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Grid Parity and Defection Studies in Major Philippine Cities Using Solar Photovoltaic-Plus-Storage Configuration

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Due to the rapidly declining costs of solar photovoltaic (solar PV) modules and batteries, the possibility of defecting from the grid is starting to become an alternative for some consumers. Should many consumers defect from the grid, given the current rate structures, electricity prices would increase even faster which will further encourage more people to defect from the grid. This positive feedback loop has been called the "utility death spiral". Previous grid defection studies were conducted in the United States, Australia, as well as some countries in Europe. In this work, the technical feasibility and economic viability of grid parity and defection were determined for residential customers in the major cities of the Philippines (Manila, Cebu and Davao) based on the franchise areas of Manila Electric Company, Visayan Electric Company, and Davao Light and Power Company. The grid defection analysis was divided into customer clustering, levelized cost of electricity (LCOE) calculation, and finally grid parity comparison. Three main clusters were identified based on the k-means clustering by utilizing 18 different features in order to get a more detailed overview on how many customers of each type are more likely to defect based on the representative load profiles from MERALCO. Average silhouette widths of 0.657, 0.587 and 0.585 were obtained for the three clusters. Based on the clusters, the LCOE of optimally sized solar PV-battery systems were calculated using Hybrid Optimization Model for Multiple Energy Resources Software, from 2018 up to 2050. The LCOE data were then compared to the projected retail electricity prices based on the actual data from the mentioned distribution utilities to find the economic viability of grid defection per customer cluster. Results show that grid parity and defection would be possible for residential customers starting in the next 30 y, with customers from Cebu more likely to defect first followed by Manila and then Davao. Based on the clustering, it was observed that the grid parity occurred earliest in Cluster C, followed by Cluster B, and then Cluster A. Different scenarios were also explored depending on the rate of decrease of local prices of photovoltaics, lithium-ion batteries, and a combination of both. Results show that decreasing battery prices play a bigger role achieving grid parity in the country.

1. Introduction

As energy technologies improve, electricity consumers today now have multiple options of where to source their power. One of the more popular renewable alternatives to being connected to the grid is solar energy through the use of solar PV modules. This could in effect become an economical alternative to the traditional sourcing of energy. Grid defection happens when a customer leaves the grid in favor of another more economical source of energy. Grid parity occurs when grid defection becomes an economical alternative to grid connection. Across the world, the study of grid parity and defection has been done recently in the past five years in countries such as United States (Bronski et al., 2014), Australia (Khalilpour et al., 2015), and the Netherlands (Waleson, 2017) as well as systems with combined heat and power systems for cogeneration (Kantamneni et al., 2016). If numerous people choose to defect from the grid, the fixed costs of the distribution utility would be shared among the remaining grid connected consumers, effectively increasing their retail electricity price. This increase in retail electricity prices, when coupled with the continuously decreasing prices of alternative sources of electricity,

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makes it even more encouraging to leave the grid or defect from it. If the traditional tariff models of utilities do not change, this could potentially result into what is more commonly known as the “utility death spiral” which have been studied previously (Muaafa et al., 2016), where grid defection becomes a more economical alternative driving customers to continually leave their distribution utility.

The Philippines has one of the highest residential electricity rates in Asia, with an average retail price of 10.22 PHP/kWh or 0.20 USD/kWh, second only to Japan with 0.25 USD/kWh (Lectura, 2018). Due to its geography as well as location, solar energy has been an abundant source of energy all over the country. Aside from this, the cost of solar PV was also observed to decrease in the past year while at the same time photovoltaic technology adoption continues to increase in the country with 3.22 MW out of the total 684 MW installed capacity in 2017 belonging to private use (Department of Energy, 2016). An average growth rate of 3,795 % was also observed from 23 MW in 2014 to the 896 MW total installed capacity of solar PV in 2018 (Department of Energy, 2019). Energy storage systems increase the reliability of solar PV by storing the energy gathered during the day for later use. The most common energy storages coupled with solar PVs are batteries. Lithium-ion batteries continue to outperform other battery chemistries because of its lightweight, deeper depth of discharge, as well as longer lifespan. Solar PV and lithium-ion battery technology help decrease the LCOE of the system in order to achieve grid parity earlier.

The LCOE of an energy system represents the total annualized cost of the system divided by the annual energy supplied by the system through its lifetime. By comparing the LCOE of a solar PV system-plus-battery configuration to the retail price of electricity, it is possible to find out when grid parity and defection would occur. Optimized LCOE, RE share, and optimal component sizes are just some of the information that could be obtained by using commercially available software like the Hybrid Optimization Model for Multiple Energy Resources (HOMER). Clustering on the other hand, is a method of classifying data based on their pattern by choosing an appropriate algorithm and determining the number of clusters in a given dataset. Load profile clustering analysis has been done before using different techniques and for different types of customers (Damayanti et al., 2017). Obtaining specific information on the feature of a load profile can identify which group of customers would be able to reach grid parity first.

The objective of this work is to identify when and where would defecting from the grid be an economical alternative for residential customers in major cities in the Philippines using the franchise areas of Manila Electric Company (MERALCO), Visayan Electric Company (VECO), and Davao Light and Power Company (DLPC). It aims to find out which groups of residential customers are able to defect from the grid first via k-means clustering. It also aims to identify the order at which grid parity would occur based on these clusters and location and how different scenarios such as rapidly decreasing photovoltaic and battery costs affect the time of grid parity. As far as it is known, there has not been any previous grid defection study for the Philippines. Previous grid defection studies worldwide have not included the clustering of distribution utility customers which could help fill the gap in identifying consumer load profile features that help reach grid parity. This work would provide valuable insight for energy policy making in the government as well as provide the distribution utilities an understanding of what could happen, should the current trends continue to progress. Ultimately the analysis can be helpful to the consumer as it provides them the information of when, where, and in what specific conditions they can leave the grid for the more renewable solar energy. The scope of this work includes only complete defection and does not take into consideration grid tied systems.

2. Methodology

The general flow of analysis is shown in Figure 1 below and is divided into three main parts. The first part involves the clustering of the load profiles of the residential customers. The second part involves the calculation of the LCOE based on the optimal sized photovoltaic-plus-battery systems and the available solar data. Finally, the calculated LCOE is compared to the projected retail electricity rates per franchise area.

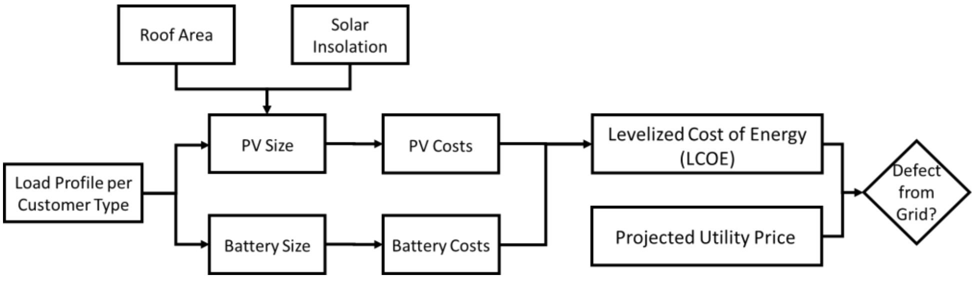

Figure 1: General Flow of Analysis

2.1 Customer Clustering

A sample size of 384 monthly residential load profiles was first obtained from MERALCO to get a 5 % margin of error and 95 % confidence level based on the 99,194 population size of customers with available load profile of the franchise area (Daniel, 2019). Load profiles from MERALCO were used for all three distribution utilities. An analysis of k-means was then performed in order to cluster the given data and was done using a 2 z-transformed principle component based on 18 features for each observation in order to identify distinct characteristics that lead to grid parity. These 18 features include the monthly energy consumption for the 12 months of the year, the minimum, maximum, mean, median, standard deviation, and the sum of energy for each customer. Boxplots, scatterplots, and silhouette plots were done in order to showcase the differences in the clusters, as well as to quantify the quality of clustering.

2.2 LCOE Calculation

The optimization of the LCOE was based on the technical assumptions summarized in Table 1 below. This information was obtained from a survey of costs in the Philippines. The yearly solar energy resource per city was obtained from the Phil-LiDAR 2 dataset. These data were then analyzed using HOMER in order to generate the optimal system configuration that minimizes the system cost while at the same time meeting the energy demand of the customer. Based on this configuration, the LCOE of the system can then be generated. The calculations were performed from 2018 up to 2050.

Table 1: Summary of Technical Parameters

Technology	Parameter	Value	Unit
Solar PV	Initial Costs	670	[USD/kW]
	Operation and Maintenance	10	[USD/kW/y]
	Lifetime	25	[y]
Lithium-ion Battery	Initial Costs	900	[USD/kW]
	Operation and Maintenance	10	[USD/kW/y]
	Lifetime	15	[y]
	Maximum Depth of Discharge	80	[%]
	Maximum no. of Cycles	4,500	Cycles
	Initial State of Charge	0	[%]

2.3 Grid Parity Comparison

The calculated LCOE values can then be compared to the retail electricity projections of each of the franchise areas of MERALCO, VECO, and DLPC. A retail price wedge was used to cover a wider range of price projections. The lower bound of 0.1 % was calculated based on the historical prices of the distribution utilities while the upper bound of 3.5 % was based on the Electricity Price Index Projection of the Philippines for 2018. These price projections were then compared with the calculated LCOE. Grid parity was then identified by taking the year where the LCOE for the solar PV-plus-battery configuration becomes lower than the projected retail price of electricity which indicates the economic viability of grid defection. These grid parity comparisons were examined for four different scenarios shown below:

- Case 1: Base – This case considers solar PV projections based on the New Energy Outlook of the Bloomberg New Energy Finance which projects solar PV costs to drop by up to 71 % by 2050 (Henbest et al., 2018). On the other hand, lithium-ion battery price projections were based on the work of (Schmidt et al., 2018) which predicts a decrease in lithium-ion battery prices of up to 33 % by 2030, and as much as 50 % by 2050
- Case 2: Accelerated PV Cost Reduction – This case considers a 5 % faster reduction of solar PV prices compared to the base case.
- Case 3: Accelerated Battery Cost Reduction – This case considers a 5 % faster reduction of lithium-ion battery prices compared to the base case.
- Case 4: Combined – The combined improvement scenario applies both of the accelerated PV and battery cost scenarios.

3. Results and Discussion

This section describes the results of the customer clustering, LCOE calculation, and the grid parity comparisons described in the methodology above.

3.1 Customer Clustering

Out of the 384 samples, three main clusters were obtained from the clustering algorithm. The boxplots shown in Figure 2 below show the main difference of the three clusters. It was observed that 8.97 %, 68.34 % and 22.69 % of consumers were grouped into clusters A, B, and C. It can be noted that cluster A was found to have decreasing energy consumption in the latter part of the year, although it represents less than 10 % of the whole sample size. Mean monthly energy consumption was found to be 195.03, 79.27, and 266.49 kWh for clusters A, B, and C. It can be seen that cluster C has a high average monthly consumption which is more than triple of that of cluster B even if majority of residential consumers are grouped in cluster B.

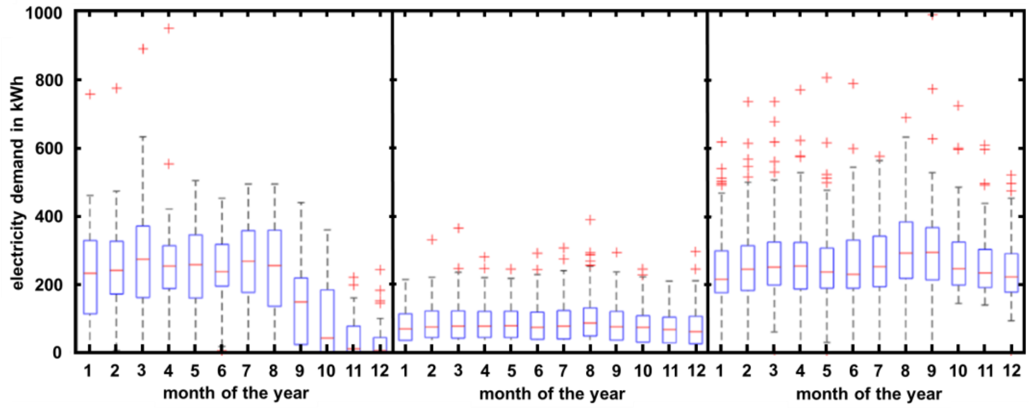

Figure 2: Boxplots of three main clusters of monthly load profiles

A silhouette plot of the clusters was also created to quantify the quality of the clustering. This is shown in Figure 3 below. Average silhouette widths of 0.657, 0.587, and 0.585 were calculated for different k indicating good clustering. A scatter plot is also shown below to visualize the grouping and inter-relationship of each of the clusters.

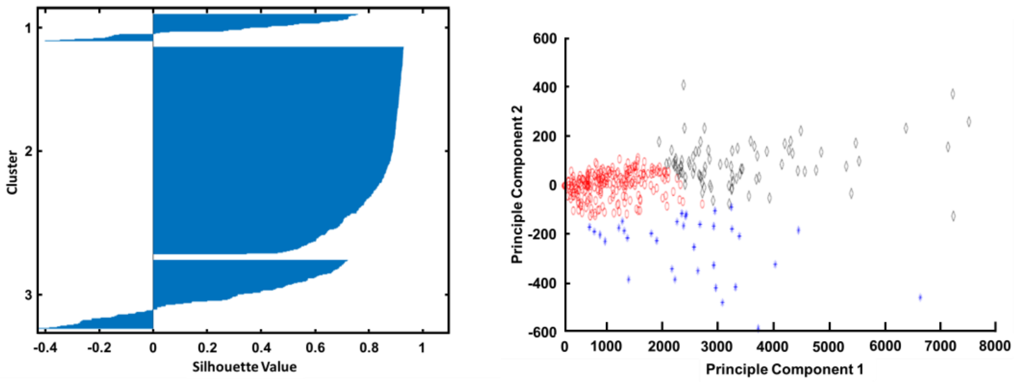

Figure 3: Silhouette Plot and Scatter Plot

3.2 Grid Parity and Defection Comparison

After clustering the customers, the representative annual energy and load profile were used to calculate the LCOE for each franchise area. The plots were superimposed with the corresponding projected retail electricity price as shown in Figure 4 below which shows the Manila Base Case through the three different residential clusters identified. It can be seen that the order of reaching grid parity is cluster C, then B, and then A.

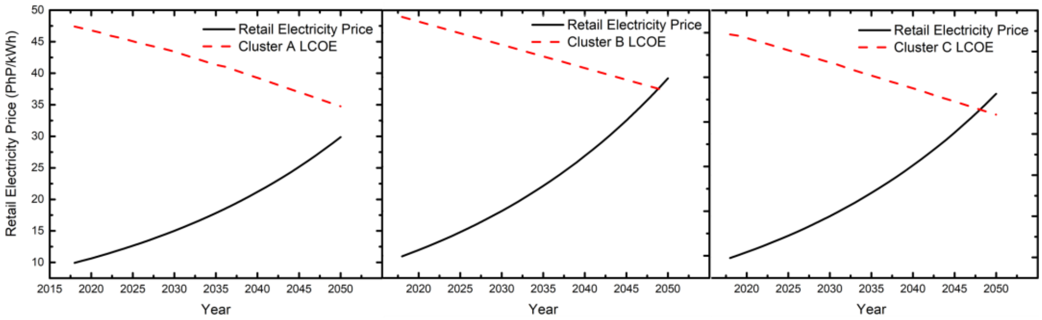

Figure 4: Grid Parity for Manila Base Case across Clusters A, B, and C.

On the other hand, the summary of grid parity for a specific cluster across different locations were found to be uniform in all three clusters. Figure 5 below shows the grid parity comparisons for cluster C. It can be seen that Cebu would reach grid parity followed by Davao, and then by Manila. This is mainly due to the higher electricity rates in Cebu as compared to Davao and Manila.

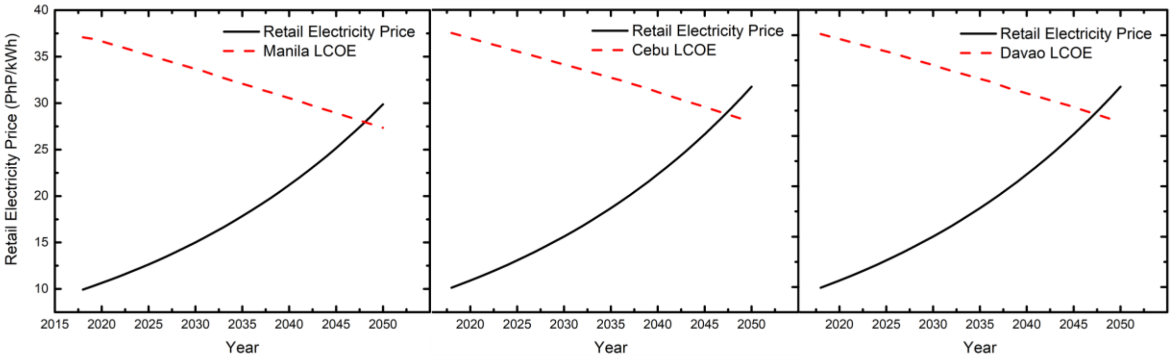

Figure 5: Grid Parity for Base Case Manila, Cebu and Davao for Cluster C.

3.3 Scenario Analysis

Grid parity comparison was also done for the four different scenarios mentioned above. The results are summarized in Figure 6 below. It can be seen that the combined reduction of battery and solar PV prices were able to decrease the time it took for grid parity to occur by more than half a decade. It was observed that the decrease in battery prices had a much bigger effect than the solar PV because of the current high prices of lithium-ion batteries in the Philippines.

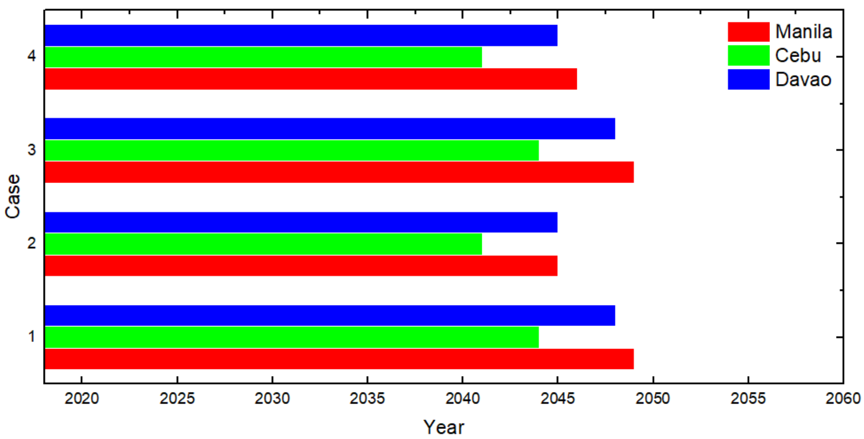

Figure 6: Grid Parity Timeline for Residential Cluster C

4. Conclusion

In this work, grid parity in Manila, Cebu, and Davao was predicted based on the monthly load profiles grouped together through the use of k-means clustering. Three main clusters were identified representing 8.97 %, 68.34 %, and 22.69 % of the sample residential customers. Cluster C was found to have the highest average monthly energy consumption of 266.49 kWh followed by cluster A with 195.03 kWh and cluster B with only 79.27 kWh. Silhouette plots have shown average silhouette widths of 0.657, 0.587, and 0.585 indicating good clustering. Based on this information, it was estimated that grid parity would occur first in Cebu in 2047, then in Davao in 2050, and finally in Manila post 2050. This was mainly due to the higher retail electricity price in Cebu as compared to Davao and Manila. Across all locations, it was observed that residential customers from cluster C would most likely defect first followed by cluster B, and then A. Rapidly decreasing battery prices were also found to have the greatest effect on the time of grid parity due to the high prices of lithium-ion batteries in the Philippine market. It was found that for case 4, where both solar PV and lithium-ion battery prices decreased rapidly, grid parity was achieved earlier by 7 y as compared to the base case. There is still ample time for distribution utilities to adjust their business revenue models to adapt the concept of grid defection unless the prices of batteries drop more than the estimated amount in the next few decades. Future work in the Philippine context could include the step by step transition to grid defection. Nevertheless, many insights could be gained from identifying when grid tied solar PV as well as grid tied solar PV-plus-battery systems would be economical for residential customers.

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