Implementation of Photovoltaic-Wind Hybrid Systems with Battery Back-up in the State of Texas

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EXECUTIVE SUMMARY

The focus of this report is how a small capacity wind turbine when combined with a photovoltaic system can result in a good energy harvest over entire period of the year, by reducing the capacity of battery and complementing the solar resources during day-nights and winter-summers.

The aim of this study is to assess the feasibility of a hybrid wind-photovoltaic power system to meet the load requirements of a grid-tied apartment complex with 50% load met by the alternative energy sources [13]. Our study broadly covers three segments associated with Energy Management [16] - Technology Selection, Financial Viability, Policies and Regulations which ultimately dictate the implementation of the system.

Our methodology employs a techno-economic approach to determine the system that would guarantee a reliable energy supply with the lowest investment. The results obtained show that the reliable solution is that in which 95% of load is covered by photovoltaics and the other 5% by wind turbines.

Different types of analysis have been done for selection of the PV panel. These analyses take into consideration the weather conditions in the State of Texas. A similar procedure has been applied in selecting an appropriate wind turbine; one that would not be affected by zoning problems. In addition, different economic analyses have been done to come up with the most cost-effective approach for sizing all subsystems. Technological evaluations for battery and inverter selection have been done in parallel to economic analyses for all the components.

The Life Cycle Costing with payback time and Levelized Cost of Energy (LCOE) with Net Metering are provided as part of the economics in the project. Federal incentives like Investment Tax Credits, MACRS and Bonus Depreciation, and Renewable Energy Grants were taken into account to evaluate overnight costs for owners.

Some barriers to the growth of PV are also outlines, and solutions proffered. The state of the Renewable Energy insurance scene is also discussed. In deciding what solutions to suggest, some benchmarking was done, particularly with Europeans markets due to the renowned success of their renewable energy markets. Regulatory changes are also suggested.

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1 INTRODUCTION

1.1 General

The central idea of this solar primer is to propose and evaluate the hybrid PV-Wind System for apartment complexes, cooperative housing projects in the state of Texas which is blessed with an ideal climate and terrain for generating electricity from the wind, sun and plants [9]. But the development of clean energy in this state is still in its early stages. Fig.1. Due to high penetration of wind power in Texas [23], many companies are familiar with logistics for wind and have workforce, they can diversify their operations by offering the customers PV + Wind package.

Fig 1. Resource maps for Wind and Solar PV with Latitude tilt –Texas [4]

Figs 2, 3 and 4 represent the complementary nature of the solar and wind resources over a day and during a year.
Fig 2. Hourly Correlation Pattern for Solar and Wind Resources during 21st Nov 2010 [2],[5]

Fig 3. Correlation pattern for average monthly Solar and Wind Resources
1.2 Objective of Solar Primer

In this investigation, wind turbine generators, photovoltaic panels, and storage batteries are used to build hybrid generation systems which are optimal in terms of multiple criteria including cost, reliability, and emissions. Time dependent and intermittent nature of wind speed and solar insolation but high degree of correlation between the two resources made us choose the hybrid PV-Wind System. Stand-alone systems based on just one energy source must be oversized to guarantee a reliable supply. In this context hybrid power generation systems, which use at least two energy sources, represent an excellent option [7].

To mitigate or even cancel out fluctuations energy storage technologies such as storage batteries are also employed. SBs may absorb the surplus power and provide the deficit power under different operating conditions. Due to different life spans of components involved reliability analysis is critical. Here we consider only grid linked power generation scheme.

For the conditions of College Station, TX with class1 wind and 45%-60% sunshine, we used techno-economic approach to determine the system that guarantee a reliable energy supply with a lowest investment. The obtained results show that the more reliable solution is that in which 95% of load is
covered by photovoltaics and the other 5% by wind turbines. Furthermore, this methodology sizes not only the generation subsystem but also the storage one in order to not over sizing the renewable subsystems and increasing the total cost [7]. Based on resource profiles in Texas the fraction of loads met by PV and Wind are summarized in Table-1.

Table 1. Summary of Hybrid PV-Wind Generation Fractions for Various Locations in Texas

<table>
<thead>
<tr>
<th>Sunshine \ Wind Class</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>75%-90%</td>
<td>95% PV, 5% Wind</td>
<td>90% PV, 10% Wind</td>
<td>80% PV, 20% Wind</td>
<td>80% PV, 20% Wind</td>
</tr>
<tr>
<td>60%-75%</td>
<td>N/A</td>
<td>90% PV, 10% Wind</td>
<td>80% PV, 20% Wind</td>
<td>80% PV, 20% Wind</td>
</tr>
<tr>
<td>45%-60%</td>
<td>95% PV, 5% Wind</td>
<td>90% PV, 10% Wind</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The algorithm for sizing of the system is explained in the section 2.1

1.3 Motivation for Solar Primer

35% of rented houses in Texas and 41% percent of owners have mortgage, hence only financial burden is there on 65% people to install renewable sources of energy [24]. Community based ownership or apartment complex installation by landlords, would bring the per-capita for installed cost down and enables efficient sharing of energy resource. The owner can increase the rent and will receive good income over 20 years using net metering.

1.4 Standards Followed

IEEE 1547 for performance of the PV system, UL1741 for Safety and Inverter Islanding, National Electric Code for Wiring are followed in the selection of components for designing Hybrid PV-Wind System.

1.5 Literature Survey

Cooperative solar installations among housing communities and solar leasing are becoming very popular and cost effective for house owners [27]. The following are few success stories that underline this trend
A new home with PV installed does not cost significantly ($227,000 versus $210,000 at Discovery at Spring Trails – a housing community in Houston.

United Power at Brighton- Colorado’s- owning a 210 W PV panel at $1050 for 25 year lease with roughly 15-17 yr payback time.

1.6 Organization of the Report

The report is organized into five chapters. Chapter 1 provides an overview of the selected system and motivation behind our work. Chapter 2 presents case study for an apartment complex in College Station. Chapter 3 gives the overview of the Technology selection and Sizing of systems. Chapter 4 presents cost, price, and payback time analysis. Chapter 5 discusses barriers for the deployment of PV Systems, including possible solutions by way of federal legislation, state and local policies that can help promote distributed PV.

2 CASE STUDY FOR AN APARTMENT COMPLEX

The apartment complex consists of 70 units with 28 two story buildings with wood frame construction, brick, stone and wood siding and gable and pyramid roofs with composition shingle cover over wood decking. Owner paid for gas, electricity, water, sewer and trash service. Tables-2, 3, 4 and Fig.5 give summary of type of units in the apartment complex and their energy usage.

Rentable Units: 69; Office: 1 unit

Table 2. Summary of different unit types in the Apartment Complex

<table>
<thead>
<tr>
<th>Type of Unit</th>
<th>No. of units</th>
<th>Area of unit (sq. ft)</th>
<th>Rounded Fair Market Rent in Brazos (2010) $</th>
<th>Type of Building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>2</td>
<td>620</td>
<td>590</td>
<td>2 – Buildings</td>
</tr>
<tr>
<td>1bed 1bath</td>
<td>20</td>
<td>700</td>
<td>670</td>
<td>10, two story building</td>
</tr>
<tr>
<td>2 bed 1bath</td>
<td>10</td>
<td>850</td>
<td>770</td>
<td>10, two story building</td>
</tr>
<tr>
<td>2bed 1.5 bath</td>
<td>10</td>
<td>950</td>
<td>790</td>
<td>22 two story buildings</td>
</tr>
<tr>
<td>2bed 1.5bath</td>
<td>22</td>
<td>1000</td>
<td>800</td>
<td>22 two story buildings</td>
</tr>
</tbody>
</table>
### Table 3. Summary of energy usage for different units in the Apartment Complex

<table>
<thead>
<tr>
<th>No. of units</th>
<th>No. of people X No. of Houses</th>
<th>Average No. of people in a housing unit</th>
<th>Average consumption per unit in Kwh/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2 in office, 1 in house</td>
<td>1.5</td>
<td>830</td>
</tr>
<tr>
<td>20</td>
<td>2 X 13 houses, 1X7 houses</td>
<td>1.65</td>
<td>940</td>
</tr>
<tr>
<td>10</td>
<td>2X7 houses, 1X3 houses</td>
<td>1.7</td>
<td>1150</td>
</tr>
<tr>
<td>10</td>
<td>2X2 houses, 3X4 houses, 4X4 houses</td>
<td>3.2</td>
<td>1280</td>
</tr>
<tr>
<td>22</td>
<td>2X2 houses, 3X5 houses, 4X15 houses</td>
<td>3.6</td>
<td>1350</td>
</tr>
<tr>
<td>6</td>
<td>2X2 houses, 4X4 houses</td>
<td>2.67</td>
<td>1410</td>
</tr>
</tbody>
</table>

**Fig 5. Residential Load Profiles for Center Point Service Area (Near and Around Houston)**
Using center of mass approach for loads, 830kwh is in between 500 and 1000, $500p + 100(1-p) = 830$, $p=34\%$. Hence 830kwh has 34\% resemblance to 500kwh load pattern and 66\% of resemblance to 1000kwh load pattern. Using the same methodology, we have following load patterns for the complex.

Table 4. Monthly Usage for Various Buildings

<table>
<thead>
<tr>
<th>Month</th>
<th>2X 830kwh</th>
<th>20X 940kwh</th>
<th>10X 1150kwh</th>
<th>10X 1280kwh</th>
<th>22X 1350kwh</th>
<th>6X 410kwh</th>
<th>Total Demand (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>1497.32</td>
<td>16957.6</td>
<td>10373</td>
<td>11545.6</td>
<td>26789.4</td>
<td>7630.92</td>
<td>74793.84</td>
</tr>
<tr>
<td>Feb</td>
<td>1243</td>
<td>14080</td>
<td>8612</td>
<td>9584.4</td>
<td>22237.6</td>
<td>6334.08</td>
<td>62091.08</td>
</tr>
<tr>
<td>Mar</td>
<td>1088.96</td>
<td>12332.8</td>
<td>7544</td>
<td>8396.8</td>
<td>19483.2</td>
<td>5549.76</td>
<td>54395.52</td>
</tr>
<tr>
<td>Apr</td>
<td>1085.64</td>
<td>12295.2</td>
<td>7518</td>
<td>8365.6</td>
<td>19408.4</td>
<td>5527.92</td>
<td>54200.76</td>
</tr>
<tr>
<td>May</td>
<td>1281.52</td>
<td>14513.6</td>
<td>8878</td>
<td>9881.6</td>
<td>22928.4</td>
<td>6531.12</td>
<td>64014.24</td>
</tr>
<tr>
<td>Jun</td>
<td>1882.44</td>
<td>21319.2</td>
<td>13041</td>
<td>14515.2</td>
<td>33679.8</td>
<td>9593.64</td>
<td>94031.28</td>
</tr>
<tr>
<td>Jul</td>
<td>2355.2</td>
<td>26676</td>
<td>16317</td>
<td>18160.4</td>
<td>42136.6</td>
<td>12002.28</td>
<td>117647.5</td>
</tr>
<tr>
<td>Aug</td>
<td>2499.96</td>
<td>28312.8</td>
<td>17319</td>
<td>19276.8</td>
<td>44728.2</td>
<td>12740.76</td>
<td>124877.5</td>
</tr>
<tr>
<td>Sep</td>
<td>2423.6</td>
<td>27448</td>
<td>16790</td>
<td>18688</td>
<td>43362</td>
<td>12351.6</td>
<td>121063.2</td>
</tr>
<tr>
<td>Oct</td>
<td>2020.56</td>
<td>22880.8</td>
<td>13997</td>
<td>15580.4</td>
<td>36152.6</td>
<td>10298.28</td>
<td>100929.6</td>
</tr>
<tr>
<td>Nov</td>
<td>1326</td>
<td>15020</td>
<td>9187</td>
<td>10224.4</td>
<td>23722.6</td>
<td>6757.08</td>
<td>66237.08</td>
</tr>
<tr>
<td>Dec</td>
<td>1215.12</td>
<td>13761.6</td>
<td>8418</td>
<td>9369.6</td>
<td>21740.4</td>
<td>6192.72</td>
<td>60697.44</td>
</tr>
<tr>
<td>Avg</td>
<td>1660</td>
<td>18800</td>
<td>11500</td>
<td>12800</td>
<td>29700</td>
<td>8460</td>
<td>82920</td>
</tr>
</tbody>
</table>

2.1 Sizing of the PV-Wind Hybrid System

As per 1997 Residential Energy Consumption Survey, residential usage = 5.42 thousand btu per sq.ft in Texas. Use: 1 BTU = 0.000293 KWh

The EIA reports that in 2008, the average residential home in Texas used 1,130 kilowatt-hours of electricity each month.

Percapita Usage of Electricity in Texas (includes industrial consumption as well): 454.083 kWh per person per month in 2003-05

Total Estimated Usage as per sq.ft : 97674 kWh per month

Total Estimated Usage as per average usage: 79,100 kWh per month

Total Estimated Usage as per percapita usage: 83,551 kWh per month
Observing the above three estimates, the usage can be in between 83,551-79100, by averaging we get: 82,000 kWh per month.

Texas State Average Insolation for Flat Roof: 4.6 kwh/m²/day - Weighted by Region of Use Based on 2005 Electricity Use Patterns.

Calculation of energy yield in Table-5 was performed using the PVWatts tool for Houston Area, using the default average DC-AC conversion efficiency of 77%.

Table 5. Incident Solar Energy Data from PV Watts Tool of NREL for College Station

<table>
<thead>
<tr>
<th>System Type</th>
<th>Incident Solar Radiation (kWh/ array m²/day)</th>
<th>AC Energy from 1KW DC (kWh/month)</th>
<th>Energy Savings in $ Per Year at 7.7 cents/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low / med / high</td>
<td>low / med / high</td>
<td></td>
</tr>
<tr>
<td>Fixed Tilt: 30.6 and Azimuth :180</td>
<td>4.08 / 5.27 / 5.97</td>
<td>93 / 112 / 123</td>
<td>103.41</td>
</tr>
<tr>
<td>Flat roof: Tilt 0 and Azimuth :180</td>
<td>2.83/4.87/6.59</td>
<td>62/102/136</td>
<td>94.48</td>
</tr>
</tbody>
</table>

Per capita roof area in Texas: 76m² per person.

Hence total available roof area for 184 people: 13984 m², using 7/12 roof pitch we get effective roof area by using a pitch factor of 1.16 = 16,221 m².

Under STC 1000 W/m² irradiance at 25°C, silicon cell with 10-15% efficiency gives 100-150 DC Watts and thin film with 6-12% gives 60-120 DC watts.

Using a First Solar’s 80W PV panel and Wintronics 1.5KW Wind Turbine generator, the average energy generation for every month are tabulated in Table-6.

Table 6. Summary of Solar and Wind Power Generation Capability

<table>
<thead>
<tr>
<th>College Station</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Wind (mph)</td>
<td>9.2</td>
<td>9.2</td>
<td>11.5</td>
<td>11.5</td>
<td>10.4</td>
<td>10.4</td>
<td>8.1</td>
<td>9.2</td>
<td>6.9</td>
<td>9.2</td>
<td>8.1</td>
<td>9.2</td>
<td>9.4</td>
</tr>
<tr>
<td>Wind</td>
<td>87</td>
<td>78</td>
<td>140</td>
<td>135</td>
<td>113</td>
<td>109</td>
<td>66</td>
<td>86</td>
<td>45</td>
<td>86</td>
<td>63</td>
<td>86</td>
<td>110</td>
</tr>
</tbody>
</table>
The use of two renewable sources causes the energy generation to be divided into two parts. If the photovoltaic subsystem’s energy contribution fraction to the demand rate is named $f$, then $(1-f)$ is the fraction corresponding to the wind turbines.

Sizing the hybrid system to meet 50% of demand every month and using the results in Table-4.

$P_{PV} = f (Q_D/Q_{PV})$, where $Q_D$ is the demand in kWh to be met by the renewable energy for that month, $P_{PV}$ is the installed capacity required to meet the PV fraction of $Q_D$ and $Q_{PV}$ is the A.C energy in kWh generated by the PV system for 1KW installed DC.

$P_W = (1-f) (Q_D/Q_W)$, where $Q_D$ is the demand in kWh to be met by the renewable energy for that month, $P_W$ is the installed capacity required to meet the wind fraction of $Q_D$ and $Q_W$ is the A.C energy in kWh generated by the wind system for 1KW installed wind turbine generation.

$P = P_{PV} + P_W$;

For various values for $f=0-1$ with 0.1 steps, the results are tabulated in Table 7.
Sizing of the system is determined by worst month which requires the maximum amount of installed capacity to cover the load which is the month of September. This methodology to size the generation subsystems takes into account the generation, demand and resource variability. A fictitious average month is not used because the system designed in this way would not be able to satisfy the load during some periods. On the other hand, the calculation of each subsystem (wind and photovoltaic) separately for the worst month in each resource makes the total system be oversized [7].

Designing the hybrid system to be 95% PV and 5% makes it suitable for mismatch in sources of energy over entire course of the year without compromising much on the sizing of the system. It improves reliability and that addition of wind turbine can partially offset the battery requirements on less sunny days.

No. of thin film panels required to generate 228 kW (96%) are 2850 panels spanning just 2050 m² which is roughly 12% of available roof area.
Required demand to be met by Wind Turbine is 10kW (4%) which requires 10 wind turbines in DC charging mode

As can be seen from Fig.6, Wind energy is highly variable but it is present for most of the time while the solar energy is present only for limited amount of time but produces almost constant energy. So having a hybrid PV-Wind System with optimal sizing provides good reliability over the entire course of year.

![Wind energy vs Photovoltaic energy](image)

Fig 6. Typical Diagram for energy produced from Wind and PV Hybrid System [7]

Sizing done in a traditional way using ‘Solar-Estimate.org’, where each PV and Wind systems are sized independently to meet average load demand would result in:

PV System Size to meet 50% of Demand = 393.3 kW.

Wind System Size to meet 0.5% of Demand = 50kW wind turbine.

### 2.2 Sizing of the Battery Storage Subsystem

The battery system is required when the solar and wind resources are unable to meet 50% demand due to poor weather conditions. Alternatively the battery system can be sized only to supply power during high utility cost periods which are during day time and there by earning more money. Taking into account of load variations as represented in Fig.7 and using the wind speed and solar insolation data for the month of November, the margins of demand as seen in Fig.8 are calculated when demand is not met from PV-Wind Hybrid System.
The highest margin came on Nov25 with 959.2983169 kWh of demand not met over the entire day due to low wind and solar conditions.

\[ N_{\text{Bat}} = \frac{\text{Margin}_{\text{max}} \times 1000}{V_{\text{sis}} S_{\text{Bat}} P_{\text{Des}}} \]

- \( S_{\text{Bat}} = \) Capacity of battery
- \( P_{\text{Des}} = \) Depth of discharge
- \( V_{\text{sis}} = \) Voltage

Trojan Battery L-16P, 6 volt 390 AH has 5-10 year expectancy with 80% depth of discharge. \( N_{\text{Bat}} = 500. \)

Comparing with a commercially available 5.5 kW system which requires 75 of 12V 300Ah batteries (4090 Ah/KW), our system requires very less battery capacity (819 Ah/KW) [7].

3 TECHNOLOGY SELECTION
Fig 9 shows the general schematic of the system, the system can be divided into three stages. The first stage which is the generation stage includes: PV panel, charge controller for PV panel, wind turbine integrated with DC charger, and battery bank. These are the main component for this stage. This stage has the 48 V DC voltage, we selected 48 V for this stage because most of the commercial inverters available in this stage has this voltage. The next stage is the conversion of the DC power to AC output power; inverter is the main component of this stage. It converts the 48 V DC voltage to 208 V three phase AC. The last stage is the load and connection of power grid throughout the Main Service Panel to the loads. The system is designed to supply the 50% of the total demands of the loads; the remaining power will be supplied to the loads from the power grid. In the case of excess generation of power, it will go throughout the charger controller to battery bank, and charges the batteries. Following sections will go throughout the individual components selection and sizing of them more in details.

![Diagram of the system](image)

**Fig 9. General schematic of the system**

### 3.1 Technology and Material Selection for Photovoltaic

#### 3.1.1 Polycrystalline and Thin Films

Two categories of PV cells are used in most of today's commercial PV modules: crystalline silicon and thin film. The crystalline silicon category, called first-generation PV, includes monocrystalline and Multicrystalline PV cells, which are the most efficient of the mainstream PV technologies and accounted for about 84% of PV produced in 2008 (Bartlett et al. 2009) [22].
The thin-film category, called second-generation PV, includes PV cells that produce electricity via extremely thin layers of semiconductor material made of amorphous silicon (a-Si), copper indium diselenide (CIS), copper indium gallium diselenide (CIGS), or cadmium telluride (CdTe). Another PV cell technology (also second generation) is the multi-junction PV cell [22]. Various emerging technologies, known as third-generation PV, could become viable commercial options in the future, either by achieving very high efficiency or very low cost. Examples include dye-sensitized and organic PV cells, which have demonstrated relatively low efficiencies to date but offer the potential for substantial manufacturing cost reductions [22]. Thin-film PV, which requires little or no poly-silicon feedstock, has become a major competitor to crystalline silicon PV [22].

3.1.2 Total energy harvest for a Thin Film and Polycrystalline—Which One is good

Thin film CdTe has been selected to use for this system, here are the advantages of this type of PV Panel:

- Cost effective
- Low temperature coefficient, have good performance in high temperature
- Energy production during cloudy weather
- CdTe efficiency increased during last 4 years more than other technologies as it is shown in Fig10


Table 8 shows some other data that used for cost analysis. The result of this analysis had been shown in fig11. As it is shown the by increasing the installed capacity the cost ($/watt) of thin film will decrease more than Polycrystalline.
Table 8. Module price, manufacturing costs, and efficiency estimates by Technology 2008

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>High-efficiency monocry stalline silicon</td>
<td>$3.83</td>
<td>$2.24</td>
<td>17.5%</td>
</tr>
<tr>
<td>Multicrystalline silicon</td>
<td>$3.43</td>
<td>$2.12–$3.11</td>
<td>13.5%</td>
</tr>
<tr>
<td>Amorphous silicon (a-Si) thin film</td>
<td>$3.00</td>
<td>$1.80</td>
<td>6.5%</td>
</tr>
<tr>
<td>Copper indium diselenide/copper indium gallium diselenide (CIS/CIGS) thin film</td>
<td>$2.81</td>
<td>$1.26</td>
<td>10.2%</td>
</tr>
<tr>
<td>Cadmium telluride (CdTe) thin film</td>
<td>$2.51</td>
<td>$1.25</td>
<td>10.0%</td>
</tr>
</tbody>
</table>

Mehta and Bradford 2009

Fig 11. Thin Film VS PolyCrystalline

Since most of the manufacturers give only prices of the PV panels, it is good to have some analysis of retail cost of the selected technology for the system. Fig12 shows the retail cost versus manufacturing cost in $/watt for Thin film panels.

Fig 12. Retail cost VS Manufacturing cost of Thin Film panel
As it can be seen from the ratio of the retail cost to manufacturing cost is almost 1.5 in $/watt. Fig.13 shows also another analysis that has been done to select the thin film, it shows the descending of the cost in $/Watt of thin film in last four years.

![Cost per Watt Graph](image)

**Fig 13. First Solar’s Commercial Success**

### 3.2 Technology Selection for Wind Turbine Generator

There are several constraints that should be taking into consideration for selecting the wind turbine generator such as the height of the tower, start in speed, cost, vibration, and etc. HoneyWell model WT 6500 wind turbine generator selected as the alternative generation source in addition to PV panels for this system. This wind generator has several advantages which are:

- Wide Wind Acceptance – Auto Directional
- Vibration (Fixed blades, no gear box)
- Zoning problem reduction (For Texas the max height is 40 ft)
- 2 mph cut-in speed
- Shut down wind speed 42 mph
- Charge controller included
- 5 year limited warranty

This type of generators doesn’t need tower; they are coming like a box that can be installed on the top of any roof which is one of the most advantages of them. Fig.14 shows the installation of this wind generator on the roof of a house.
Fig 14. Honeywell model WT 6500 wind turbine generator

The other parameter that is always important before any selection is the cost. The total cost of this type of wind generator including the DC charger is 6495 USD. Fig. 15 shows the analysis had been done to come up to the result that this model is cost effective. This shows the cost in $/watt of different wind turbine generators, as it can be seen this model has one of the lowest cost in $/watt.

Fig 15. Small Wind Turbine costs
Other parameter is the power generation versus the wind speed, Fig. 16 shows the power versus wind speed of honeywell wind turbine. Since most of the Texas areas are classified as class 2 to 4, and the wind speed varies more around 30 mph, it has an acceptable rated power.

Fig 16. Variation of rated power versus the wind speed of Honeywell WT6500 wind turbine

3.3 Charge Controller

Charge controller act like voltage regulators in cars, they regulate the voltage and currents coming from the power generators, in this system wind turbine and PV panel, and going to batteries and prevent from over charging of the batteries. In addition to that it also block the reverse current, because when there are no sun lights the PV panel acts as the load, this will cause some loses, charger controller block the reverse current and prevent this loses. The charger controller is typically rated against Amperage and Voltage capacities [26], [25]. The first step in selecting the charger controller is the voltage selection; we need to make sure the voltage of the charger controller, solar panel array, and the battery bank are the same. This voltage called the system voltage. As mentioned in previous section the 48 V selected as the system voltage. The selected wind turbine is already integrated with solar charge controller. Solar charge controller rating can be finding from the following equation:

\[
\text{Solar charge controller rating} = \text{Total short circuit current of PV array} \times 1.3
\]

3.4 Material Selection for Storage Battery

The battery type that is recommended for using in most of renewable energy systems is the deep cycle battery; this is also applicable for the proposed system. There are two categories of deep cycle battery: flooded batteries using fluid electrolyte, and sealed batteries using non-fluid electrolyte. Here are some advantages and disadvantages of these two categories [25]:

- Flooded batteries use a fluid electrolyte
- Disadvantage
AGM sealed batteries use non-fluid electrolyte

- **Advantage**
  - Cost effective
- **Sealed batteries use non-fluid electrolyte**
- Absorbed Glass Mat (AGM)
  - **Advantages**
    - Cost effective
    - No Maintenance needed
- **Gel Cell**
  - **Disadvantages**
    - Expensive

AGM sealed batteries has been selected for this system, since it doesn’t need any maintenance, which is one of the most important factors for residential areas. Because the people living in the complexes may be not technical to maintain the batteries, and if a technician wants to maintain the batteries or checking them weekly it will add additional cost to the proposed system. In addition this is one of the cheapest batteries. However they may not be as efficient as the other type of existing batteries such as lithium ion batteries which are one of the most efficient batteries, but since the power in the residential area is not as critical as in industrial places; it will not be necessarily to add additional cost to the system.

The next step is to find out the size of the battery, the battery capacity can be find from the following procedure [24][25]:

1. Calculate total Watt-hours per day used by appliances.
2. Divide the total Watt-hours per day used by 0.85 for battery loss
3. Divide the answer obtained in 2 by 0.6 for depth of discharge.
4. Divide the answer obtained in 3 by the nominal battery voltage.
5. Multiply the answer obtained in 4 with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) to get the required Ampere-hour capacity of deep-cycle battery.

\[
\text{Battery Capacity (Ah)} = \frac{\text{Total watt-hours per day used by loads}}{(0.85 \times 0.6 \times \text{nominal battery voltage})} \times \text{Days of autonomy}
\]

The last step is the array sizing of the battery bank, since the system voltage is 48 V, and 496 batteries with 6 V nominal voltages decided to be used, therefore there should be 8 batteries in each array to have 48 V battery bank. So the battery bank will be 8x62 batteries with 48 V voltages.
3.5 Inverter selection for Hybrid System

Inverter is used in the middle stage of the system. An inverter is used in the system since the AC output power is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as the selected battery which is 48 V in this system. For stand-alone systems, the inverter must be large enough to handle the total amount of Watts that will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting. These were few basic points that we need to take into consideration before selecting an inverter for the system [27][26].

For this system as mentioned in previous sections the total installed capacity of the PV is 228 KW, and wind turbine generation is 10 KW so the inverter rating is 310 KW (30% higher):

Inverter rating = (228+10)*1.3=310 KW

“Xantrex GT100-208 100KW 3-Phase 208VAC” Inverter has been selected to use for proposes system, since the inverting rating should be 300 KW approximately, three of this inverter should be use in parallel.

4 ECONOMICS AND FINANCIAL VIABILITY

Economics play a key role in determining the growth of PV systems as they bring a complex interplay of incentives and various supply-demand factors around the world to determine the net cost to the owner. Fig.17 represents the trend for cost per watt, which is a very common yardstick for the cost of PV systems.

![Graph showing $0.3/W Cost Reduction per Year](image)
Non module Cost: Non-module costs can include inverters, other hardware, labor, permitting and fees, shipping, overhead, and profit. From Fig.18, we can see that they dropped from $5.9/W in 1998 to $3.8/W in 2008, a drop of $2.1/W. By comparison, module prices dropped by only $1.3/W over this 11-year period.

Note: Non-module costs are calculated as the reported total installed costs minus the global module price index.

4.1 Photovoltaic Costs

4.1.1 Fixed Costs
The share for different components that constitute the fixed costs for PV system are depicted in Fig.19.

A 12% efficient multi-crystalline PV panel from Dmsolar 120w, 1 m\(^2\) area and cost is $1.80 per watt.
8.33% efficient CdTe thin film Panel with 60W and having 0.72 m² and manufacturing cost $0.77/watt, has retail cost of $1.37/watt using curve fit.

For 11.1% panel with 80W, the cost increase would be $0.1 per 1% efficiency increase [22], would give the cost $1.65 per watt.

10% DuPont Solar Panel 100 Watts amorphous silicon (a-Si) thin-film technology 1.56 m² and cost of $1.7/watt.

For PV System Capacity=228kW and using the 80W First Solar Panel with Cost =$1.65/W Module Cost of System in 2008=$4.2/W for $2.51/W CdTe Thin Film Retail Cost [22]

Assuming the same difference between module cost for system and thin film cost and using Fig.20 as a reference, we get $3.34/W as the module costs.

![Fig 20. Global PV module and system price forecasts](image)

Keeping 52% share of modules cost for the entire system, we get System Cost= $6.4/W

Total PV System Cost= $1,459,200

4.1.2 Variable Costs

Using JEDI PV model from NREL [28], we get the Annual Direct Operations and Maintenance Cost of $12.00/kW.

4.2 Wind Energy Costs

4.2.1 Fixed Costs

The following costs are taken into account for calculating fixed costs of wind turbine generators:
The Honeywell Wind Turbine and DC controller have a combined MSRP of $6,495.

For 10 kW of Wind Turbine Generation, a 12kW inverter costing $6,600 would be required (Additional costing for wind turbine inverter is used as we accounted inverter cost only for PV)

Total Generation Unit Cost=$71,550

Average Installation and Overhead Costs=$5,500 (Source: Earth Tech)

Total Wind Energy System Cost= $77,000

4.2.2 Variable Costs

Using a JEDI Wind Energy Model from NREL [28], for same capacity wind farm (Which considers tower structures and Land Lease) O&M Costs =$200 per year.

4.3 Storage Batteries Costs

4.3.1 Fixed Costs

500 units of storage batteries would amount to $200,000 capital investment.

4.3.2 Variable Costs for Batteries and Inverters

In the study of TEP’s utility-scale PV described above, replacing/rebuilding inverters, batteries every 10 years was projected to almost double annual O&M costs by adding an equivalent of 2*0.1% of the installed system cost.

It would bring total annual O&M cost to 2*0.22% of installed system cost (Moore and Post 2007).

4.4 Total System Cost

Capital Cost =$1,736,200

4.5 Incentives and Financing Summary

4.5.1 Investment Tax Credit

Most notably, Section 1603 of the Recovery Act enables wind (and other qualifying) power projects to temporarily choose a 30% cash grant administered by the U.S. Treasury in lieu of either the PTC or a 30% investment tax credit (ITC). Of importance to the distributed wind segment, turbines under 100 kW in size are now eligible for an uncapped 30% investment tax credit [23].
4.5.2 Modified Accelerated Cost Recovery System (MACRS) and Bonus Depreciation

Assuming a 40% combined effective state and federal tax bracket and a 10% nominal discount rate, on a present-value basis, this 5-year MACRS depreciation schedule provides a tax benefit equal to about 26%. Taken together, the 30% ITC and accelerated depreciation provide a combined tax benefit equal to about 56% of the installed cost of a commercial solar system (Bolinger 2009).

In addition to the standard MACRS, the EESA includes a bonus depreciation schedule for solar projects installed in 2008. Qualifying projects can receive 50% depreciation in the first year, with the remaining 50% depreciated over the 5-year MACRS schedule. The ARRA extends the 50% year-one bonus depreciation incentive for qualified renewable energy investments made through 2009 [22].

4.5.3 Renewable Energy Loan Guarantee Program:

The ARRA permitted the guarantee of about $40 billion of loans by the Section 1705 program, in addition to the $51 billion authorized for Section 1703 in Title XVII of the Energy Policy Act of 2005.

4.5.4 Renewable Energy Grants for developers-ARRA up to 30%

4.5.5 Other income generating sources

- Load leveling: Using energy at off-peak and selling it during peak load using batteries
- When carbon dioxide trading becomes part of the energy policy in the United States, PV-Wind energy will also be more valuable (a 2¢ to 3¢ per kWh increase). This is based on the average equivalent carbon produced per kWh at conventional fossil fuel power plants and a metric ton of carbon having a value of $30/ton or greater [21].


Investment Tax Credit=30% of Capital Cost
Modified Accelerated Cost Recovery System (MACRS) and Bonus Depreciation = 26%.
Renewable Energy Cash Grant =30%
Renewable Energy Loan Guarantee Program=30% of Total Cost for 30 yrs at 6.5% APR

4.6 Economics Benefits Summary

Using the electricity cost as 77 cents/Kwh and Annual Inflation rate of 3.78%
Average Annual Utility Savings: $44,423
LCOE for Hybrid System=$0.14/kWh, it is less by 8 cents as can be seen from Fig. 21.

Appreciation increase in Property Value: $826850

Return on Investment=17 years

![Fig 21. LCOE with and without Investment Tax Credits (ITC) [22]](image)

Greenhouse Gas (CO2) Saved=10,995 tons

Gallons of water saved as shown in Fig. 22, is a real value addition for using alternative sources of energy.

![Fig 22. Water Consumption Saved from Thermal Plants](image)
A recent study by analysts at U.C. Berkeley concluded that the renewable energy technologies, solar PV creates the most jobs per unit of electricity output. Solar PV was estimated to create 0.87 job-years/GWh, whereas natural gas and coal were each estimated to create 0.11 job-years/GWh. Solar PV thus generates almost eight times as many job-years/GWh as natural gas or coal (Wei et al. 2010) [22].

5 BARRIERS TO ENTRY/GROWTH

Some utilities require small wind turbine owners to maintain liability insurance in amounts of $1 million or more. Utilities consider these requirements necessary to protect them from liability for facilities they do not own and have no control over. Others consider the insurance requirements excessive and unduly burdensome, making wind energy uneconomical for them. In the 21 years since utilities have been required to allow small wind systems to interconnect with the grid, there has never been a liability claim, let alone a monetary award, relating to electrical safety [23].

5.1 High Initial Cost

The initial cost of installing a new PV system could be a deterrent, especially for non-commercial/non-industrial applications. The installed cost of a PV system, including parts, labor, and all other initial costs could start from right under $1,000 and it increases with system output. A $1,000 system however would probably only provide about 75 W. Assuming that on average, the system produces for 5 hours a day throughout the year, then a 75 W system would only produce 136.875 kWh (0.075 kW × 5 hr × 365 days) per year. The average energy consumption for a U.S home in the year 2008 was 11,040 kWh [3]. To reduce one’s electricity bill by a noticeable amount, a residential customer would need a PV capable of producing a few kilowatts. As is usually the case with buying in the bulk, the cost per unit is lower for higher output PV systems, however the total installed cost also increases significantly. For instance a 2 kW system (approx. output of 3650 kWh) could cost anywhere from “$16,000 to $20,000 installed, or $8 to $10 per watt” [1], as opposed to the 75 W unit which could cost up to $12/watt [1]. Going by the above estimated annual energy output of 136.875kWh, the 75W system and 2 kW system costs range from $5/kWh to $7/kWh. When distributed over the lifetime of the panels, the costs begin to resemble the cost of fossil fuel-generated electricity, which is about $0.12/kWh [39]. The main difference however lies in the fact that the customer who relies solely on the grid does not have to part with thousands of dollars in initial investments as does the owner of a PV system.

Since most PV/Wind energy system customers are home owners, zone way to finance their new renewable energy system is by obtaining a mortgage loan. There are different kinds of mortgage loans available for financing renewable energy systems and the customer may choose based on their
preference and circumstances. For instance, a customer who is either building or buying a home may include the cost of the PV/Wind energy system in their mortgage and thus obtain a single loan to cover both expenses. On the other hand, a customer who already has a house may go with the option of a solar lease, or a third party Power Purchase Agreement, where such options are available. A power purchase agreement is especially favorable since it absolves the host of virtually all costs, and the only payments made are ostensibly for power purchased under the agreement. In reality however, there is the possibility that other factors could factor into the price of electricity in a power purchase agreement. One such factor is the uncertainty in the renewable energy insurance sector, the risk that comes along with this uncertainty is usually passed on to the system host [8]. The insurance scene is discussed in the next subsection.

5.2 Underdeveloped Insurance Scene

From the cost analysis of both photovoltaic and wind energy systems presented in section 4 of this report, it can be seen that these systems require a sizeable investment. Like most pieces of machinery however, additional costs would be incurred over the lifetime of the equipment. While the issue of insurance may be considered a good precautionary measure by some, it is usually required of those users who intend to interconnect with the utility grid, and for this reason liability insurance coverage becomes a more important issue.

There are two main reasons why utilities require a minimum of liability insurance coverage on wind turbines; against property damage, and personal injury. Although property damage reports from wind turbines are very few, the possibility of its occurrence still remains. The greater concern lies in the personal injury causing potential of wind turbines [7]. PV systems and wind turbines alike present a risk of electrocution to utility workers during line outages, as they could potentially back feed power into the grid at any time. This issue has been addressed by the inclusion of circuit breakers which disconnect the equipment from the grid when grid failures occur. Nevertheless, this issue still serves as a contributory factor to the insurance requirement for grid-tied systems.

The renewable energy insurance sector has remained underdeveloped for a number of reasons. Among these reasons are a dearth of information about historical losses and insurance claims related to PV systems, as well as limited independent test data for the verification the actual performance of the systems, apart from manufacturers’ assertions [8]. Due to the absence of these essentials, insurance premiums account for a lot more than is expected for a system with no moving parts. In order to get past these problems, and make for a better insurance scene, there needs to be open communication between all parties involved; PV developers, the insurance industry, and government labs. When this is
accomplished, the insurance industry would have a better chance at developing insurance products to keep up with the growth of the PV industry. Furthermore, the establishment and enforcement of uniform standards for installers would help allay some of the fears of the underwriters. The expected overall effect of these measures would be a reduction in insurance premiums for renewable energy systems.

5.3 Cost of Integration

Owing to the variability of insolation (and wind), the energy output of renewable energy systems is deemed unreliable. This, in part, explains the percentage of renewables in the energy mix of many states including Texas is low. To gain a better understanding of the situation, one needs to consider the standard operating procedure of the current power system. Because of the long startup times of certain generator, load forecasting is used extensively in planning. Since the load forecast cannot be perfectly accurate, load-following is used to adjust the power output of the generators all through the day, in order to balance generation and load. An important characteristic and major advantage of traditional sources is the ability to increase generation to match demand whenever it is needed. However, whereas the same cannot be said for renewables, as these sources are unpredictable and therefore somewhat unreliable.

One outcome of the limited reliability of renewables is that it creates a need to keep the traditional generators online as backup for contingencies. Thus, when renewables are integrated with traditional sources, the legitimacy of a load forecast suffers due to uncertainty in weather forecasts.

Apart from ongoing research in weather forecasting, a number of possible solutions have been proposed. One approach, which goes hand in hand which energy storage, is to consider renewable energy as a means of “reducing load.” What this means is that the energy harvested from the renewable will cancel out some of the load, leaving the fossil fuel generators to service the remainder [9]. This approach seems promising, although it relies on the storage of electrical energy, which is known to be expensive.

5.4 Complexities Resulting from Restrictive Incentive Eligibility Criteria

FIT policies have to be carefully formulated to prevent two things; overpayment and underpayment. They must not be too high, or PV system owners tend to profit unduly from the system. On the other hand, if FIT payments are too low, they would fail to achieve their intended purpose accelerating grid parity. To achieve the desired results while preventing the undesirable, eligibility for FITs is usually accompanied by appropriate restrictions, most notably such as system size (installed capacity). Incidentally these same restrictions, while serving their purpose, also have some undesirable results. One example is the under-utilization of spaces due to installed capacity limits on FIT supported
systems, as can be seen on the California rooftop in Fig.23. Owing to system size restrictions for incentive eligibility, this system owner, like many others deems it wise to install just enough capacity even though the rooftop has more useful space lying fallow [37].

Fig 23.An Outcome of System Size Caps – Underutilization of Useful Rooftop Space [37]

5.5 Promoting Growth of Photovoltaics

Financial incentives are the backbone of PV. Without them, most homeowners would not be able to afford PV and may lose their interest in solar. There are several different policies designed to foster the growth of PV. Some of these mechanisms have yielded outstanding results which could be directly attributed to their implementation; feed-in tariffs in particular can be credited for the growth of the renewable energy sectors in Spain and Germany.

Feed-in tariffs are arguably the most successful financial incentive in the PV industry worldwide. Many countries have recorded tremendous growth in their renewable energy sectors, attributable to the implementation of FIT policies. Generally, an FIT policy is a legal agreement between a PV system owner and a utility, in which the utility commits to purchase excess power generated by the customer’s PV system. Although different varieties exist, certain attributes are common to FITs; a long-term contract, pricing that is targeted at attaining grid parity, and guaranteed grid access for the customer are among the common ones. The implementation of FIT policies has yielded very positive results in many different settings. If implemented in Texas, it promises favorable results.

In spite of the potential for good results, FIT policies have not yet been widely adopted in the United States. Several contributory factors exist. The background work needed to ensure that the tariffs are placed at the right amount is immense. Also, the nature of a FIT as a recurring payment does not
relieve a PV system owner of the initial costs of the system; consequently, intending owners must find other sources to fund the purchase of their systems [38]. However, once these have been surmounted, the FIT program holds a lot of promise.

In the U.S, there is a mix of financial incentives, and this could potentially be a good approach. However, because is usually no coordination between them, their purpose is not being maximized. Of particular interest is the system adopted in the E.U, where feed-in tariffs have been employed heavily. A direct correlation could be made between the financial incentive in that region, and the state of their PV markets. It is interesting to note that although California has about 50% more sunshine than Germany, “Germany installed ten times more solar than California in 2008.” Figs 24 and 25 illustrate these points. It may be a little simplistic to suggest that the U.S should immediately drop all its existing financial incentive policies, nevertheless a thorough analysis of how the European system might benefit the U.S needs to be done and FIT policies seriously considered.

Fig 24.US vs. EU RE Policies [39]
6 CONCLUSIONS

Texas has developed wind resources and some biomass resources, but it has accomplished very little in promoting solar energy, either for large-scale generation or for distributed use by homes or businesses. The report shows that renewable energy development is going to be a force in creating jobs and investment in the years ahead. The study explains how state policies that support the clean energy sector of our state’s economy can create jobs, increase our gross state product (GSP) and increase local and state tax revenue [9].

Opponents may argue that clean energy is too expensive. However, the costs of clean energy in Texas are not as great as opponents claim – about a postage stamp a day for the average Texas family -- even before considering how carbon pricing would affect cost comparisons between traditional fuels and clean energy. Costs for clean energy have declined steadily over the last 30 years as clean energy technology improved, and the trend is expected to intensify. Overall, the cost differences between clean and traditional energy are less extreme than critics often imply and the differential continues to decline steadily [9].

If the 2011 Texas Legislature decides to raise the state’s RPS to 13,000 MW of clean power and sets aside 3,500 MW for solar photovoltaic energy, as the High Range scenario assumes, Job gains would jump to 22,900 per year, Texas GSP would increase by $2.7 billion per year, and state and local tax revenues would increase by $279 million per year, or more than half a billion dollars per biennium [9]. The report makes a series of recommendations for Texas’ clean energy policy, including:
• Expanding financial incentives for clean energy, such as rebates, bond programs or exemptions from state and local sales taxes for clean energy devices and installation costs [9].

• Enacting a statewide net metering program [9].

• Development of enhanced and accurate data analysis tools which take into account the solar and wind resource patterns in an area as they can help optimize the system size with respect to cost and energy delivered.
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