IPRO 311

Integration of Plug-in Hybrid Electric Vehicles and Renewable Energy Systems

Fall 2010

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Acknowledgements

Sincerest thanks to our faculty advisor, Dr. Alireza Khaligh of the Illinois Institute of Technology, Electrical and Computer Engineering Department, for his dedicated guidance and support throughout the IPRO 311 Project. Thank you to Illinois Institute of Technology, Electrical Engineering PhD candidate, Seshadri Raghavan for his guidance and support throughout the IPRO 311 Project. Thank you to the Illinois Institute of Technology for providing and supporting the Interprofessional Projects Program and the IPRO 311 Project.

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I. Executive Summary

The United States has been searching for the past several decades for a way to reduce the country's dependence on foreign oil. In addition to political reasons, there is a practical necessity to reduce oil consumption simply because it is a finite energy resource. The energy crisis has been recently complicated by the fact that green-house gases are contributing to global warming and therefore drastic climate change. There is little doubt, even amongst the skeptics, that conventional methods for electrical energy production and use are no longer viable options for the World.

The energy conscious Obama administration has mandated that the Department of Energy utilize 20% wind energy generation by 2030 [7]. Wind farms consisting of numerous wind turbine generators will provide an electrical energy source that produces zero emissions, is a safe form of energy production, and utilizes a renewable source of energy. Wind power generation is therefore advantageous over coal generation which is inherently dirty, nuclear generation which has the stigma of being dangerous, and oil or gas generation which, like coal, relies on a finite resource.

Wind energy has inherent limitations. Natural patterns of the wind are unpredictable and inconsistent. Wind is not always present to excite wind driven electricity generators. The amount of electricity demand is similarly inconsistent. There are certain times or climate induced scenarios when electricity demand will be low or high. Typically, but not always, this demand trend can be approximated. The situation will inevitably occur, however, when wind energy will be plentiful but the electricity demand will be low. Conversely, the situation will occur when wind energy is scarce but the demand for electricity is high. These variations in supply and demand pose a complex problem for the practical adoption of wind energy as a viable source of power generation. A method or apparatus is needed for storing energy when supply is high but demand is low. Stored energy could therefore be utilized when the power generation supply cannot meet electricity demand.

The United States government is aiming to introduce over one million energy efficient plug-in hybrid electric vehicles (PHEVs) by 2015 [8]. PHEVs use onboard batteries to power the vehicle. Many scientists and engineers believe that the high-capacity onboard batteries could be used for energy storage and supply electricity to the power grid when power grid demand is highest.

The research project conducted and detailed within the following report has examined different power generation and demand scenarios with and without the utilization of PHEVs as energy storage. The in-depth analysis has suggested that wind energy, coupled with plug-in hybrid electric vehicle energy storage could reduce the operational cost of energy production by up to 30%. These findings indicate that further research into alternative forms of energy storage and production would likely yield significant cost and energy savings.

II. Purpose and Objectives

The purpose of the research project is to investigate the economic effects of the integration of wind power generation systems and PHEVs. For wind generations it is important to investigate factors that impact the generation of wind, like location of the wind farm, speeds of wind in the specific location, type of turbine and its characteristics. In the case of PHEVs a significant research on driving habits, type of battery and its life will be pursued. The final goal of the research is to determine the effectiveness of the method on lowering the operational cost by analyzing various cases which introduce the use of PHEVs into the power generation system. The results obtained from the research will serve targeted markets including, but not limited to, automotive industry, wind power generation industry, and utility companies. The advancement of alternative energy technology will also benefit the environment.

III. Organization and Approach

A. Introduction

The problem of creating a basic model for the purpose of studying the effects of the integration of PHEVs and wind energy is split into four parts; wind energy, PHEVs, power generation costs, and creation of an objective function to minimize the operational cost of the model. These four parts are split up between the members of the group, who are responsible for researching their topic and reporting back to the team.

The first three parts require finding the necessary data regarding the topic. Analysis of how the data is to be used in the objective function, namely as a cost function or power curve, is determined. This determination requires deciding which variables are pertinent to the topic.

Conclusions for the initial three parts of the approach are used in the formulation of the objective function. The objective function is subsequently utilized to determine the effectiveness and feasibility of integration of PHEVs with wind energy.

B. Wind Energy

Wind is one of the most important renewable energies used to generate electric energy. Wind energy is clean, renewable, and a potentially cost efficient method for energy production. The American Wind Energy Association AWEA notes that “wind power is one of the fastest growing methods of electricity generation in the United States. Approximately 40 % of all new generation capacity contributing to the power grid in the United States was from wind power projects in the recent years." ("Utilities & Wind Energy") The U.S. Department of Energy's goal is to have 20% wind power generation by 2030. (20percentwind)

The downside of wind energy is that wind is typically intermittent. When wind is present, the laws of thermodynamics state that it is not possible to translate all the kinetic energy in wind into the same amount of electrical energy. Moreover, the implementation of more wind power to the grid will create storage problems. Wind will inevitably be available when electricity demand is low. Ideally, there would be a method or apparatus for storing the wind energy for use when electricity demand is low. PHEVs are a potential solution to the electrical energy storage problem.

When studying wind generation, it is important to take into account different variables such as, the speed of wind in a determined place, turbine location, and turbine characteristics. For the project's investigated system the above stated variables have been analyzed. The analysis of the problem has allowed for assumptions regarding some of the variables as constants to permit the simulation of a scenario to determine the feasibility of wind energy. The variables analyzed are described below.

1. *Wind turbine location determination:*

A wind map is a useful tool to locate the areas of the United States where the winds are the highest. This map bases its determination of particular areas on the wind's annual average speed and power. For the study of this particular research project, an urban area of Chicago, Illinois is the focus of the group research interest for the simulation.

Figure 1 shows the map of wind speeds at 80 meters above the ground level for Illinois. Chicago is indicated as the spot where the turbines are going to be sitting.

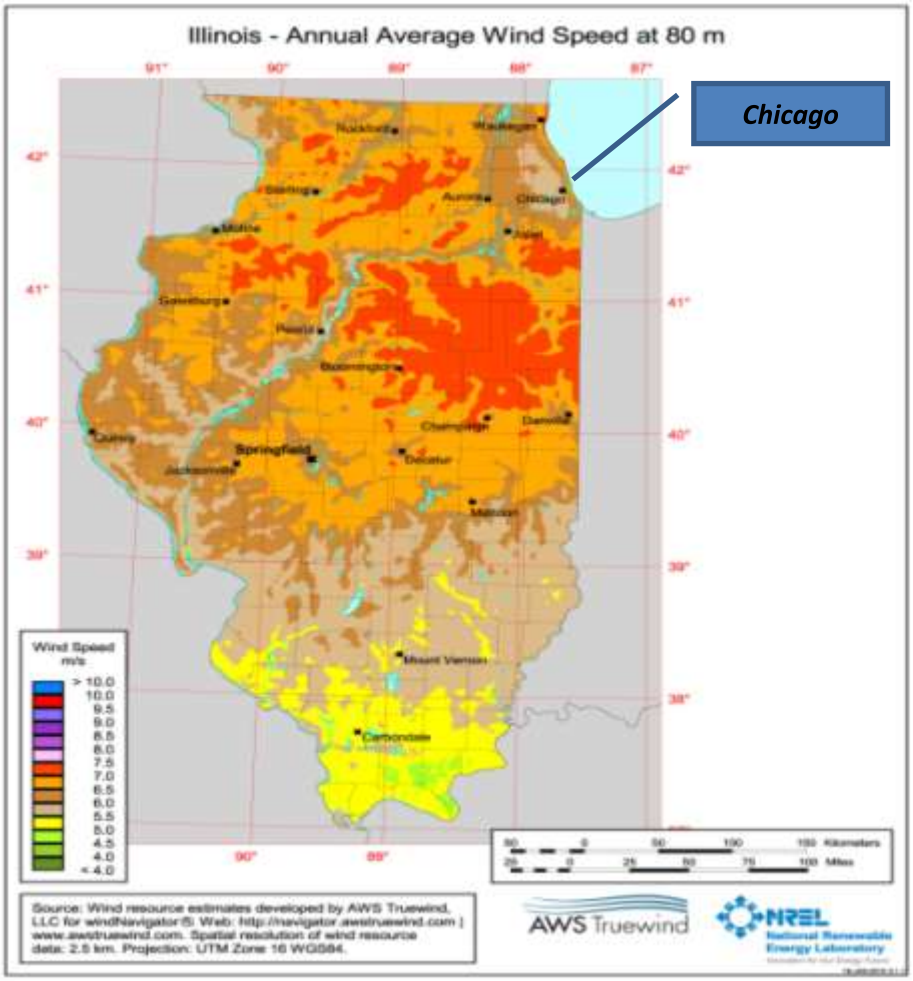


Figure 1: Wind map supplied by the U.S. Department of Energy

2. *Wind speed at each hour in the Chicago urban area.*

Having determined the location of a wind turbine, it is now possible to determine the friction coefficient and the roughness length which enables calculation of wind speed. The friction coefficient is a quantity that is used to quantify the resistance that an object imparts on wind flow. Obtaining the values of friction coefficient will allow for calculation of the wind speed at ground level. These values are taken into account when forecasting wind speeds. Since friction coefficient is already included in the forecast calculated data, it is not necessary for the research to obtain the friction coefficient value at this point. The research uses a 24 hour wind forecast to determine the wind speed per hour. The data will be considered for the months in which the winds are at their yearly average speeds. This speed forecast gives the speeds at ground level in the Chicago urban area.

Table 1 shows the wind speed forecasted values.

Table 1: 24 hour forecasted wind speeds.

Time	Wind Speed [mph]	Wind speed at ground level [m/s]
12am	8	3.576
1am	8	3.576
2am	8	3.576
3am	8	3.576
4am	8	3.576
5am	9	4.023
6am	9	4.023
7am	9	4.023
8am	9	4.023
9am	9	4.023
10am	8	3.576
11am	8	3.576
12pm	8	3.576
1pm	8	3.576
2pm	8	3.576
3pm	10	4.470
4pm	10	4.470
5pm	10	4.470
6pm	10	4.470
7pm	11	4.917
8pm	11	4.917
9pm	11	4.917
10pm	8	3.576
11pm	8	3.576
Average	***8.917***	***3.986***

The roughness length (z) [meters] depends on the terrain where the wind turbines are located. Roughness length is used to find hourly wind speed 80 meters above ground level. The values of roughness length are tabulated according to terrain conditions and roughness class. The terrain conditions are the characteristics of the various places where the turbines can be located. The roughness class is the rating of the terrain in ascending form. A value of zero is assigned to less rough terrain such as a water surface. A value of four is assigned the roughest terrain such as a dense urban area or forest. For the case of urban districts and farm lands with many windbreaks (obstacles) the roughness length is equal to 0.4 meters.

The equation to calculate the wind at a height above the ground level is shown below.

$$v = v_{ref} \frac{\ln \frac{z}{z_0}}{\ln \frac{z_{ref}}{z_0}}$$

Equation 1

Where,
v is wind speed at height z above ground level;
z is height above ground level for the desired velocity (v);
z_0 is roughness length in the current wind direction;
z_{ref} is the height where the exact wind speed, v_{ref}, is known.

Table 2 shows the values of wind speed at 80 meters above ground level.

Table 2: 24 hour wind speed values at 80 meters above ground level.

Time	Wind Speed [mph]	Wind speed at ground level [m/s]	V [m/s] @ 80 m above ground
12am	8	3.576	8.058
1am	8	3.576	8.058
2am	8	3.576	8.058
3am	8	3.576	8.058
4am	8	3.576	8.058
5am	9	4.023	9.066
6am	9	4.023	9.066
7am	9	4.023	9.066
8am	9	4.023	9.066
9am	9	4.023	9.066

10am	8	3.576	8.058
11am	8	3.576	8.058
12pm	8	3.576	8.058
1pm	8	3.576	8.058
2pm	8	3.576	8.058
3pm	10	4.470	10.073
4pm	10	4.470	10.073
5pm	10	4.470	10.073
6pm	10	4.470	10.073
7pm	11	4.917	11.080
8pm	11	4.917	11.080
9pm	11	4.917	11.080
10pm	8	3.576	8.058
11pm	8	3.576	8.058
Average	***8.917***	***3.986***	***8.982***

3. Turbine selection & output power:

The Vestas V90 wind turbine is selected for research analysis. The performance, mechanical, and physical characteristics are listed in the table below.

Table 3: Vestas V90 wind turbine characteristics.

Model	Capacity [MW]	Blade Length [m]	Hub Height [m]	Total Height [m]	Area Swept by blades [m^2]	RPM Range	Maximum Blade Tip Speed [m/s]	Rated Wind Speed [m/s]
Vestas V90	1.8	45	80	125	6,362	8.8-14.9	70	11

The maximum power that wind can produce in a determined area depends on blade size of the turbine and density of air. Note that the values of maximum power do not take into account the losses incurred from transformation of kinetic energy to electrical energy.

Equation 2 shows the maximum wind power equation.

$$P_{total} = \frac{1}{2} \cdot \rho \cdot R^2 \cdot \pi \cdot v_b^3$$

Equation 2

Where,
ρ is the air density;
R is the radius of the blades;
v_b are the wind speeds after and before passing through the turbine.

Wind turbines cannot absorb all the wind available in a certain location. Equation 3 calculates the turbine's captured power.

$$P_{total} = \frac{1}{2} \cdot \rho \cdot c_p \cdot R^2 \cdot \pi \cdot v_b^3$$

Equation 3

Where,
c_p is the power coefficient.

The power coefficient is the ratio of the electrical output power of the wind turbine to the total (potential) wind power. The values of the power coefficient depend on the type of turbine and are usually provided by turbine manufactures. For this specific case the power coefficient is 0.44

The turbine does not output more than is specified by the generator. Therefore, 1.8 MW is the maximum power that the turbine used for this case of study can provide. In order not to surpass this value most turbines have mechanisms which prevents excessive angular velocity thereby preventing mechanical failure of the turbine. One mechanism used is the pitch control which rotates around the turbines longitudinal axis of the blades to control the amount of wind energy captured.

The maximum power output for the simulation is set to 75 MW. 42 Vestas V90 turbines are required to produce 75 MW

$$\frac{75\ MW}{1.8\ \frac{MW}{turbine}} = 42\ turbines$$

Table 4 shows the maximum power, the captured power and the power produced by 42 turbines in a 24 hour window.

Table 4: Maximum power, captured power, and produced power by 42 turbines.

Time	Wind Speed [mph]	Wind speed at ground level [m/s]	V [m/s] @ 80 m above ground	P [MW]	Pcaptured [MW]	P output [MW]	nominal P @ 42 turb [MW]	Pcaptured @ 42 turbines [MW]
12am	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
1am	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
2am	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
3am	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
4am	8	3.576	8.058	2.041	0.898	0898	85.712	37.713
5am	9	4.023	9.066	2.906	1.279	1.279	122.039	53.697
6am	9	4.023	9.066	2.906	1.279	1.279	122.039	53.697
7am	9	4.023	9.066	2.906	1.279	1.279	122.039	53.697
8am	9	4.023	9.066	2.906	1.279	1.279	122.039	53.697
9am	9	4.023	9.066	2.906	1.279	1.279	122.039	53.697
10am	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
11am	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
12pm	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
1pm	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
2pm	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
3pm	10	4.470	10.073	3.986	1.754	1.754	167.406	73.659
4pm	10	4.470	10.073	3.986	1.754	1.754	167.406	73.659
5pm	10	4.470	10.073	3.986	1.754	1.754	167.406	73.659
6pm	10	4.470	10.073	3.986	1.754	1.754	167.406	73.659
7pm	11	4.917	11.080	5.305	2.334	1.800	222.818	75.600
8pm	11	4.917	11.080	5.305	2.334	1.800	222.818	75.600
9pm	11	4.917	11.080	5.305	2.334	1.800	222.818	75.600
10pm	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
11pm	8	3.576	8.058	2.041	0.898	0.898	85.712	37.713
Average	***8.917***	***3.986***	***8.982***	***2.953***	***1.299***	***1.233***	***124.034***	***51.770***

Figure 2 below shows the Power Output curve for 42 turbines outputting a maximum of 75 MW.

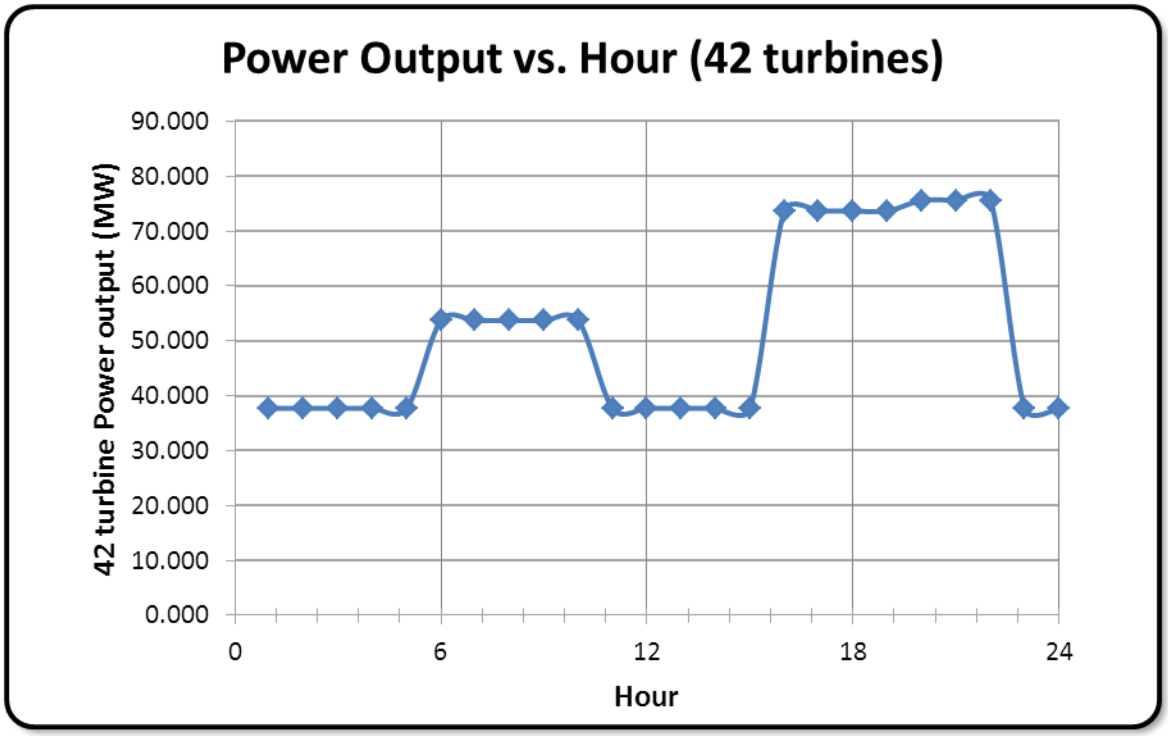


Figure 2: Power output vs. Hour for 42 turbines.

C. Plug-in Hybrid Electric Vehicles

A PHEV is a vehicle that uses both an internal combustion engine and an electric motor, which utilizes an externally or internally charged battery. The distance the battery can solely drive the car is referred to as the All Electric Range (AER). The type of car that is focused on in this project is termed PHEV40, which has an AER of forty (40) miles. Another type of PHEV is the PHEV20, which can drive the car solely on the battery for approximately twenty (20) miles. The PHEV40 will be used for the reasons listed below.

- There are statistics from the University of Michigan Transportation Research Institute (UMTRI) that show the average distance traveled per day for Americans is about 40 miles with a standard deviation of about 10 miles. [Khaligh]
- The current price for low-weight lithium ion batteries for use in PHEVs is relatively high: $400-700/kWh [1]. Therefore, the maximum battery pack size is limited, but this may change in the future as technology reduces battery cost.
    - Low weight batteries are preferred because the weight of the car has a great impact on the energy efficiency, and therefore, AER range of the vehicle.

A measure of the battery is its State of Charge (SOC), which is the percentage that the battery is charged. A battery cycle is defined as fully charging and discharging a battery, from its manufactured minimum SOC to maximum SOC. Batteries that go through too many cycles too often will have a reduced capacity and battery life. In order to increase the battery life, the usable SOC of the battery is limited to only half of its capacity. The model used in analysis is the Chevrolet Volt. Some specifications for the Chevrolet Volt are listed below [2]:

- Total battery size of 16 kWh
- SOC range of 0.3 to 0.85
- Battery energy range of 4.8 kWh to 13.6 kWh, which reflects the SOC range

The large size of the PHEVs battery allows it to be used as an energy storage system; when not in use, the PHEV can be used to feed energy back into the power grid. This interaction of the vehicle with the power grid called Vehicle to grid (V2G) technology. V2G used during peak grid demand hours can reduce the cost of the grid operations but will also increase the cycling rate of the battery, reducing its capacity and life.

The Chevrolet Volt is able to charge at two speeds; fast and slow. Fast charging occurs at 240V and takes 3 hours to charge the battery from minimum SOC to maximum SOC. Slow charging occurs at 120V and takes 8 hours to charge the battery. Slow charging is the charging rate assumed for analysis simulations.

In order to derive an objective function with which to optimize the operational cost of the integrated PHEV and wind energy system, it is necessary to come up with several scenarios describing PHEV charging times and times that the PHEV would utilize V2G. The scenarios are created assuming the fleet of PHEVs leave home charging stations and travel to work between the hours of 8:00 am and 10:00 am and return home between the hours of 5:00 pm and 7:00 pm. The scenarios are varied by assuming certain percentages of the fleet would have differing states of charge and are discharging or charging during different parts of the day. From these scenarios an hourly load curve is generated for the PHEVs. Using the PHEV's load curve, the objective function is used to simulate the associated operational costs.

D. Power System Operation Cost

The power system optimal operational cost is the least amount of cost used to create electrical power to satisfy the load demand in a specific time. The power system operational cost is different from one generator to the other generator based on the type and the efficiency of energy convergence.

To compare and find the best optimal operational cost, objective function is used. The objective function is a function that enables to find the optimum value (either largest or smallest) by comparing all possible situations. However, the objective function is only effective on a linear function.

In this case the objective function is used to find the minimum operational cost spent by operating 3 conventional generators and 42 wind generators (wind farm). It is assumed that there is no operational cost for wind generators because they are the renewable resources. The cost functions of each generators is given in a polynomial way; fG1 = c + b*X + a*X2 (the cost function for the 1st generator). In our case the coefficients of cost function, a, b, and c, are given but it can be obtained by analyzing the cost vs. time graph. The coefficients of cost function for generators are shown in Table 5.

Table 5: The coefficients of cost function for generators

Unit	a [$/MW^2]	b [$/MW]	c [$/h]	P_{min} [MW]	P_{max} [MW]
G1	0.099	6.589	211.4	100	320
G2	0.203	7.629	217.4	10	160
G3	0.494	10.07	102.8	10	100
Wind	0	0	0	37.7	75.6

At first, the power capacity should be divided as a certain value and the cost should be measured by each segments. In our case, we divided each segments by 20 MW power generations. We assumed all the generators are operating (never shutting down) so each generators are analyzed from the minimum power generations. The wind generators are not analyzed because of the assumption that there is no operational cost. The data is shown on the Table 6 below.

Secondly, using the data from the Table 6, it is possible to calculate the gradient on each segment Table 7. At last, linear cost function is obtained. For example, the cost function for the 1st generator can be re-written as $f_{G1} = 1860.3 + 28.369*X_{1,1} + 32.329*X_{1,2} + 36.289*X_{1,3} + 40.249*X_{1,4} + 44.209*X_{1,5} + 48.169*X_{1,6} + 52.129*X_{1,7} + 56.089*X_{1,8} + 60.049*X_{1,9} + 64.009*X_{1,10} + 67.969*X_{1,11}$. The code to find the minimum operational cost is attached on the appendix.

Table 6

Dispatch	Gen1	Gen2	Gen3
P1(MW)	100	10	10
F1($)	1860.3	313.99	252.9

P2(MW)	120	30	30
F2($)	2427.68	628.97	849.5
P3(MW)	140	50	50
F3($)	3074.26	1106.35	1841.3
P4(MW)	160	70	70
F4($)	3800.04	1746.13	3228.3
P5(MW)	180	90	90
F5($)	4605.02	2548.31	5010.5
P6(MW)	200	110	110
F6($)	5489.2	3512.89	7187.9
P7(MW)	220	130	
F7($)	6452.58	4639.87	
P8(MW)	240	150	
F8($)	7495.16	5929.25	
P9(MW)	260	170	
F9($)	8616.94	7381.03	
P10(MW)	280		
F10($)	9817.92		
P11(MW)	300		
F11($)	11098.1		
P12(MW)	320		
F12($)	12457.48		

Table 7

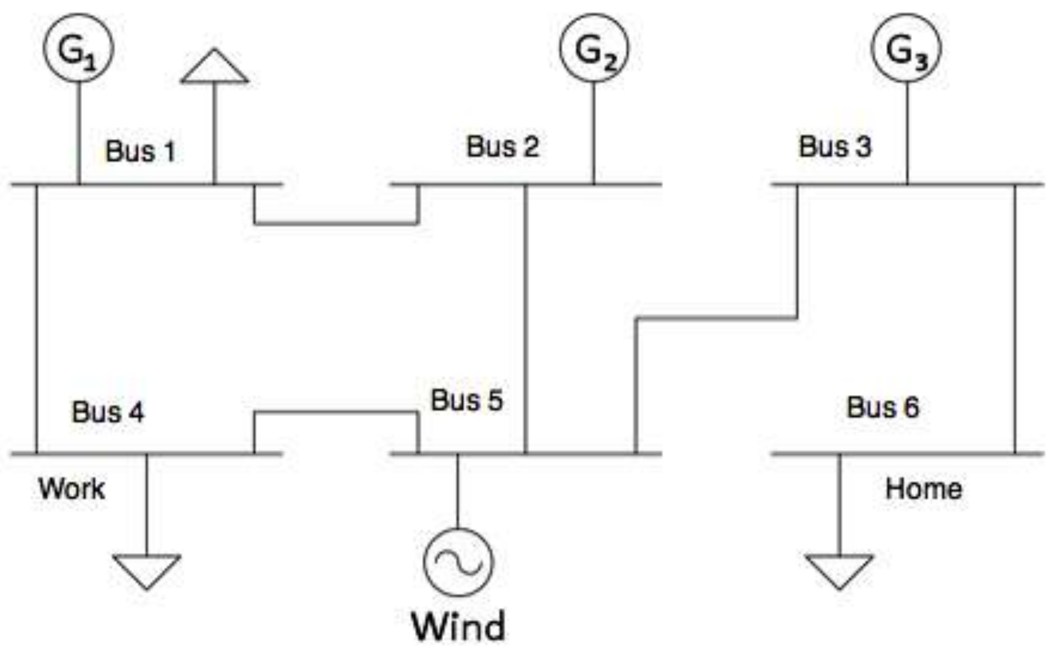
Segment	Gen1	Gen2	Gen3
1	28.369	15.749	29.83
2	32.329	23.869	49.59
3	36.289	31.989	69.35
4	40.249	40.109	89.11
5	44.209	48.229	108.87
6	48.169	56.349	
7	52.129	64.469	
8	56.089	72.589	
9	60.049		
10	64.009		

11	67.969		

IV. Analysis and Findings

The four cases that utilize PHEVs are labeled as Scenario 1, Scenario 2, Scenario 3, and Scenario 4. These scenarios were developed as a way to test the operational cost on the grid due to the introduction of PHEVs. The factors that affect the operational cost include the time of charging of the PHEVs and the time of V2G of the PHEVs. These PHEVs move around the six-bus system as fleets, with a total fleet size of ten thousand (10,000) units. We have designated bus 6 as the homes of the owners of the PHEVs and bus 4 as the workplace of the owners of the PHEVs. All cars stay at home at night, go to work in the afternoon, and come back home in the evening.

Throughout the research we analyzed 6 different scenarios to find the effectiveness of integrating wind energy and PHEV to the current system. All the scenarios are analyzed in a 6-bus system. The 6-bus system is the most commonly used system to simulate the real world. As you can see from the diagram below, we have 2 load bus, 2 generator bus, 1 wind generator & load bus, 1 generator & load bus. PHEV moves from one bus to the other bus. We assumed that there is no fault in the system, there is no transmission line loss, and there is no operational cost for wind power generation.



In this analysis, we are going to analyze the result in two ways. At first, we are going to observe how peak hour changes as wind energy and PHEV are integrated. Secondly, we are going to observe the total operational cost and find the best scenario based on it.

The first scenario is the 6 bus system that doesn't have any wind energy. We are investigating the following scenarios:

1. Scenario 1: No wind
2. Scenario 2: Only wind
3. Scenario 3: PHEVs, no V2G, and night G2V (grid-to-vehicle)

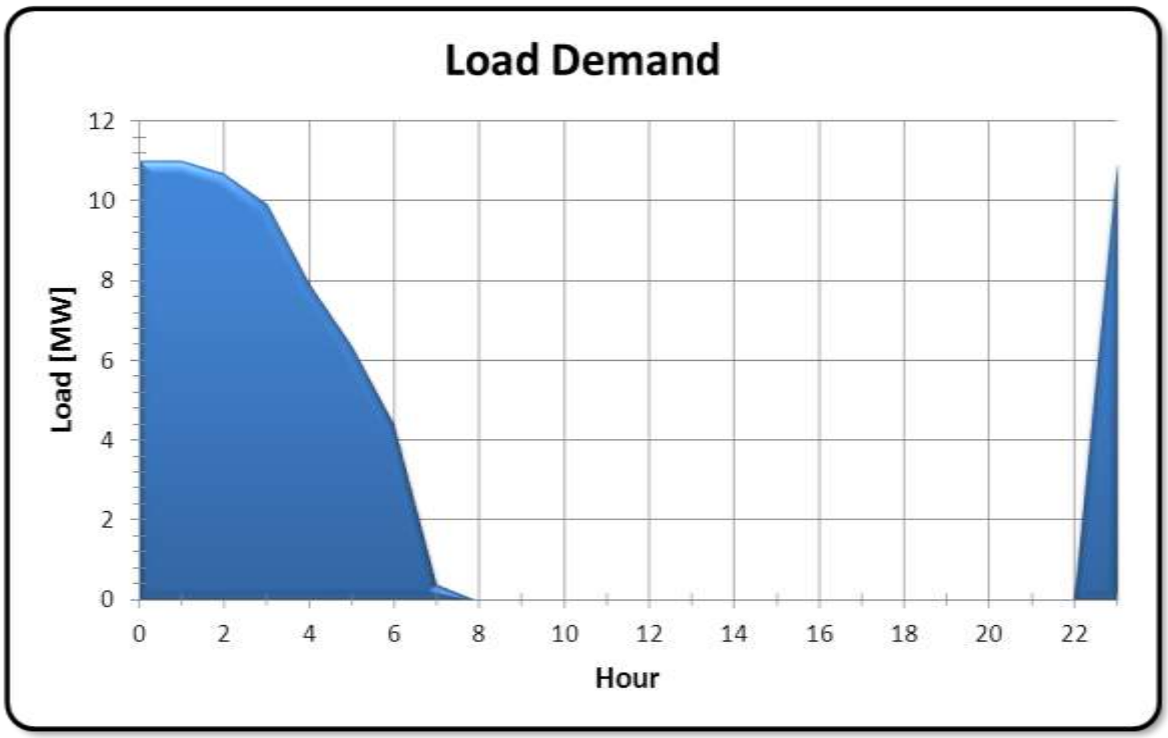


Figure 3 (Scenario 3 PHEV Load Demand)

4. Scenario 4: PHEVs, day time V2G, and night G2V

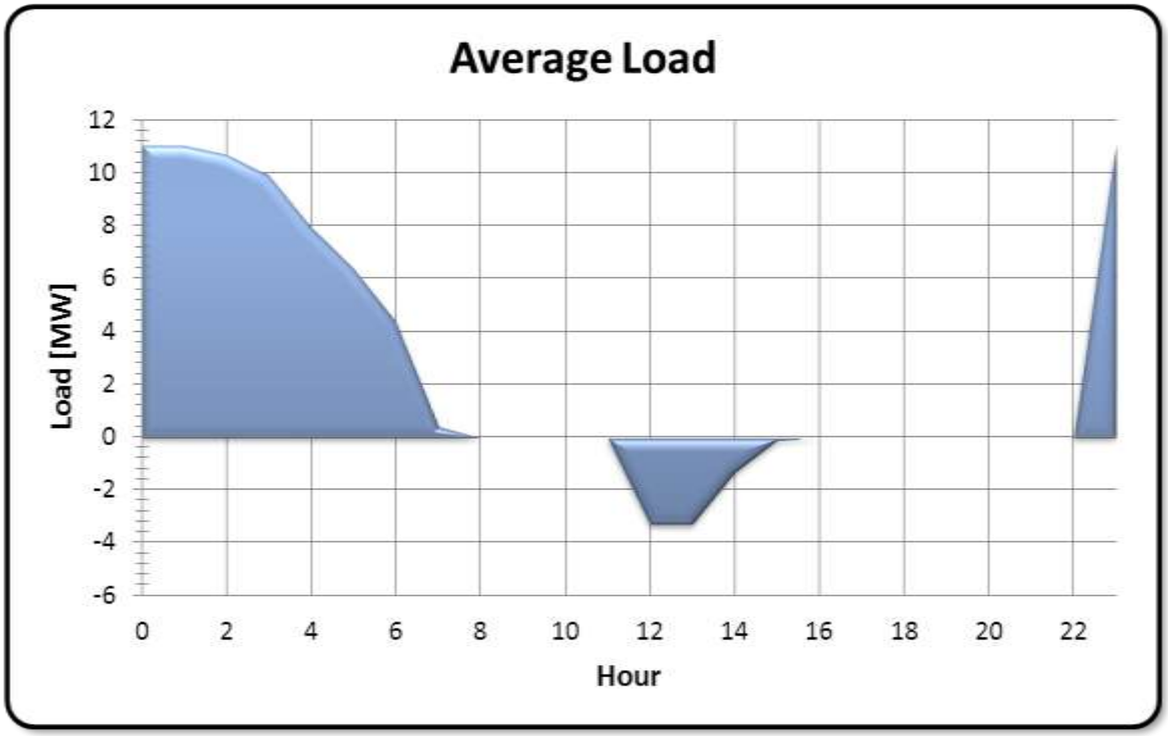


Figure 4 (Scenario 4 PHEV Load Demand)

5. Scenario 5: PHEVs, evening V2G, and night G2V

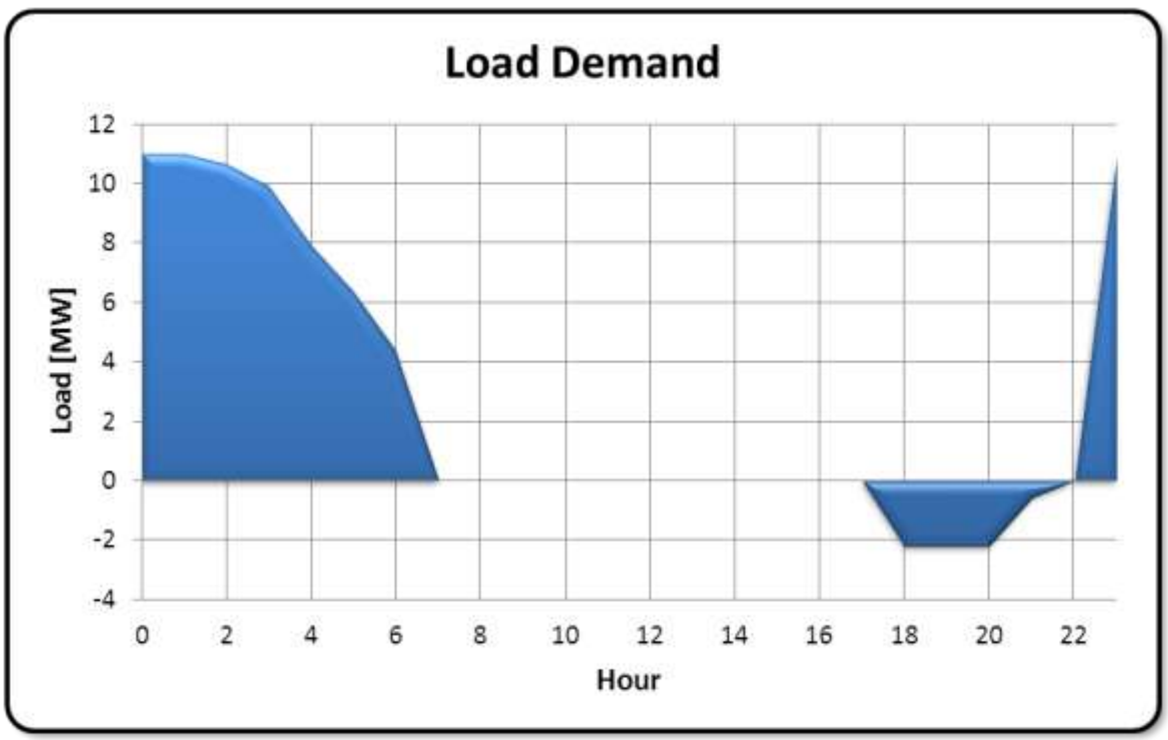


Figure 5 (Scenario 5 PHEV Load Demand)

Scenario 6: PHEVs, afternoon G2V, evening V2G, and night G2V

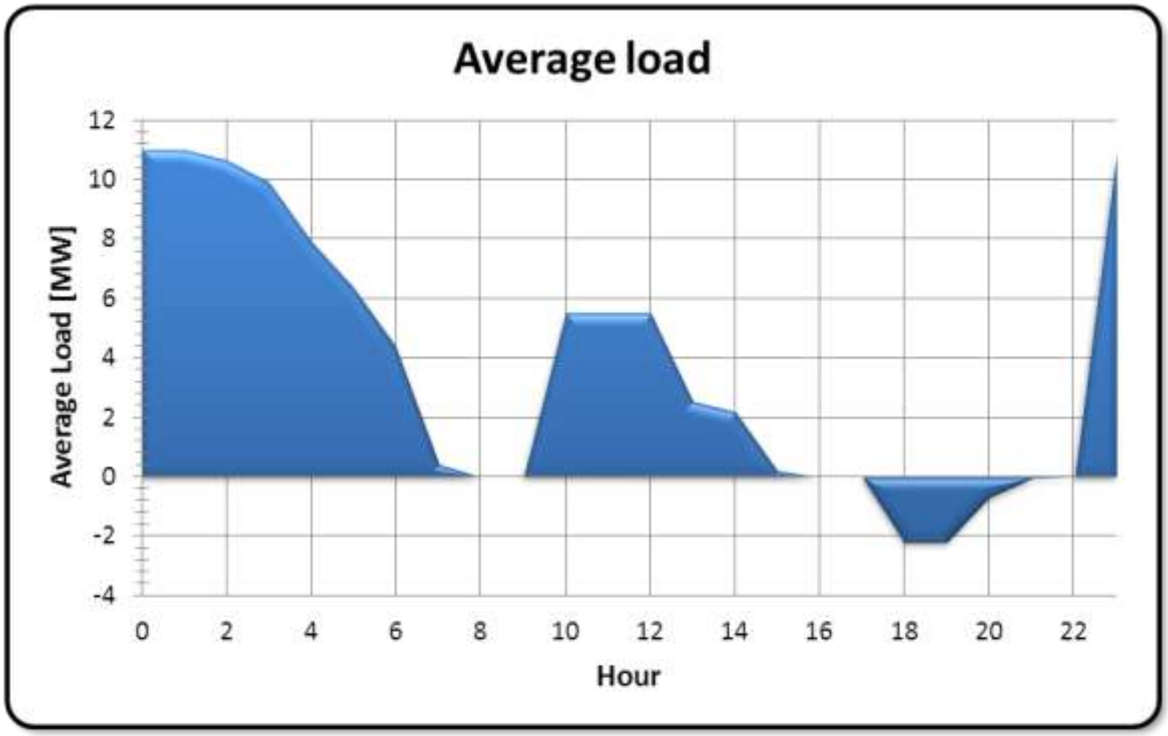


Figure 6 (Scenario 6 PHEV Load Demand)

The peak demand is between 8:00pm to 10:00pm. The average load demand in an hour at this area is 261MW. As we said, we are going to observe how this peak demand changes as wind energy and PHEVs are integrated. Besides, we can also observe the patterns of power generation in 24 hours. For example from 2:00am to7:00am, 1st generator supplies 120MW, 2nd generator supplies 50MW, 3rd generator supplies from 22 MW to 26MW depending on the time. It is shown that the cheapest way to generate 1MW after the 1st generator reaches 120MWand 2nd generator reaches 50 MW would be the generation from the 3rd generator. However, once the 3rd generator reaches 30 MW generation and the 1st generator reaches 120 MW, the 2nd generator creates more power to satisfy the load demand (8:00am to 10:00am). In this analysis, we are going to focus on only the first part which is analyzing the peak demand.

The second scenario is the 6 bus system that does have only wind energy. The peak demand supplied by conventional units, which is between 8:00pm to 10:00pm, is delayed to 10:00pm to 1:00am because wind farm is added (The peak demand defines the amount greater than 140MW). The average load demand in an hour at this area is 154.6MW. In other word, adding wind energy relieves the stress to supply the power from the conventional units. From now on, the peak demand and the average load demand imply the values subtracting the amount supplied by wind energy. Besides, there is one more peak demand between 10:00am to 3:00 pm. The average load demand in an hour at this area is 151.2MW. The peak demand is reduced about 90MW which is 34.5% of the peak demand from the first scenario.

The third scenario has the same as peak demand as the second scenario. The first peak demand is between 10:00pm to 1:00am. The average load demand in an hour at this area is 161.9MW. The average load demand should be higher than the second scenario because we are starting to do G2V at night time. The second peak demand is between 10:00am to 3:00pm. The average load demand in an hour at this area is 151.2MW.

The first peak demand for the fourth scenario is between 10:00pm to 1:00am. The average load demand in an hour at this area is 161.9MW. The second peak demand is between 10:00am to 3:00pm. The average load demand in an hour at this area is 149.6MW. The reason for the decrease is because there is an afternoon V2G.

The first peak demand for the fifth scenario is between 10:00pm to 1:00am. The average load demand in an hour at this area is 161.9MW. The second peak demand is between 10:00am to 3:00pm. The average load demand in an hour at this area is 151.2MW. In this scenario, there is an evening V2G instead of afternoon V2G. Therefore, the average load demand is higher than the one from the fourth scenario.

The first peak demand sixth scenario is between 10:00pm to 1:00am. The average load demand in an hour at this area is 161.9MW. The second peak demand is between 10:00am to 3:00pm. The average load demand is 155.4MW. The reason for the increase is the afternoon V2G around 10:00am to 3:00pm.

In other word, by adding wind energy and PHEV, the peak demand have not been changed but it released the stress of the conventional units by 38.0% (comparing the first peak demand between scenario1 and scenario4).

Secondly, we are going to compare the total operational cost in each scenario and find the best scenario based on it. As you can see from Figure , the optimal operational cost dropped significantly when we added wind generation. No operational or installation cost for wind generation is assumed. In other words, wind generation acts like a free source so theoretically adding wind generation should reduce the operational cost. In the analyzed case, the total operational cost diminished by $37,590.35 which is 30.8% of the power generation without wind generation. The total power generation without wind and PHEV for one day is estimated to be 5308 MW. However, wind generation creates 1242.5 MW for one day which is

23.4% of total generation. Therefore, introducing 23.4% of wind generation reduced 30.8% of total operational cost.

As you can see from the Figure 2, the best scenario is the fourth scenario because it shows the least operational cost. The fourth scenario utilizes charging at night time (11pm ~ 7 am) and discharging at day time (12 pm ~ 3 pm). The total operational cost at this time is estimated as $85,953.03. The least efficient way of charging and discharging PHEVs is the fourth scenario. The sixth scenario utilizes charging at night time (11pm ~ 7am) and also day time (10 am ~ 3pm) and discharge during the late afternoon (6pm ~ 9pm). The total operation cost in this case is estimated as $86,681.53 which is $728.50 more expensive than the worst case. While this is a small difference between two cases, if the system is expanded to, a 150 bus system, there would be a significant difference between the two scenarios.

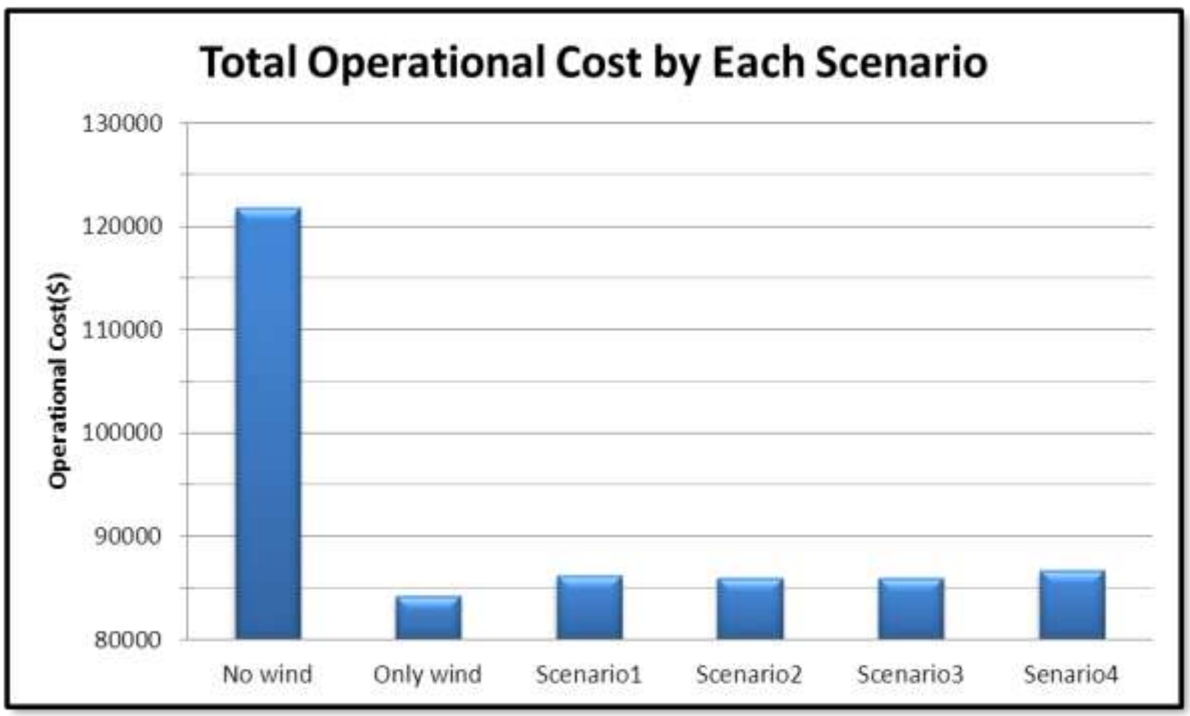


Figure 2: Total operational cost.

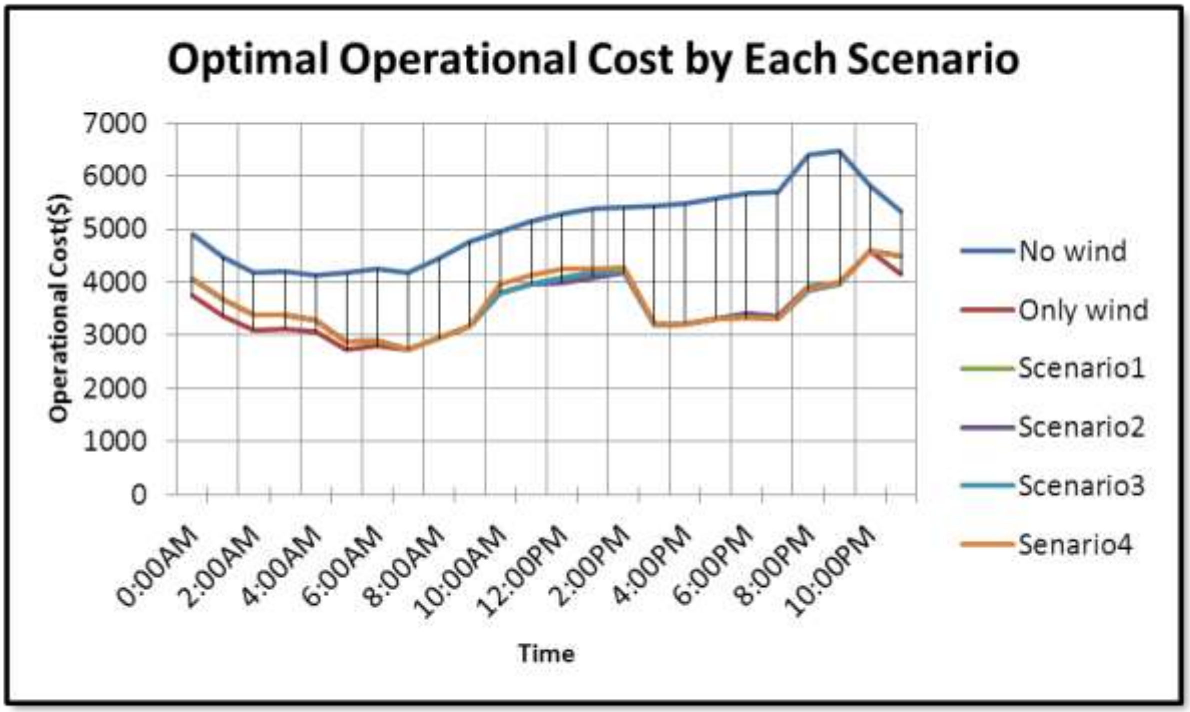


Figure 3: Optimal operational cost.

The fourth scenario utilizes charging at night time (11pm ~ 7 am) and discharging at day time (12 pm ~ 3 pm). The total operational cost at this time is estimated as $85,953.03. The least efficient way of charging and discharging PHEVs is the fourth scenario. The sixth scenario utilizes charging at night time (11pm ~ 7am) and also day time (10 am ~ 3pm) and discharge during the late afternoon (6pm ~ 9pm). The total operation cost in this case is estimated as $86,681.53 which is $728.50 more expensive than the worst case. While this is a small difference between two cases, if the system is expanded to, a 150 bus system, there would be a significant difference between the two scenarios.

V. Conclusions and Recommendations

This IPRO team has researched the factors affecting the integration of renewable energy systems and PHEVs in the future. Wind power is expected to provide a 20% generation of all energy produced in the US and the introduction of PHEVs into the market will increase demand for electric power. Wind power was found to reduce the operational cost of the grid considerably, due to wind power's negligible operational cost relative to other power generation methods. There is the potential for reducing the operational cost of the grid by PHEVs being charged at night and utilizing the V2G feature during peak power demand on the grid. Our case simulations showed that the second scenario provided the optimal operational cost with respect to the charging times of the PHEVs. This scenario has the PHEVs utilizing charging at night time (11pm ~ 7 am) and V2G discharging at day time (12 pm ~ 3 pm), Our simulation may be improved in the future by including and/or simulating the following features:

- Simulation of more than 6 buses
- Operational cost of the PHEV batteries due to V2G (cycling)
- More scenarios of PHEV charging situations
- The feasibility of using PHEVs as an electric storage system to mitigate the natural inconsistencies of wind generated power can be investigated.

Our analysis was sufficient to provide us with answers to the question of how to integrate renewable energy systems and PHEVs.

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Appendix

Contents

A. Team Members

- James Lee – Electrical Engineering
- Peter Ryszkiewicz – Electrical Engineering
- Joseph Charles – Mechanical Engineering
- Byron Enriquez – Mechanical Engineering
- Joseph Krause – Mechanical Engineering
- Robert Veitch – Computer Science
- Ghita Pop – Architecture

B. Objective Function

% Objective function at 0:00am Scenario 4

%Declare the coeficients

Aeq = [1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];

%All the coefficients are lineal

beq = [69.3];

%The load demand is 227 MW. 227-100(Starting power of Gen1)-10(Starting power of Gen2)-10(Starting power of Gen3)-37.7(wind power)

A = [];

b = [];

% There is no constraint on the power supply lb = [0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0; 0;];

ub = [20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20; 20;];

% There is no upper bound or lower bound

f = [28.4; 32.3; 36.3; 40.2; 44.2; 48.2; 52.1; 56.1; 60.0; 64.0; 68.0; 15.7; 23.9; 32.0; 40.1; 48.2; 56.3; 64.5; 72.6; 29.8; 49.6; 69.4; 89.1; 108.9];

%Test the objective function

[x, fval, exitflag, output, lambda] = linprog (f, A, b, Aeq, beq, lb, ub);

%Plot the graph

%plot(t,x);

%Print out the variables

fprintf('The value of x is: %f ', x);

fprintf('The value of fval is:%f', fval);

fprintf('The value of exit flag is: %d', exitflag);

disp(output);

disp(lambda);

%If you analyze another time, only the value for beq changes corresponds to the load at each time and the available wind energy.