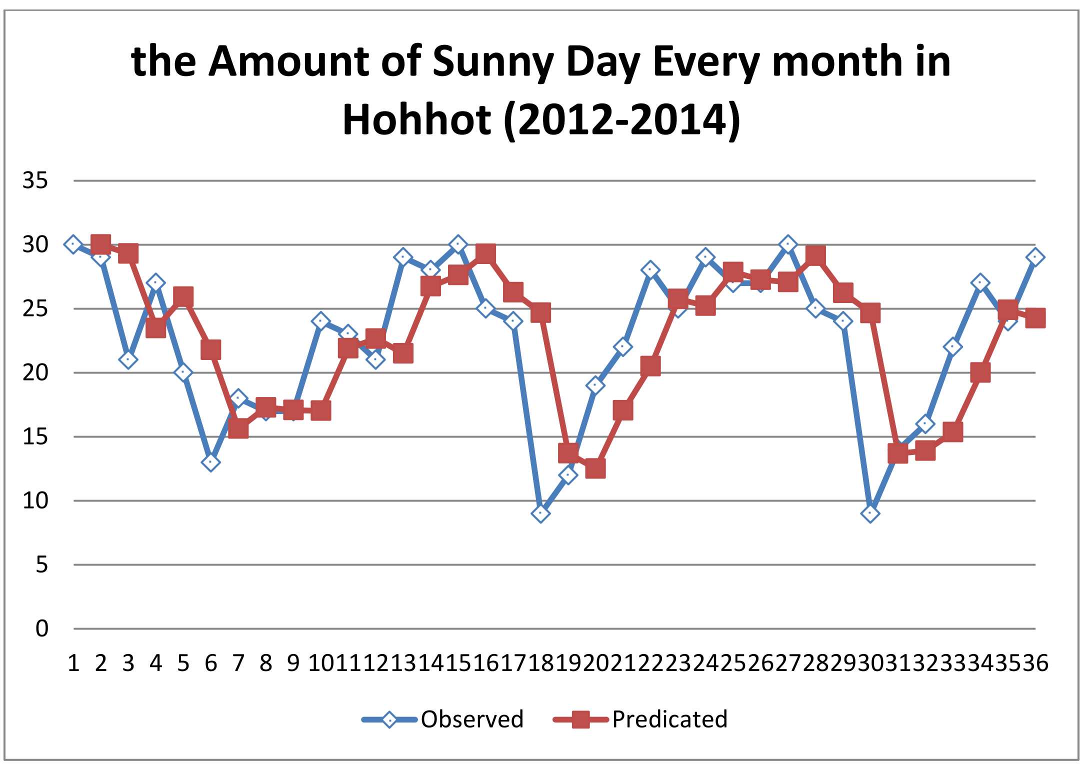


Fig 13: Observed and Simulated Sunny Day of Hohhot.

## 3.5 Battery Storage System

There are many different types and sizes of battery package on the market. The electric cell is an actual basic unite serving as the chemical energy storage device. According the need, a number of units of electric cells are series connected together. The battery is one of the critical components in this research project. The capacity of the battery in the charge station may vary in different location due to the variation of wind speed and weather condition. The lead acid battery is the first generation battery, and it has existed for nearly 170 years. Today the rechargeable lithium-ion battery has become the dominant technology in market since 1980. Lithium-ion batteries (Li-ion or LIB) will be used as the storage system of charging stations. The working principle and parameter of LIB will be introduced in this section.

A rechargeable battery has dual functions: charging and discharging. When surplus energy from WT and PV are available, it can be temporally stored in the battery if empty capacity is available. During this process, the battery transfers electric energy into chemical energy. On the other hand, if the renewable power from WT and PV is less than the load of the charge station, the energy stored in the battery can be released to complement the electricity gap. The chemical energy is converted into electric energy in this process. Below two simple models are presented to characterize the charging and discharge processes, respectively.

### 3.5.1 Modeling Charging Process

$$S(t+\Delta t) = \{S_{\max}, \quad S(t) + \frac{S_{\max}}{T_c}\Delta t\} \tag{3.20}$$

Where

$t$=current time in hour,

$\Delta t$=charging time or charging duration (unit is hour),

$S_{max}$=maximum battery capacity in (KWh),

$T_c$=full charging cycle in hours.

3.5.2 Discharging Process

Let $S(t)$ be the battery energy state at time t, then after discharging t, the residual electric energy is

$$S(t+\Delta t)=\{0, \quad S(t)-P_d \Delta t\} \tag{3.21}$$

Where

$P_d$=discharging power (KW)

$\Delta t$=discharging time or duration (unit is hour)

3.6 Chapter Summary

This chapter establishes the mathematical models to simulate and predicted wind speed and solar radiation according the historical weather records of every location due to the variable nature of the wind and solar resources. The weather data collects from National Weather Service and weather underground website. They provide hourly wind speed and annual daily condition. Using historic weather data, I calculate the *c*, *k* value. Time series and Weibull model are used to predicate the wind speed and weather condition. The simulation result of time series model appears more seasonal pattern than Weibull.

# CHAPTER IV

# ELECTRIC VEHICLE AND CHARGING STATION

Electric Vehicles (EVs) are not new, and they have existed for more than 100 years. Thomas Davenport developed the first generation of electric motor for commercial use in 1834. Production of the EVs began in 1912 (Kirsch 2000). All EVs work on electricity stored in a battery or series of batteries with electric motor for vehicle propulsion. However, the EV market significantly shank in 1940s due to the large scale unearthing of crude oil coupled with the customer requirements on long distance travel. The recent resurgence of EV is largely driven by the concern of the climate change and the advance of battery technology. EVs have positive effects on the economic and environmental impacts. EVs can save 3.0 cents/mile compare with gas vehicle (EV = 4.1 cent per mile, Petrol = 7.1 cent per mile). In the recently, the EVs market booms expansion, due to the technology development, the increasing gas price and the policy supporting from government.

Along with the development of automobile industry, EVs is gaining the strong momentum in the vehicle market. Nissan Leaf, Honda Insight, and Chevy Volt are all targeted at middle class markets and have proven to be successful in transitioning into a lower-carbon and gas-independent transport paradigm. The Obama Administration set a near-term goal of one million electric vehicles on the road by 2015 (Obama 2011). There were over 180,000 EVs running on road at the end of 2012. During 2012, sales of pure electric cars were led by Japan with a 28% market share of global market, followed by the United States with a 26% share, China with 16%, and France with 11%, and Norway with 7% (Trigg et al. 2013). According to the 2010 National Automobile Dealers

Association Report, vehicle registrations for plug-in electric vehicles (PEVs) are anticipated to be 2.8% of the total by 2015.

EVs have an excellent performance on energy efficient and environmental protection compared with internal combustion engine (ICE) cars, but EVs need long charging time and have limited driving range that become a handicap when customers purchase them. The size and the chemistry of the vehicle battery typically become the solution to resolve above these two challenges. The battery of electric vehicle is one of the vital factors influencing the performance of electric vehicle that underpins the design criterion for electric vehicle. The batteries available for the EVs include lead acid battery, lithium-ion battery, and nickel-metal hydride battery.

This chapter aims to elaborate the structure of the EV system, types of batteries, charging levels of EVs, and EV charging station.

### 4.1 Types of EVs

According to Bailey, J statement, there are four primary types of EVs available in current market: hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), extended-range electric Vehicles (E-REV), and battery electric vehicles (BEV), and fuel cell vehicles (FCVs) (Bailey2012).

#### 4.1.1 Battery Electric Vehicles (BEVs)

BEVs are purely battery powered cars, and propelled by the electric motor that receives power from an onboard battery pack. Namely, BEVs entirely use batteries' power to drive the vehicle with no additional engines. The controller takes power from the batteries and delivers it to the motor. Nissan LEAF, Mitsubishi, Ford Focus Electric belong to BEVs. EVs can be recharged through wall socket or other forms. Owners of

EVs are able to recharge their vehicles at home or public area power, such as working place, store or café shop.

### 4.1.2 Plug-in Hybrid Vehicles (PHEVs)

A hybrid electric vehicle includes an ICE and an electric motor that can switch seamlessly according driving condition. Typically, the electric motor alone drives the vehicle at low speeds, using power stored in batteries. Under acceleration and during hill climbing, both the engine and the motor provide torque to drive the vehicle. The combustion engine alone drives the vehicle in steady state highway cruising. PHEVs can be recharged through regenerative braking system. They can go anywhere from 10-40 miles before their gas engine is kicked in to power the car. The Chevy Volt and Ford Fusion Energi belong to PHEV.

### 4.1.3 Hybrid Electric Vehicles (HEVs)

HEVs combine the engine of a traditional internal combustion engine vehicle with the battery and electric motor of an electric vehicle. The combined engine allows HEVs to achieve better fuel economy than traditional vehicles. They do not need to be plugged in.

### 4.1.4 Extended Range Electric Vehicles (E-REVs)

E-REVs are extended range electric vehicles. They have an electric motor that powers the car that can run for 20-60 miles using zero gasoline. The GM Chevrolet Volt is an E-REV.

### 4.1.5 Fuel Cell Vehicle

Fuel cell vehicles utilize chemical reaction as power to drive cars. For instance, hydrogen and oxygen are commonly used as the reactants in fuel cell powered cars. They usually have a longer driving rang than PEVs. The basic chemical reaction of fuel cell vehicles:

$$2H_2 + O_2 \rightarrow 2H_2O \tag{4.1}$$

4.2 The Battery of EVs

There are many different types or sizes of battery on the market, lead acid battery, lithium-ion battery, nickel-metal hydride battery. The performance of battery ultimately decides the capacities of vehicle, such as driving range, mass and service life of vehicle, the length of recharging time, and the cost of the car.

A battery is rechargeable and consists of more than one electric cell that is connected together. The energy stored in a battery is chemical energy. The electric cell is an actual basic unite – chemical energy storage device. It transfers electric energy into chemical energy during charge procedure and converts chemical energy into electric energy during discharge process. Each battery includes negative (anode), positive (cathode) and electrolyte. The chemical reaction would take place between the anode and the cathode. The chemical energy releases through a chemical reaction. The battery can be recharged through general electricity networks from municipal power that operation is convenient and safe.

Table 9: Batteries of EVs (Ivanovic 2012)

| Name of battery | Anode of material | Electrolyte of material | Cathode of material |
|---|---|---|---|
| **Lead Acid** | $P_b$ | $H_2SO_4$ | $P_bO_2$ |
| **Nickel Cadmium** | $C_d$ | KOH | NiOOH |
| **Nickel Metal Hydride** | $H_2$ | KOH | NiOOH |
| **Lithium** | Lithium-ion | Lithium salt in an organic solvent | Metal oxide |
| **Metal –Air** | Metal (Aluminium, Zinc) | $H_2O$ | $O_2$ |

Table 9 shows the materials of different types batteries make of the anode, cathode, and electrolyte. All these rechargeable batteries can be used in the EVs. Lead acid battery is the first generation battery used in EV fleet. Now, the rechargeable lithium battery (LIB) has become dominant battery in market since 1980s. Leading EV models such as Nissan leaf, Mitsubishi MiEV, Tesla Roadster and Chevrolet Volt all adopt lithium ion batteries as the energy storage medium. The lithium-ion batteries have a lifetime between 500 and 1,200 cycles depending on the state of charge.

### 4.2.1 Working Principle of LIBs

Lithium Ion Batteries (LIBs) include three primary functional components that are the positive, negative electrodes and electrolyte. Generally, the Negative Electrode (Anode) is made of carbon. The positive electrode (cathode) is a metal oxide and the electrolyte is a lithium salt in an organic solvent. The electrons flow from positive electrode to negative electrode at the outside of battery, on the contrary, the electrons flow from the cathode to anode inside of battery.

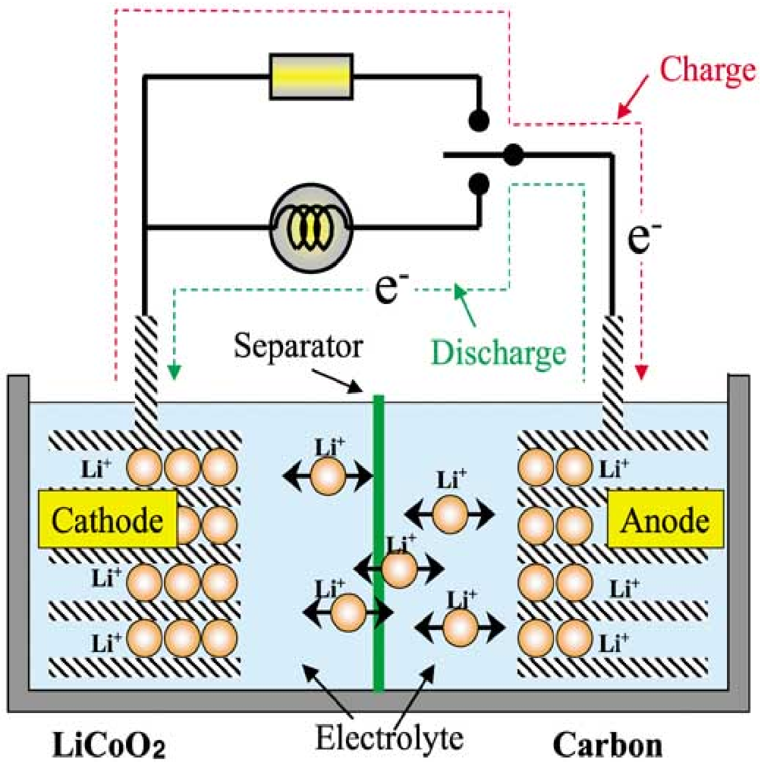


Fig14: The Working Principle of LIBs (Nishi 2001).

4.2.2 Parameters of LIBs

There are some important parameters of the lithium ion battery that can make LIBs become the appealing battery technology used on electric road vehicles. It has high energy density, relatively low self-discharge, and can provide very high current to applications. EVs equipped with LIBs have longer driving range, lighter mass, and shorter recharging time compare with other rechargeable batteries. In general, driving range, battery weight, recharging time and cost will ultimately determine the future developing direction of EVs.

Table 10: Nominal Properties of LIBs (Ivanovic 2012)

| No | Categories | Parameters |
|---|---|---|
| **1** | Specific energy | 140 $WhKg^{-1}$ |
| **2** | Energy density | 250-620 $Whm^{-3}$ |
| **3** | Specific power | 330-1500 $WKg^{-1}$ |
| **4** | Nominal cell voltage | 3.5 V |
| **5** | Amphour efficiency | Very good |
| **6** | Internal resistance | Very low |
| **7** | Commercially available | Large LIBs have become the standard battery for electric road vehicles |
| **8** | Operating temperature | Ambient |
| **9** | Self-discharge | Very low,10% per month |
| **10** | Number of life cycles | >1,000 |
| **11** | Recharge time | 2-3 hours, but can be charge to 80% of their capacity in under 1 hour. |

Where, specific energy is the amount of electrical energy stored for every kilogram of battery mass. It would approximate the mass of battery once the value of energy capacity is known; Energy density is the amount of electrical energy stored per cubic meter of battery volume.

Table 11: Comparison of Commercially Available Batteries

| Battery | Specific Energy ($WhKg^{-1}$) | Energy Density ($WhM^{-3}$) | Specific Power ($WKg^{-1}$) |
|---|---|---|---|
| **Lead acid** | 30 | 75 | 250 |
| **NiCad** | 50 | 80 | 150 |
| **NiMH** | 65 | 150 | 200 |
| **Zebra** | 100 | 150 | 150 |
| **Li ion** | 150 | 150 | 300 |
| **Zinc-air** | 230 | 270 | 105 |

Table 12: Electric Vehicles with Battery Power and Driving Range (Battery University 2015).

| EVs | Power of Battery | Range (advertised) | Range (Actual) | Charging time |
|---|---|---|---|---|
| BMW Mini E | 35KWh | 250Km, 156 miles | 153Km | 26h at 115VAC; 4.5h at 230V, 32A |
| Chevy Volt | 16KWh | 64Km, 40 miles | 45Km | 10h at 115VAC; 4h at 230VAC |
| Mitsubishi iMiEV | 16KWh | 128Km, 80 miles | 88Km | 13h at 115VAC; 7h at 230VAC |
| Nissan LEAF | 24KWh | 160Km, 100 miles | 100Km | 8h at 230VAC; 30 min high ampere |
| Tesla Roadster | 56KWh | 352Km, 220 miles | 224Km | 3.5h at 230VAC high ampere |
| Smart Fortwo ED | 16.5KWh | 136Km, 85 miles | 80 Km | 8h at 115VAC 3.5 h at 230 VAC |

Table 11 depicts the important parameters of batteries that decide their performance. Lead acid battery is used broadly in the short distance transportation such as golf carts. Li-ion and Zinc-air batteries dominate battery market of EVs. These two new types of battery technologies continue reducing the weight and extending the driving range. Table 12 states parameters of EVs in the current market.

### 4.2.3 Battery Management of EVs

The Battery Managements Systems (BMS) is an electric system that monitors the status of rechargeable battery. It manages charge and discharge processes, estimated the state of charge. An intelligent battery management system can extend battery lifetime and lengthen driving range, which reduces the vehicle cost over its entire lifetime.

Avoiding full charging and deep discharging, battery will maximize the battery life. Over charging can accelerate battery degradation, catch fire, even cause explosion. On the other hand, over-discharge can result in loss of capacity and shortening of cell life. The battery capacity will decrease with the increase number of charging cycle. The energy capacity of EV battery should fall to 70% of original figure after 10 years using.

## 4.3 Charging Station

Besides focusing on improvement the capabilities of battery, building easy-to-access and sufficient amounts of charging stations is another solution to the fatal disadvantage of limited driving range. Charging stations merely deliver the electric energy to the vehicle, usually in the form of a high voltage AC or DC supply. The efficient battery charging facilities serve as a crucial part in the electric vehicle industry that can help EVs to break through the barrier and penetrate the automobile market. Charging stations in this paper are powered by intermittent renewable energy.

Particularly wind turbines (WT) and solar photovoltaic panels (PV) are integrated in the charging station in order to replace traditional fuel-fired electricity and achieve low-carbon objective.

Public and workplace charging stations are available today at public parking lots, retail chains such as Walgreens, business centers, and airports. The Google Company provides free charging for employees when they park their cars in the garage during working time. The Google's installation is the largest workplace charging installation for electric vehicles in the U.S and the portion of power of chargers is coming from grid and the onsite solar generators (Chargepoint 2011). As of October 2013, there were more than 64,000 public chargers installed globally and this number is expected to expand over the next several years (Navigant Research 2013). Most of electricity powered EVs comes from the grid. In this project, the goal is to construct charging stations powered by onsite generator of renewable energy, and strives for the zero-carbon emission.

### 4.3.1 Charging Level

The charging level is determined by the voltage and current. Broadly speaking, three different charging levels have been defined, but other options are available to accommodate the different existing power grid standards of the national electricity generating utilities. Due to the higher chargeing times of level I, it is used in residential areas. The level II and level III will be used in the public charging station.

Level I (Conventional Model): using a standard 120 voltage, 15 or 20 ampere branch circuit that is commonly found in residential and commercial buildings. Conventional battery charging methods are constant voltage or constant current charging a small current, typically charging time is 5-8 hours, or even as long as 10 to more than 20 hours. It is suitable for overnight home charging.

Although long charging time, this charger also is adopted by most people, because of the use of power and current rating is not critical, relatively low installation costs of the charger, increasing charging efficiency and prolong battery life.

Level II: a 240 voltage, single-phase, 30 ampere branch circuit. Level 2 charger is suitable for private and commercial areas like workplace, movie theaters, shopping malls etc.

Level III (Commercial Model): It is a fast charger. It is a high voltage and high-current charging implementation. By delivering direct current (DC) directly to the vehicle's battery pack, a BEV's battery pack can be charged at a much higher rate. For example, a Level 3 charger allows a Nissan Leaf's battery to be charged to its 80% capacity in 30 minutes. This model can be used in either public or the commercial, but is not feasible for private residential (Yilmaz and Krein 2013).

Table 13: Charging Topologies (Bandyopadhyay et al. 2012).

| Categories | Level I | Level II | Level III |
|---|---|---|---|
| **Charging Circuit** | 120V,15A | 240V,30A | 480V,200A |
| **Charge Power(KW)** | 1.4 | 3.3 | 50-70 |
| **Full Charging Time** | 17 hours | 7 hours | 30 minutes (80%) |

4.3.2 EV Charging Standards

The first DC charging standard was the Japanese CHAdeMO which combines AC and DC charging in a single connector/inlet, so it needs two separate connectors/inlets, one for AC and one for DC . The current technology of electric vehicle charging standard regulated by SAE J1772 covered the connector and charging cable in the U.S. Society of Automotive Engineers proves the product J1772 with 120 V or 240 V. SAE J1772 is developing a Combo Coupler variant of the J1772-2009 connector with additional pins to accommodate fast DC charging at 200–450Vand up to 90 kW. The SAEJ1772 is commercial standard Coupler for all DC faster chargers.  It can be used in the public charging station. The SAE J1772-2009 was adopted by the car manufacturers, and used in the third generation of the Chevrolet Volt and Nissan Leaf as the early models.

Fig 15: 1722 AC and DC "Combo" Coupler (SAE International 2011).

The figure16 below shows a summary of couplers available for Level 2 and Level 3 charging at different area in the worldwide.

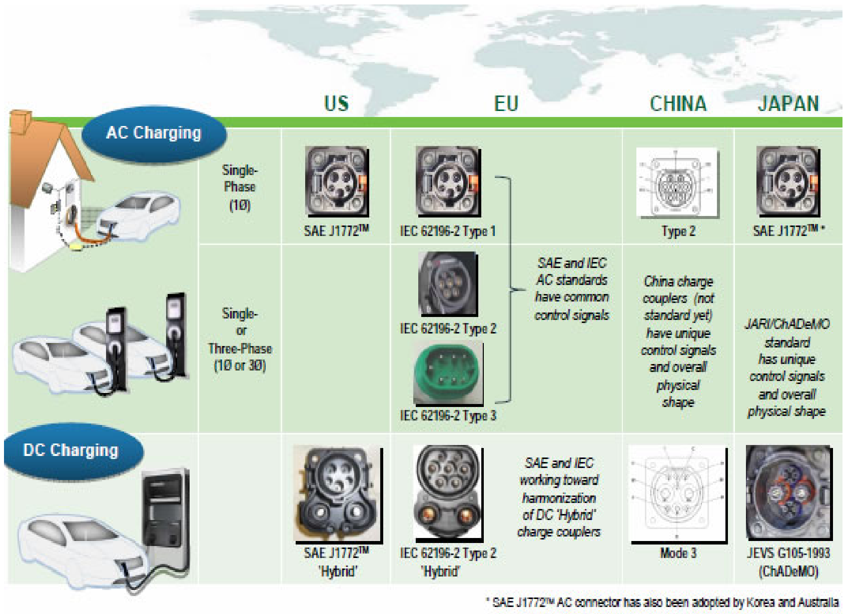


Fig 16: Couplers Available for Level 2 and Level 3 Charging (Electropaedia 2014).

4.3.3 Development of Charging Station

San Diego airport runs test on portable solar-paneled EV Charging. The EV ARC, invented and produced by Envision Solar International Inc., fits inside a standard parking space. It uses solar panels to recharge the battery.

Fig 17: EV ARC at San Diego Airport (Webb 2013).

The people can search the public charging station location through website, such as plugincars.com, the EV project.com and pulgshare.com to review charger map to current charging station, or down load the APP software to find the charging station and make sure which charger is available now.

Tesla Superchargers provide 170 miles of range in as little as 30 minutes. 347 Supercharger stations have 1,902 Superchargers with average of 5-6 charge points per station.

Fig 18: Tesla Supercharging Station (Motavalli 2012).

Fig 19: Japanese Charging Station with Solar PV (Quick 2010).

## 4.4. Battery Storage System

The battery storage system of charging station has two functions charging and discharging. When surplus energy from WT and PV are available, it can be temporally stored in the battery if empty capacity is available. On the other hand, if the aggregate power from WT and PV is less than the electric load, the energy stored in the battery can be discharged to complement the electricity gap. Below we present two simple models to characterize the charging and discharge processes, respectively.

## 4.5 Assessment Method

The charging station can adopt two ways to charge access fee when an EV owner uses the charging point. The first is based on the time of the EV connected to charging point. Charging by time connected to the charger prevents the charger point from being occupied, especially in the commercial center with heavy traffic flow and high charging demands. The average price is 2.00 $/hour in today's commercial charging station (Chang et al. 2012). The price is 0.04 $/minute if you are a membership; otherwise the price is 0.06/minute in Los Angeles, CA. The second is based on the amount of energy used that the EV consumes like rate household electricity billing. This paper will calculate the access fee based on the amount of electricity of customer consumption. The cost is assumed to be 0.50 $/KWh. The price is 0.49 $/KWh, if you are a membership; otherwise the price is 0.59 $/KWh in Los Angeles. The price based on the location is different. There are still other methods to calculate the access fee. EVs' owners will be charged 19.99 $/month for using charger with unlimited time. In this paper, the access fee is based on 0.49 $/ KWh to calculate.

4.6 The Capacity of the Charging Station

All the charging stations are near a community. The charge point in every charging station accommodates four standard DC chargers and two DC fast chargers (the fast charger needs 20 minutes to charge 80%completion, the standard charger needs 1 hour for charge 80% completion).Nissan leaf has 24 KWh lithium-ion batteries to store and provide power for motor. It can be within 30 Minutes to reach its 80% capacity at level 3 charge condition and is as the usage of the charging station. The most popular fast charger technology, based on association of Japan's EV charging standard, can provide 50 KW. So in this paper, the output of the faster DC chargers adopts 50 KW.

Table 14: The Equipment and Output

| | Output | number | Working hours |
|---|---|---|---|
| **Faster DC charger** | 50 kW | 2 | 24 |
| **DC standard charger** | 10 kW | 4 | 24 |
| **lights** | 10 kW | | 12 |
| **The total output** | 150 kW | | |

- Maximal output power is 150KW.
- Every charging station will operate 24 hours every day and 7 days a week.
- The battery capacity of Nissan Leaf 2014 is 24 KWh (as the based targets)
- The maximal daily demand of charging station is 4,728 KWh; (24hrs*3times*2chargers+4chargers*24times)*24KWh*(120%) +10kw*12hrs=4,728 KWh.

The cost of the charging station is simulated under three conditions: (1) the charging stations only use wind generations as the power resource; (2) integrate wind and solar generators; (3) building onsite wind and solar generators with a grid-connected distributed generation (DG).

## 4.7 Chapter Summary

This chapter assumes the maximal capacity of the output power of a charging station. The demand load is considered as a variable parameter and follows normal distribution. As a public charging station, the charger should adopt standard chargers, so they can be used for different types of EVs. AC charging is as the domestic device and DC faster charging is broadly used in the commercial charging station.

# CHAPTER V

# CHARGING STATIONS WITH ONSITE RENEWABLE GENERATION

The chapter will determines the optimal sizing or capacity of WT, solar PV, and battery packs to meet the distributed generation (DG) design criteria, such as cost, energy reliability and carbon savings. The cost of charging station will be reduced as the prices of solar and wind generator equipment decline. Any surplus energy from WT and PV can be stored in the batteries, or injected into main grid to bring extra income to the charging station owners via the feed-in tariff policy.

We analyze our planning model in different locations with a wide spectrum of weather conditions. Even though the cost parameters are the same, the optimal decision on the capacity of WT, PV and battery could change due to the variation of wind speeds and sunny days. The configurations of the charging station are divided into four types: 1) wind power integration, 2) solar photovoltaic integration, 3) wind and solar PV mix, and 4) wind and solar PV mix with battery packs.

The most popular charging technology, based on association of Japan's EV standard, can provide 50 KW output. The power of the charging station is 90KW at the Tesla's supercharger charging station. The car can travel about 240 kilometers after charging 30 minutes. In this chapter, it is assumed that the DC faster charger adopts 50KW output.

## 5.1 System Configuration

The grid-connected DG system consists of the WT, solar PV panels, a net metering system, battery system. The system can reduce the carbon footprint and mitigate the power transmission losses. The battery system has a dual role in the whole system that works as the energy consumer and provider depends on the output of wind and PV generation.

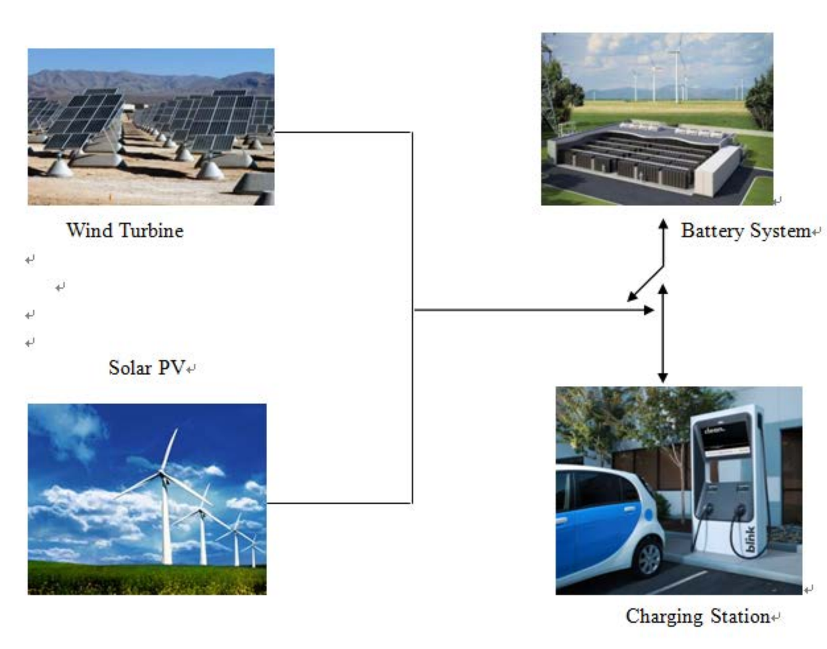


Fig 20: A Grid- Connected Distributed Generation System

5.2 Modeling System

5.2.1 Cost Analysis

The costs of system include the capital investment, operation and maintenance cost, revenue incomes from surplus energy, and the utility bill (Sanders et al.2012)

(1). Installation cost (annualized cost)

$$C_{in}(P_1^c, P_2^c, P_3^c) = \phi(n,r)\sum_{i=1}^{N} a_i P_i^c \qquad (5.1)$$

With

$$\varphi(n,r) = \frac{r(1+r)^n}{(1+r)^n - 1} \text{ (Newnan 2004)} \qquad (5.2)$$

Where

$P_1^c$=capacity of wind turbine (unit: KW), decision variable;

$P_2^c$=capacity of CPV (unit: KW), decision variable;

$P_3^c$=capacity of battery (unit: KWh), decision variable;

$a_1$=capacity cost of WT ($/KW);

$a_2$=capacity cost of CPV ($/KW);

$a_3$=capacity cost of battery system (BS) ($/KW);

$n$= payment periods (Year);

$r$=interest rate (5-6%);

Note that a decision variable means this is an unknown parameter to be optimized. The φ is capital recovery factor (CRF) that converts a present value into a stream of equal annual payments over a specified period, at a specified discount rate (interest). We also can use the interest table to get it when we have the data of payment periods and interest rate.

(2).Operation and Maintenance (O&M) Cost

Though wind and solar energy resources are free, the operation and maintenance cost has to do with two aspects: (1) leasing the land to install and place WT, PV units, and battery systems; and (2) repair and maintenance of WT, CPV and BS due to component aging and wear-out.

$$C_{om}(P_1^c, P_2^c, P_3^c) = \sum_{t=1}^{T}\sum_{i=1}^{N} b_i P_{it} \tag{5.3}$$

Where

$P_{it}$=the power output from generation type $i$ at time $t$;

$b_1$=annual O/M cost of WT ($/KWh);

$b_2$=annual O/M cost of CPV ($/KWh);

$b_3$=annual O/M cost of battery ($/KWh);

$T$=number of hours in a year (i.e. $T$=8,760 hours).

(3). Electricity Bill

The charge station has to purchase electricity from main grid when it has not enough power to charge EVs. When the owner adopts onsite generation, significant amounts of utility cost are to be saved because a large portion of the electric load is met by WT, PV and BS units. The actual utility cost incurred by the owner becomes,

$$R_{Ebill}(P_1^c, P_2^c, P_3^c) = \rho \sum_{t=1}^{T} (P_t - D_t)^- \tag{5.4}$$

With

$$P_t = \sum_{i=1}^{N} P_{it} \text{ , for } t=1, 2, \ldots, T \tag{5.5}$$

Where

$\rho$= the utility price ($/KWh), in general $\rho$=$0.07-0.11/KWh;

$D_t$ is the power demand (KW) in hour t.

5.2.2. Income Analysis

(1). Revenue

$$R_{SleE} = \eta \sum_{t=1}^{T} D_t \tag{5.6}$$

Where $D_t$= the power demand by customers;

$\eta$ = the access fee ($/KWh) when customer charged the VEs with $0.49/KWh or $2.5/hr. (EVADC 2014).

(2).Carbon Credits

This is the compensation received by the owner of charging station due to the adoption of onsite renewable energy technology**.** Also note that carbon credits are given based on the amount of renewable energy produced in unit of $/KWh. That is

$$R_{cd}(P_1^c, P_2^c, P_3^c) = \sum_{t=1}^{T} \sum_{i=1}^{N} c_i P_{it} \tag{5.7}$$

Where

$c_1$=carbon credits of WT ($/KWh);

$c_2$=carbon credits of CPV;

$c_3$=carbon credits of battery;

$P_{1t}$=output power of WT unit in $t$ for $t$=1, 2, …,$T$;

$P_{2t}$=output power of CPV unit in $t$ for $t$=1, 2, …,$T$;

$P_{3t}$=output or charging power of battery unit in hour for $t$=1, 2, …,$T$.

Note that $P_{3t}$ is positive when the battery is discharge the electricity, and is negative if the battery under charging. In the latter, the battery actually becomes the load. The carbon credits are applied only to WT and PV units as they actively produce the carbon-free electricity. The battery simply serves as the storage function, yet it does not possess the capability of producing renewable energy. Hence $c_3$=0.

(3).Net Metering and Feed-in Tariff Income

Net metering occurs when the output from onsite WT and PV units exceeds the power demand of the charging station and storage batteries. In this case, the surplus energy is returned to the main grid. Financially, the owner of the charging station actually gains the income by selling this surplus energy to the utility company.

$$R_{nm}(P_1^c, P_2^c, P_3^c) = q\sum_{t=1}^{T}(P_t - D_t)^+ \qquad (5.8)$$

Where, $q$= the income received (unit: \$/KWh) by selling electricity to the main grid. For example, we can assume $q$=0.5$\rho$ or 0.75$\rho$, where $\rho$ is the regular utility rate.

5.2.3 The Aggregate Annualize Cost Model

Here is the aggregate cost model incorporating all the terms discussed previously. Note that carbon credits, revenue, and net metering income are negative with respect to the installation, operation, and maintenance costs of the onsite DG system.

$$f(P_1^c, P_2^c, P_3^c)$$
$$= \phi(n,r)\sum_{i=1}^{N} a_i P_i^c + \sum_{t=1}^{T}\sum_{i=1}^{N} b_i P_{it} + (\eta - \rho)\sum_{t=1}^{T}(P_t - D_t)^- - (\sum_{j=1}^{T}\sum_{i=1}^{N} c_i P_{ij} + q\sum_{t=1}^{T}(P_t - D_t)^- + \eta\sum_{t=1}^{T} D_t)$$

(5.9)

Table 15: Aggregate Cost Model Variables and Parameters:

| Name | Meaning | Value |
|---|---|---|
| $r$ | Annual interest rate | 5% |
| $h$ | The planning horizon (years) | 20 |
| $a_1$ | capacity cost of WT ($/KW) | $\$2.2\times10^3$ |
| $a_2$ | capacity cost of CPV ($/KW)<br>capacity cost of RPV ($/KW) | $\$2.75\times10^3$<br>$\$3.37\times10^3$ |
| $a_3$ | capacity cost of battery systems ($/KW) | $\$1.7\ x10^3$ (Capacity:200KWh) |
| $c_1$ | carbon credits of WT ($/KWh) | $\$5\times10^{-3}$ |
| $c_2$ | carbon credits of CPV ($/KWh) | $\$10\times10^{-3}$ |
| $c_3$ | carbon credits of battery ($/KWh) | $ 0 |
| $P_1^c$ | the capacity of wind turbine (KW) | Range from 0 to 200 |
| $P_2^c$ | the capacity of CPV (unit: KW) | Range from 0 to 200 |
| $P_3^c$ | the capacity of storage battery (unit: KW) | Range from 0 to 100 |
| $P_1$ | output power of WT | This is a random variable to be simulated |
| $P_2$ | output power of PV | This is a random variable to be simulated |
| $P_3$ | output power of battery | This is a random variable to be simulated |
| $b_1$ | annual O/M cost of WT ($/KW) | $0.01 |
| $b_2$ | annual O/M cost of CPV ($/KW) | $\$2\times10^{-3}$ |
| $b_3$ | annual O/M cost of battery ($/KW) | $\$3\times10^{-3}$ |
| ρ | the utility price of grid electricity ($/KWh) | $0.07 or 0.1 |
| $q$ | the net metering rate | 50 or 100% of 0$\rho$ (see above) |
| $\eta$ | Access fee($/KWh) | $0.49/KWh or $2.5/hour |
| $D_j$ | Hourly power demand(KW) | We assume a normal distribution with mean demand 150KW, and the standard deviation is 0.75 KW. That is, in each hour, we randomly generate a power demand based on Normal($\mu$=15, $\sigma$=0.75) distribution (see Villarreal et al. 2013) |

5.3 The Weather Data

The paper collects the weather data of Dallas (Texas, USA), Phoenix (Arizona, USA), Hohhot (China), Delhi (India), London (UK) and other worldwide cities (see table). They are total fifteen cities involved. The data obtained from the national climate data center includes average daily temperature, average length of daytime, average daily solar radiation and the average wind speed. The weather conditions in these places have the representativeness and uniqueness in terms of the geographical diversity and climatic patterns. For instance, Dallas has relatively high wind speed and the number of sunny days in Phoenix has the high solar radiation based on the data comparisons.

Due to different weather conditions of world, the installed capacity of wind turbines and PV panels varies with the actual location where the charge station is placed. All the climate data can deduce the output power in entire year. Stimulating each day of solar and wind output will show in the chapter 3.

5.4 Simulation Algorithm

In the DG system, there contains three decision variables, $P_1^c$ for WT, $P_2^c$ for PV, and $P_3^c$ for battery package. First, initial values are assigned to $P_1^c$, $P_2^c$, and $P_3^c$. These values can be determined based on assumption load. Second, simulated wind speed and weather condition, the instantaneous power from WT and PV at time t is obtained using equations (3.5), (3.2) and (3.12). The modeling methods for wind and solar generation are statement in chapter 3. The DG power is compared with the hourly load to determine whether electricity should be imported from or exported to the main grid. This process is repeated until t reaches 8,760 hours. Then determine whether the current capacity of $P_1^c$ and $P_2^c$ meet the net-zero carbon criterion or not. If yes, $P_1^c$, $P_2^c$, are treated as a candidate solution. Finally, the capacity $P_1^c$, $P_2^c$, and $P_3^c$ is chosen as the solution. The optimization procedure is depicted in Fig5-1.

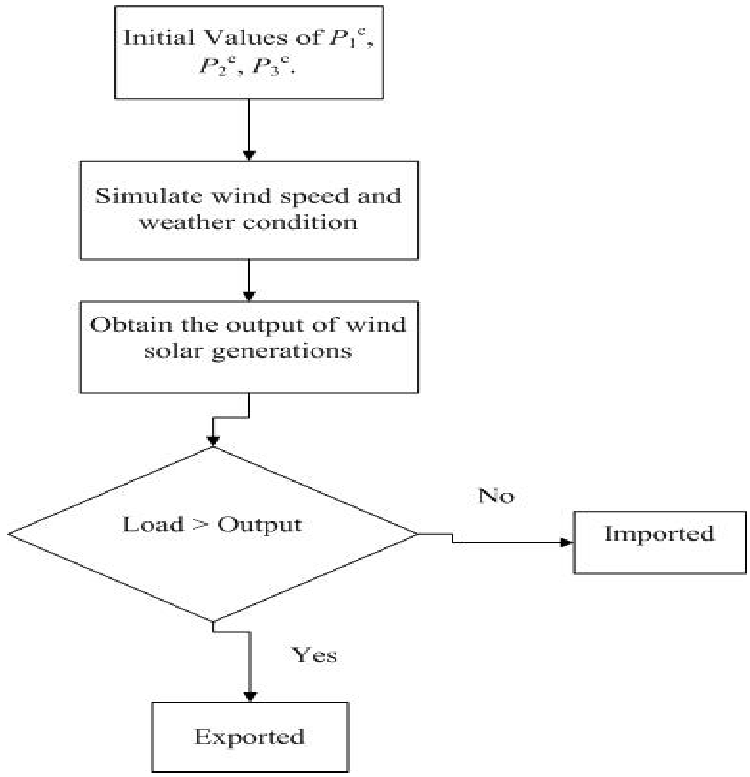


Fig 21: The Optimization Procedure

5.5 The Cost of Each Type of Renewable Generation

The costs depend on four types of simulations, but if a charging station only powered by onsite solar generator, the cost would very high and we also need to consider the occupation of the land. For example, Phoenix has the 5.47 KWh/m$^2$ daily solar radiations. The total annual solar radiation is 1996.5 KWh/m$^2$. The battery capacity of Nissan leaf is 24 KWh. The efficiency of CPV and RPV are 40% and 10%, respectively. The area of the PV system is 24KWh÷10%÷5.47=43.9 m$^2$ for PV and 24÷40%÷5.47= 11 m$^2$ for CPV. A charging station needs 43.9 m$^2$ or 11 m$^2$solar panel to full charge a leaf on one day. Only using solar PV as power resource is not practical.

So this paper just simulates and calculates three considers. The case I, the charging station is only using the wind turbine to operation. The case II, the charging station is using the wind turbine and solar PV as on site generators. The case III, the DG system is built in charging station.

Table 16: The Simulation Results for 15 Locations

| locations | case1 | Case 2 | | Case2 | | |
|---|---|---|---|---|---|---|
| | WT | WT | PV | WT | PV | Battery |
| Dallas | 63.892 | 55.360 | 2.697 | 44.481 | 2.342 | 0.936713 |
| Phoenix | 63.901 | 56.424 | 25.315 | 43.792 | 18.453 | 7.375711 |
| Hohhot | 63.849 | 56.180 | 1.346 | 44.067 | 2.321 | 0.928307 |
| Kunming | 63.904 | 55.829 | 13.509 | 43.837 | 13.844 | 5.537509 |
| Seoul | 63.900 | 55.830 | 13.510 | 43.652 | 34.462 | 13.78483 |
| Singapore | 65.070 | 57.010 | 26.020 | 43.307 | 32.708 | 12.76431 |
| Delhi | 64.014 | 55.339 | 17.585 | 44.338 | 18.669 | 7.467542 |
| Brisbane | 63.876 | 55.434 | 0.001 | 43.805 | 0.002 | 0.000632 |
| Munich | 63.944 | 56.083 | 4.072 | 43.773 | 4.615 | 1.843246 |
| London | 63.927 | 55.880 | 18.937 | 43.213 | 20.742 | 8.187894 |
| Santiago | 63.872 | 55.284 | 5.414 | 43.845 | 4.626 | 1.846354 |
| San Francisco | 63.931 | 55.802 | 2.703 | 42.678 | 2.248 | 0.89906 |
| Des Moines | 63.916 | 55.200 | 17.481 | 43.213 | 18.196 | 7.278316 |
| Toronto | 63.914 | 57.222 | 1.352 | 44.999 | 2.369 | 0.947515 |
| São Paulo | 63.944 | 55.119 | 2.699 | 44.762 | 2.357 | 0.942828 |

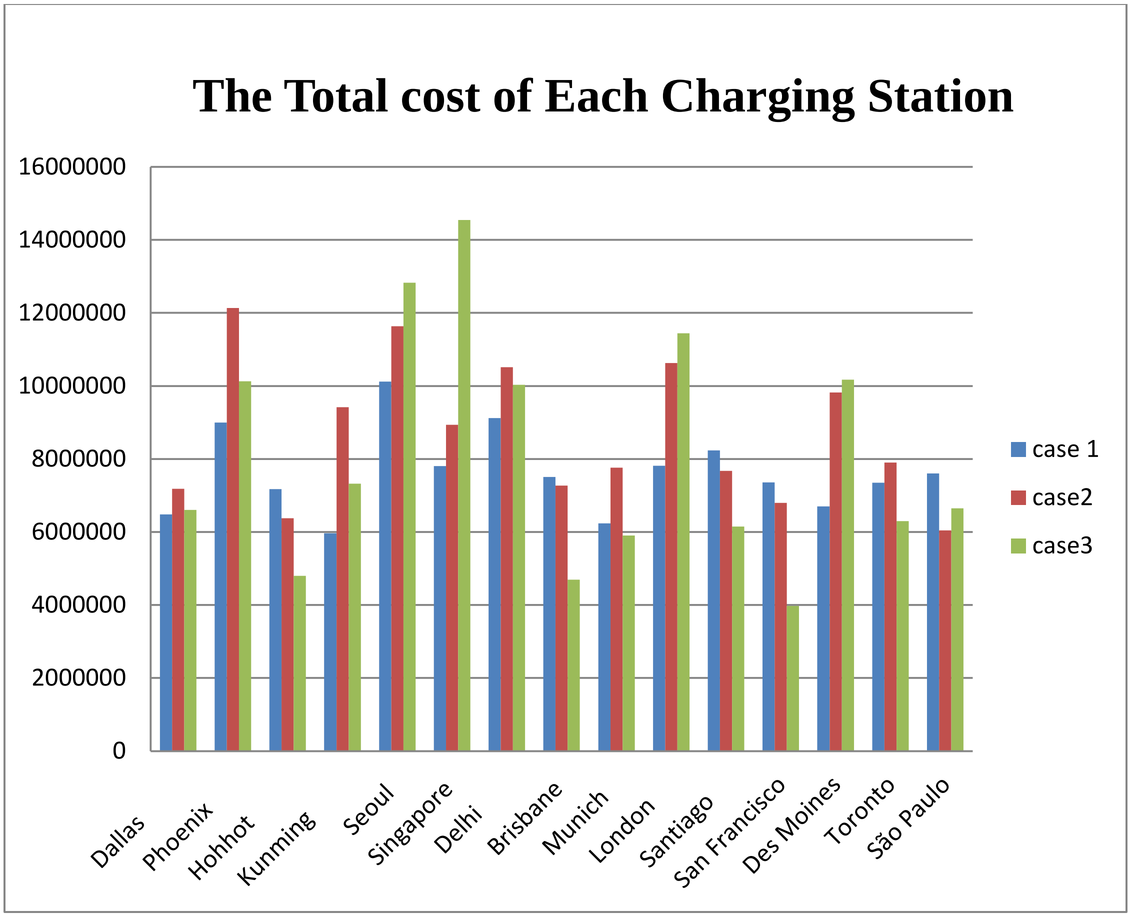


Fig 22: The Total Cost of Charging Stations

Note, Case I: The total cost of charging station powered by wind generator

Case II: The total cost of charging station powered by solar and wind generators

Case III: The total cost of charging station powered by solar and wind generators with storage battery system

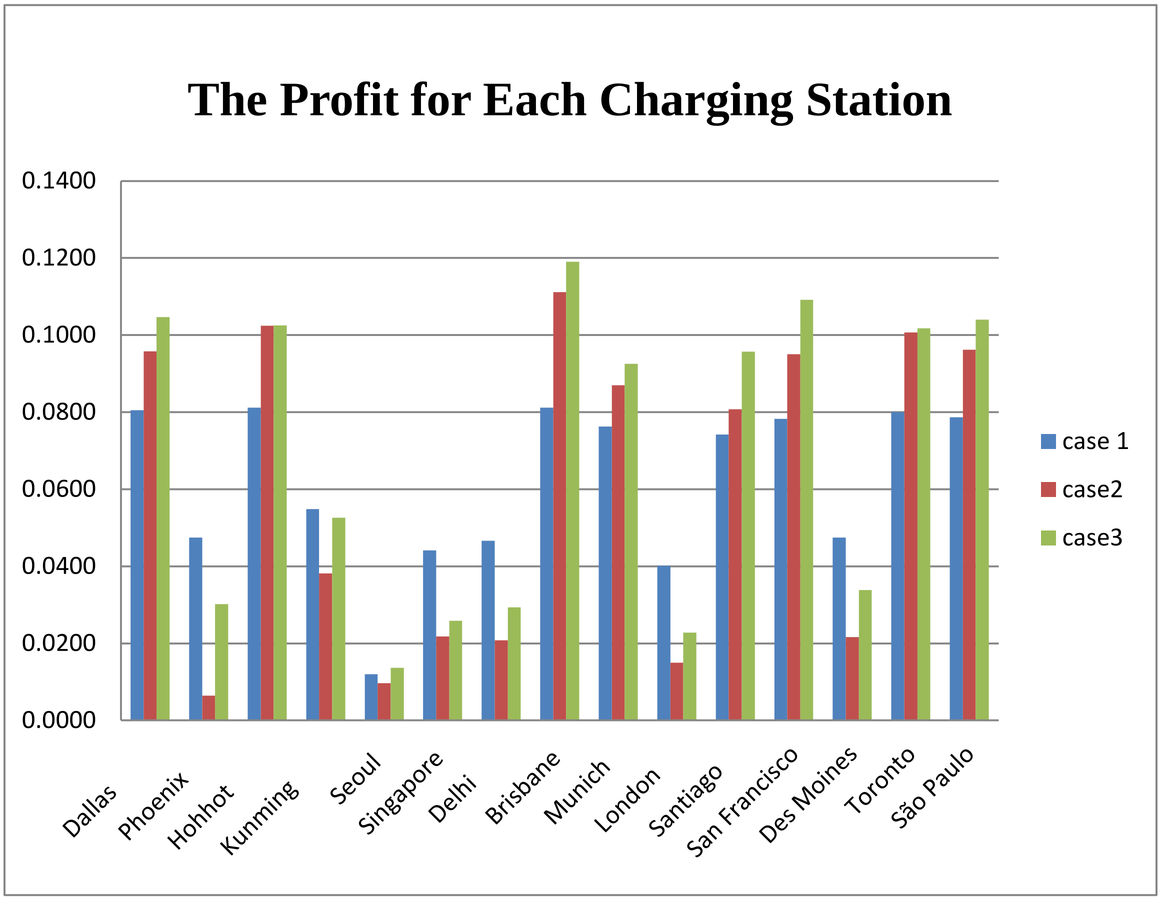


Fig 23: The Profit of Every Kilowatt Hour

Note, Case I: The profit per Kilowatt hour generated by wind generator

Case II: The total profit per Kilowatt hour generated by solar and wind generators

Case III: The total profit per Kilowatt hour generated by solar and wind generators with storage battery system

5.5 Chapter Summary

In this chapter, the simulation results illustrate that a power station can be powered by the renewable generation. There is no cost analysis just only powered by onsite solar PV generator, because the installation cost of wind energy is less than PV 2-4 times and the area occupied by solar planes is too large. So only using solar generator as power source for charging stations is not considered in this paper. With the technology development, the PV equipment cost declining and its efficiency increasing, the charging station only powered by the solar energy would be economically viable and competitive. I would use CPV instead of RPV to simulate the levelized cost as my future job.

# CHAPTER VI

# CONCLUSION AND FUTURE WORK

## 6.1 Conclusion

This research project addresses the design issues pertaining to building charging stations by integrating wind and solar power. In particular, a charging infrastructure is designed to maximize the income to the charging station owner through onsite wind and solar generation. The simulation results demonstrate that public charging stations can be powered by 100 percent of onsite wind and solar energy resources so as to attain net-zero carbon emission. The profitability of the charging stations depends on the weather condition of location during the 20 year operating time.

The main challenge for deployment of EV fleets is the limited driving ranges on board and longer charging time. In recent years, both the capacity of battery packs and the energy density continue to advance, so most of today's EVs can drive more than 100 miles with one single charge. In fact the 85 KWh Model S is able to run 270 mile with no additional charge. The maximum output power of charger also increases and reaches as high as 250 KW, like Tesla supercharger. As such the charging time can be significantly reduced.

The solution to growing fleet of EVs should involve the roll-out of a network public charging stations. The customers can drive their cars between cities without any limitation to the size of battery capacity. Tesla supercharger is the good sample for taking the initiatives of such a charging network development. It is the goal of Tesla to let drivers at the U.S. and Europe for free use of the company's supercharger network.

With the increasing capacity of battery, building suitable and system-wide charging stations are the necessary factor to eliminate customers' misgivings to buy EV and also achieve the "real green" target through the proliferation of electric transportation. Hence building charging stations powered by renewable energy sources allows us to attain net-zero carbon emission and gain the energy independence from fossil fuels.

## 6.2 The Future Work

### 6.2.1 The Smart Grid

The wind speed and the solar irradiance are the key parameters that determine the output of renewables generation for local WT and PV equipment. Geographical region decides the wind speed, and the weather condition controls the solar radiation. The smart grid will be achieved by offering differential pricing for electricity to encourage consumption to be switched from periods of high demand to periods of low demand based on the variable power generation. When the battery packs of a charging station need to be charged or the electricity produced by the onsite generation cannot meet demand, the system can draw the electricity from main grid by choosing low price period.

### 6.2.2 Charging Station to Grid Energy Transfer

We have known that vehicle-to-grid (V2G) transfers the energy drawn from the batteries of EVs to the utility grid during the hours of peak demand and returning the energy back the vehicle during period of low demand off-peak time.

The graph below shows the total California load profile for a hot day in 1999. The daytime load is doubled between 14 and 18PM compared to the off-peak period of 2-5AM.

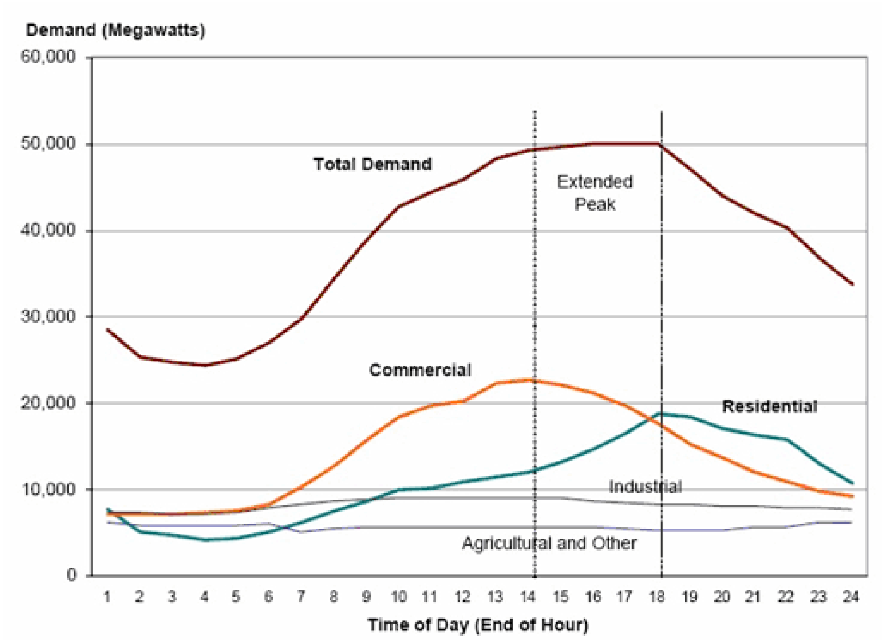


Fig 24: Demand Electricity in California (Battery and Energy Technology2014).

According to V2G concept, future study will investigate another interesting topic, namely, charging stations to grid. If a charging station has the capable bi-directional power transfer, it would sell the electricity stored in battery packs to the utility grid during peak period or draw energy from grid during low demand. This capability would not only improve the grid stability, but also increases the net income of charging stations.

6.2.3 Form a Network Public Charging Stations

The construction of charging stations shall not be confined to the cities, rather the infrastructure needs to be extended to less populated areas. In order to reduce the concerns of charge station availability, the EVs' manufactures and policy makers should consider setting up a larger network of public charging stations. Using the smart phone installed APP can easy find and access to any charging station for EV drivers. The final goal is to build a networked public charging station around the highway and across the nations.

The graph shows the goal of Tesla supercharger stations in 2016. The distribution would make the owners of Tesla to have a long trip using their EVs.

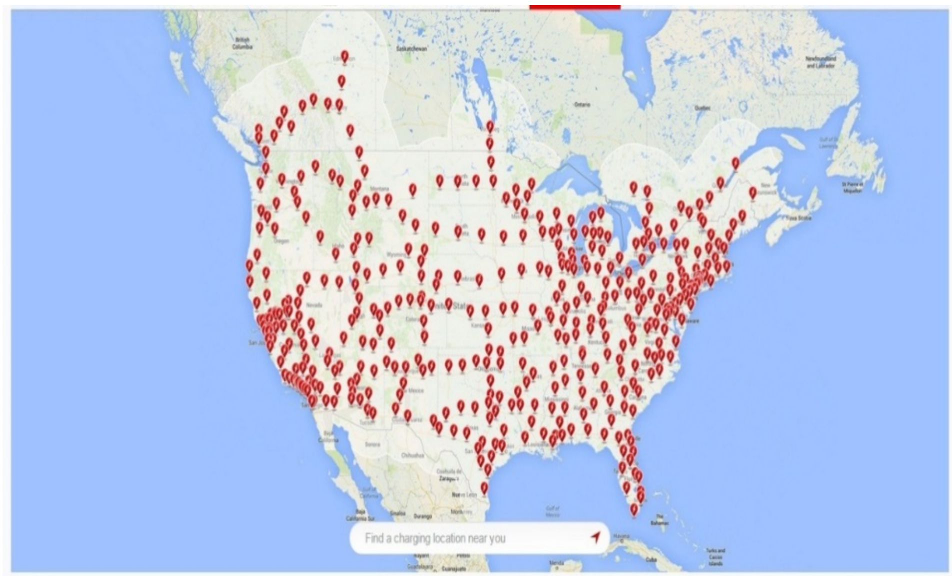


Fig 25: Tesla Supercharger Stations Distribution (Tesla 2015)

6.2.4 Provide Battery Swapping Service at Station

Since level 3 DC charging can lead to battery degradation, charging stations should consider providing another option to charging their EVs- battery swap (Mak et al. 2013). It would quickly provide the electricity by exchanging the empty battery with a pre-charged battery in 3-5 minutes. It also can improve the efficiency of using renewable energy. When the wind blow hard or the sun’s radiation is strong, a large amount of batteries can be fully charged in advance prior to the arrival of the swapping requests. Charging station would save the cost in buying battery packs to storage electricity and directly storage energy into swap’s batteries. Optimization models and strategic allocations of swapping facilities would be as my future academic research direction.

### 6.2.5 Adopt the Standard Charging Equipment and Protocols

The charging devices used in public places must have the ability to adapt to various types of battery systems and various voltage levels. A variety of voltage levels coexist in today's market, the charging system needs to have the capability of charging various types of EV battery systems at different voltage levels. Thus, at the beginning of commercialization of public charging stations and swap stations, they should use the standard chargers to meet different EVs.

## APPENDIX SECTION

The data for Fig 12 Observed and Simulated Wind Speed of Dallas by Time Series and Weibull Model.

| Day | Hr | Ob | TS | WB | Day | Hr | Ob | time series | WB | Day | Hr | Ob | TS | WB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 1 | 13 | | 11.7 | 14 | 1 | 14 | 18.2 | 11.0 | 15 | 1 | 12 | 7.8 | 22.3 |
| | 2 | 9 | 13.0 | 16.7 | | 2 | 18 | 15.2 | 19.3 | | 2 | 8 | 10.7 | 15.2 |
| | 3 | 12 | 10.2 | 18.8 | | 3 | 15 | 17.2 | 10.4 | | 3 | 7 | 8.8 | 21.5 |
| | 4 | 12 | 11.5 | 21.3 | | 4 | 13 | 15.7 | 12.0 | | 4 | 7 | 7.5 | 13.6 |
| | 5 | 12 | 11.8 | 10.6 | | 5 | 14 | 13.8 | 12.4 | | 5 | 9 | 7.2 | 25.9 |
| | 6 | 10 | 12.0 | 13.0 | | 6 | 13 | 13.9 | 14.0 | | 6 | 10 | 8.4 | 17.6 |
| | 7 | 10 | 10.6 | 23.0 | | 7 | 14 | 13.3 | 13.2 | | 7 | 10 | 9.5 | 13.9 |
| | 8 | 7 | 10.2 | 9.7 | | 8 | 15 | 13.8 | 18.0 | | 8 | 7 | 9.9 | 20.8 |
| | 9 | 8 | 8.0 | 14.5 | | 9 | 14 | 14.6 | 11.8 | | 9 | 10 | 7.9 | 24.7 |
| | 10 | 9 | 8.0 | 10.5 | | 10 | 14 | 14.2 | 22.7 | | 10 | 17 | 9.4 | 22.7 |
| | 11 | 13 | 8.7 | 16.2 | | 11 | 18 | 14.1 | 13.9 | | 11 | 16 | 14.7 | 11.3 |
| | 12 | 12 | 11.7 | 8.1 | | 12 | 13 | 16.8 | 19.7 | | 12 | 10 | 15.6 | 17.1 |
| | 13 | 13 | 11.9 | 20.4 | | 13 | 15 | 14.1 | 13.6 | | 13 | 15 | 11.7 | 20.4 |
| | 14 | 15 | 12.7 | 20.7 | | 14 | 15 | 14.7 | 20.2 | | 14 | 15 | 14.0 | 14.2 |
| | 15 | 14 | 14.3 | 25.3 | | 15 | 10 | 14.9 | 23.3 | | 15 | 15 | 14.7 | 17.7 |
| | 16 | 16 | 14.1 | 20.6 | | 16 | 21 | 11.5 | 13.2 | | 16 | 14 | 14.9 | 13.3 |
| | 17 | 16 | 15.4 | 18.7 | | 17 | 16 | 18.1 | 18.0 | | 17 | 17 | 14.3 | 13.1 |
| | 18 | 12 | 15.8 | 9.4 | | 18 | 13 | 16.6 | 25.0 | | 18 | 14 | 16.2 | 10.5 |
| | 19 | 14 | 13.1 | 9.5 | | 19 | 9 | 14.1 | 24.0 | | 19 | 12 | 14.7 | 19.4 |
| | 20 | 15 | 13.7 | 11.9 | | 20 | 7 | 10.5 | 22.1 | | 20 | 9 | 12.8 | 19.1 |
| | 21 | 13 | 14.6 | 9.2 | | 21 | 6 | 8.1 | 13.3 | | 21 | 5 | 10.1 | 23.7 |
| | 22 | 17 | 13.5 | 22.7 | | 22 | 5 | 6.6 | 17.7 | | 22 | 5 | 6.5 | 9.8 |
| | 23 | 23 | 15.9 | 21.7 | | 23 | 8 | 5.5 | 9.0 | | 23 | 13 | 5.5 | 13.1 |
| | 24 | 17 | 20.9 | 22.2 | | 24 | 8 | 7.2 | 22.9 | | 24 | 13 | 10.7 | 21.1 |

Note, OB=Observed;
TS= Time Series;
WB= Weibull.

The data for Fig 13 Observed and Simulated Weather Condition of Hohhot by Time Series Model.

| Year | Month | Observed | Predicated |
|---|---|---|---|
| 2012 | 1 | 30 | |
| | 2 | 29 | 30.0 |
| | 3 | 21 | 29.3 |
| | 4 | 27 | 23.5 |
| | 5 | 20 | 25.9 |
| | 6 | 13 | 21.8 |
| | 7 | 18 | 15.6 |
| | 8 | 17 | 17.3 |
| | 9 | 17 | 17.1 |
| | 10 | 24 | 17.0 |
| | 11 | 23 | 21.9 |
| | 12 | 21 | 22.7 |
| 2013 | 1 | 29 | 21.5 |
| | 2 | 28 | 26.8 |
| | 3 | 30 | 27.6 |
| | 4 | 25 | 29.3 |
| | 5 | 24 | 26.3 |
| | 6 | 9 | 24.7 |
| | 7 | 12 | 13.7 |
| | 8 | 19 | 12.5 |
| | 9 | 22 | 17.1 |
| | 10 | 28 | 20.5 |
| | 11 | 25 | 25.8 |
| 2014 | 12 | 29 | 25.2 |
| | 1 | 27 | 27.9 |
| | 2 | 27 | 27.3 |
| | 3 | 30 | 27.1 |
| | 4 | 25 | 29.1 |
| | 5 | 24 | 26.2 |
| | 6 | 9 | 24.7 |
| | 7 | 14 | 13.7 |
| | 8 | 16 | 13.9 |
| | 9 | 22 | 15.4 |
| | 10 | 27 | 20.0 |
| | 11 | 24 | 24.9 |
| | 12 | 29 | 24.3 |

The data for Fig 22 and 23 the total cost and the profit of each locations.

| No | locations | Case1 | | Case2 | | Case3 | |
|---|---|---|---|---|---|---|---|
| | | total cost_$ | Profit_$ /KWh | total cost_$ | Profit _$/KWh | total cost_$ | Profit _$/KWh |
| 1 | Dallas | 6482372 | 0.0805 | 7187025 | 0.0958 | 6604936 | 0.1047 |
| 2 | Phoenix | 8996667 | 0.0475 | 12139202 | 0.0064 | 10123968 | 0.0302 |
| 3 | Hohhot | 7173660 | 0.0812 | 6375584 | 0.1024 | 4799872 | 0.1025 |
| 4 | Kunming | 5968128 | 0.0549 | 9414075 | 0.0381 | 7324777 | 0.0526 |
| 5 | Seoul | 10120742 | 0.0120 | 11632541 | 0.0097 | 12823935 | 0.0137 |
| 6 | Singapore | 7807415 | 0.0441 | 8933397 | 0.0218 | 14547777 | 0.0259 |
| 7 | Delhi | 9120742 | 0.0466 | 10517873 | 0.0208 | 10034153 | 0.0293 |
| 8 | Brisbane | 7511761 | 0.0812 | 7267278 | 0.1111 | 4691038 | 0.1191 |
| 9 | Munich | 6239905 | 0.0763 | 7761483 | 0.0870 | 5903182 | 0.0926 |
| 10 | London | 7815954 | 0.0401 | 10629540 | 0.0150 | 11443702 | 0.0228 |
| 11 | Santiago | 8236375 | 0.0742 | 7674181 | 0.0808 | 6149527 | 0.0957 |
| 12 | San Francisco | 7355768 | 0.0783 | 6795609 | 0.0951 | 3977905 | 0.1092 |
| 13 | Des Moines | 6700108 | 0.0475 | 9818306 | 0.0216 | 10169905 | 0.0338 |
| 14 | Toronto | 7348532 | 0.0800 | 7899324 | 0.1007 | 6299208 | 0.1017 |
| 15 | São Paulo | 7607427 | 0.0787 | 6040090 | 0.0962 | 6648858 | 0.1040 |

# REFERENCES


American Energy Independence (2014). “American Fuels”. Retrieved from http://www.americanenergyindependence.com/fuels.aspx (accessed on Sep.20, 2015)

American Council on Renewable Energy (ACORE),(2014) “The Outlook for Renewable Energy in America”. ACORE Washington,U.S.

Bailey, J., Charging While You Work A Guide for Expanding Electric Vehicle Infrastructure at the Workplace. Published December 2012 by the Minnesota Pollution Control Agency Control Agency

Bandyopadhyay, A., Wang, L., Devabhaktuni, V. K., Yang, R., Green, R. C. (2012). Assessing the Effect of Fast Charging on the Battery Health of Plug-in Hybrid Electric Vehicles. In IEEE Power and Energy Society General Meeting, pp. 1-8.

Battery and Energy Technology (2014). “Electricity Demand” Retrieved from http://www.mpoweruk.com/electricity_demand.htm#v2g (accessed on Sep.20, 2014)

Battery University (2015). “Electric Vehicle” Retrieved from http://batteryuniversity.com/learn/article/electric_vehicle (accessed on February 12, 2015).

Bertani, R. (2007), "World Geothermal Generation in 2007", Geo-Heat Centre Quarterly Bulletin (Klamath Falls, Oregon: Oregon Institute of Technology), vol. 28, no. 3, pp. 8-19.

Billinton, R., Chen, H., & Ghajar, R. (1996). Time-series models for reliability evaluation of power systems including wind energy. Microelectronics Reliability, 36(9), 1253-1261.

Bioenergy (2007). Potential Contribution of Bioenergy to the World’s Future Energy demand. IEA Bioenergy: ExCo, 2.

Boland J.W. (2008). Time Series and Statistical Modeling of Solar Radiation, Recent Advances in Solar Radiation Modeling, ViorelBadescu (ED), Springer-Verlag, pp.283-312.

Box, J., Jenkins, G. M. (1994). Reinsel. Time Series Analysis, Forecasting and Control.

Bull, S. R. (2001). Renewable Energy Today and Tomorrow. Proceedings of the IEEE, 89(8), 1216-1226.

Burgess, J. (2012). Global Wind Energy Outlook: The Future of the Wind Industry. Retrieved from http://oilprice.com/Latest-Energy-News/World-News/Global-Wind-Energy-Outlook-The-Future-of-the-Wind-Industry.html# (accessed on Sep.18, 2014)

Center for Solar Energy Research and Applications. (2014). "How Does PV work" Retrieved from http://gunam.metu.edu.tr/index.php/solar-technology/pv-working-principles (assessed on Sep 21,2014).

Chang, D., Erstad, D., Lin, E., Rice, A. F., Goh, C. T., Tsao, A. A., Snyder, J. (2012). Financial Viability of Non-Residential Electric Vehicle Charging Stations. Luskin Center for Innovation: Los Angeles, CA, USA.

Chargepoint (2011). "Coulomb Technologies Announces Largest Electric Vehicle Workplace Charging Installation at Google, Inc". Retrieved from http://www.chargepoint.com/press-releases/2011/0609 (accesssed on Oct 21,2014)

Chen, J. C., Duan, W., Ye, F. (2011). Research on the Methods Estimating Weibull Distribution Parameters. Machinery Design & Manufacture, 18, 73-74.

Defense Industry Daily (DID) (2006). Received from: http://www.defenseindustrydaily.com/boeings-solar-subsidiary-adds-california-contract-02563/ (accessed on Sep 21,2014)

Electropaedia (2014). "Electric Vehicle Charging Infrastructure". Retrieved from http://www.mpoweruk.com/infrastructure.htm (accessed on Aug 2, 2014).

EVADC (2014). http Retrieved from://evadc.org/charging/ (accessed on Sep 5,2014).

Gordon-Bloomfield, N. (2014). Transportevolved: "It's Official: Electric Car Sales Have Doubled Every Year For Three Years" Retrieved from https://transportevolved.com/2014/04/16/number-electric-cars-world-doubled-past-year-say-academics/#comments n-selected-countries(accessed on Dec20, 2014)

International Energy Agency (IEA), ( 2012) .World Energy Outlook 2012. Paris.

International energy Agency (IEA) (2010). "Solar PV Price Competitiveness and Growth Pathway, 2000-2050" Retrieved from https://www.iea.org/media/freepublications/technologyroadmaps/solar/Solarpv_roadmap_foldout_2010.pdf (accessed on May 7, 2014).

Ivanovic, J. (2012). Electric Vehicle Technology Explained. p63. John Wiley & Sons, 2nd Edition, city of the publisher, the name of the state, name of the country

Janet, S., Eric, M. (2011). Renewable 2011 Global Status Report Renewables 2011 Global Status Report. Institute for Sustainable Enegy Policies and World Watch Institute, 1-116.

Jangamshetti, S. H., Rau, V. G. (2001). Normalized Power Curves as A Tool for Identification of Optimum Wind Turbine Generator Parameters. IEEE Transactions on Energy Conversion, vol. 16, no. 3, pp. 283-288.

Jin, T., Tian, Z. (2010) "Uncertainty Analysis for Wind Energy Production with Dynamic Power Curves." Probabilistic Methods Applied to Power Systems (PMAPS), In Proceedings of 2010 IEEE 11th International Conference on Probabilistic Methods Applied to Power Systems, pp. 745-750.

Jin, T., Jimenez, J., Tian, Z. (2013). "Managing Demand Response for Manufacturing Enterprises via Renewable Energy Integration." IEEE International Conference on Automation Science and Engineering (CASE), pp. 645-650.

Khaligh, A., Onar, O. C. (2009). Energy harvesting: solar, wind, and ocean energy conversion systems. CRC press.

Kirsch, D. A. (2000). The Electric Vehicle and the Burden of History. Rutgers Univ. Press, New Brunswick, NJ (2000)

Lave, M., Kleissl, J. (2011). Optimum fixed orientations and benefits of tracking for capturing solar radiation in the continental United States. Renewable Energy, 36(3), 1145-1152.

Lynd, L. R. (1996). Overview and Evaluation of Fuel Ethanol from Cellulosic Biomass: Technology, Economics, the Environment, and Policy. Annual Review of Energy and the Environment, 21(1), 403-465.

Mak, H. Y., Rong, Y., Shen, Z. J. M. (2013).Infrastructure Planning for Electric Vehicles with Battery Swapping. Management Science, 59(7), 1557-1575.

Matulka,R. (2014)."The History of Electric Vehicle" U.S. Department of Energy. Retrieved from http://energy.gov/articles/history-electric-car (accessed on Oct 2, 2014)

Meyers, C. B. (2013, December 09). "Type of Wind Turbines "Centurion Energy. Retrieved from http://centurionenergy.net/types-of-wind-turbines (accessed on June 7, 2014).

Motavalli, J. (2012). "Tesla Begins East Coast Fast-Charging Corridor" The New York Times. Retrieved from http://wheels.blogs.nytimes.com/2012/12/21/tesla-begins-east-cost-fast-charging-corridor/?_r=0 (accessed on Nov 11, 2014)

National Weather Service (2014). Retrieved from: http://w1.weather.gov/data/obhistory/KDAL.html (accessed on Dec5 11, 2014)

Navigant Research (2013). “Nearly 64,000 Public Charging Stations for Electric Vehicles Have Been Installed Worldwide” Retrieved from http://www.navigantresearch.com/newsroom/nearly-64000-public-charging-stations-for-electric-vehicles-have-been-installed-worldwide (accessed on Aug 7, 2014)

Newnan, D. G. (2004). Engineering economic analysis (Vol. 2). Oxford University Press.

Nishi, Y. (2001). The Development of Lithium ion Secondary Batteries. The Chemical Record, *1*(5), 406-413.

Nissan-Global Technology (2014). Retrieved from http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/leaf.html (accessed on Aug 15,2014)

Novoa, C., Jin, T. (2011). Reliability Centered Planning for Distributed Generation Considering Wind Power Volatilities. Electronic Power Systems Research, 81(8), 1654-1661.

Obama, B. (2011). President’s state of the Union address. Speech Retrieved from http://www. npr. org/2011/01/26/133224933/transcript-obamas-state-of-union-address (accessed on Aug 20,2014)

Pernick, R., Wilder, C., Winnie, T., Sosnovec, S. (2011). “Clean energy trends”

Pinto, M. (2011). Global Biofuels Outlook 2010-2020. Hart Energy, Rotterdam, Holland.

Quick, D. (2010).”Honda's gas station V2.0 – solar-powered public EV charging station part of Japanese trial”. Gizmag. Retrieved from http://www.gizmag.com/honda-solar-powered-ev-charging-station/17326/ (accessed on Aug 20, 2014)

REN21 (2011). Renewables 2011: Global Status Report. Paris, France: REN21 Secretariat.

REN21 (2014). Renewables 2014: Global Status Report. Paris, France: REN21 Secretariat.

SAE International (2011). “SAE’s J1772 ‘combo connector’ for AC and DC charging advances with IEEE’s help,” Retrieved from http://ev.sae.org/article/10128(accessed on Aug 29, 2014)

Saidur, R., Islam, M. R., Rahim, N. A., Solangi, K. H. (2010). A Review on Global Wind Energy Policy. Renewable and Sustainable Energy Reviews, 14(7), 1744-1762.

Sanders, L., Lopez, S., Guzman, G., Jimenez, J., Jin, T. (2012, December). Simulation of a Green Wafer Fab Featuring Solar Photovoltaic Technology and Storage System in Proceedings of the Winter Simulation Conference (p. 200).Winter Simulation Conference.

Scott, W. (2011). Bright Hub Engineering. Retrieved from: http://brighthubengineering.com (accessed on Nov 29, 2014)

Sieminski, A. (2013). International energy outlook 2013. US Energy Information Administration (EIA) Report Number: DOE/EIA-0484.

Sheehan, J., Camobreco, V., Duffield, J., Graboski, M., Shapouri, H. (1998). Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus. Final report (No. NREL/SR--580-24089). National Renewable Energy Lab., Golden, CO (US).

Statista (2014). “Number of vehicles registered in the United States from 1990 to 2012 (in 1,000s,” http://www.statista.com/statistics/183505/number-of-vehicles-in-the-united-states-since-1990/ (accessed on Dec 3, 2014).

Statista (2014).Electric Car Production - Forecast for Selected Countries 2015”. Retrieved from http://www.statista.com/statistics/270537/forecast-for-electric-car-production-in-selected-countries/ (accessed on Aug 2,2014).

Taboada, H., Xiong, Z., Jin, T., Jimenez, J. (2012). Exploring a Solar Photovoltaic-Based Energy Solution for Green Manufacturing Industry. In Automation Science and Engineering (CASE), 2012 IEEE International Conference on (pp. 40-45). IEEE.

Taylor, M. (2013). “Renewable Energy Solutions”. Road traffic. Retrieved from http://www.wantinews.com/news-4915563-Recent-studies-have-shown-that-the-future-of-renewable-energy-in-transport-can-compete-with-fossil-fuels-a-low.html(accessed on Aug 29,2014).

Tesla Supercharger (2015). Retrieved from http://www.teslamotors.com/supercharger (accessed on Jan.2, 2015)

Tesla (2015). “409 Supercharger stations with 2,247 Superchargers” Retrieved from http://www.teslamotors.com/supercharger (accessed on Jan.2, 2015)

Trigg, T., Telleen, P., Boyd, R., Cuenot, F., D’Ambrosio, D., Gaghen, R., Wråke, M. (2013). Global EV outlook: Understanding the Electric Vehicle Landscape to 2020. IEA, Paris, France.

Villarreal, S., Jimenez, J. A., Jin, T., Cabrera-Rios, M. (2013). Designing A Sustainable and Distributed Generation System for Semiconductor Wafer Fabs. Automation Science and Engineering, IEEE Transactions on, 10(1), 16-26.

Weather underground(2015). Retrieved from: http://www.wunderground.com/(accessed on Jan.2, 2015)

Weatherbase (2015). Retrieved from http://www.weatherbase.com/weather/weather.php3?s=95227&cityname=Dallas-Texas-United-States-of-America/(accessed on Jan.2, 2015)

Webb, A. (2013). “San Diego Airport Runs Test on Portable Solar-Paneled EV Charging” Plugincars. Retrieved from http://www.plugincars.com/san-diego-airport-runs-test-portable-solar-paneled-ev-charging-128865.html (accesssed on Dec 14, 2014)

Xia, C., Song, Z., (2009). Wind Energy in China: Current Scenario and Future Perspectives. Renewable and Sustainable Energy Reviews, 13(8), 1966-1974.

Yilmaz, M., Krein, P. T. (2013). Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles. Power Electronics, IEEE Transactions on, 28(5), 2151-2169.

Yirka,B. (2013). “Worldwide Wind and Solar Power Capacity Grew in 2012”. Phys. Retrieved from http://phys.org/news/2013-02-worldwide-solar-power-capacity-grew.html (accesssed on Dec 20, 2014).