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Economic Analysis of PV-Utility Grid Hybrid Electric Vehicle Charging Station in Mandalay City

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Abstract

Electric vehicles (EVs) are catching on everywhere worldwide. Building more clean energy infrastructure for EVs could help lessen greenhouse gas emissions and make city air cleaner. EVs charged with electricity from solar panels emit fewer pollutants compared to those charged with grid electricity. Therefore, combining solar power with EV charging stations could be a good way to promote sustainable development in the EV market. Despite rapid EV adoption in Mandalay, the charging infrastructure remains limited, mostly stations reliant on grid electricity. In this paper, the proposed system integrates photovoltaic technology with the existing utility grid infrastructure of EV charging station at the corner of 78th road & 101st road in Mandalay city, Myanmar. HOMER Grid is utilized to analyze the economic feasibility. The results of the proposed system describe that the cost of energy (COE) is reduced by $0.05/kWh. Additionally, the integrated system incurs fewer costs and generates more profits.

A. Introduction

The transportation industry plays a crucial role in emitting greenhouse gases and contributing to air pollution, underscoring the pressing necessity for sustainable alternatives. Electric vehicles (EVs) are seen as a hopeful remedy to alleviate environmental harm and decrease reliance on fossil fuels. However, the widespread adoption of EVs is subjected to the availability of effective and usable charging configuration. In this regard, the integration of solar photovoltaic (PV) technology with the grid is presented a compelling opportunity to enhance the sustainability and economic viability of EV charging stations[1-2,10].

Researchers studied both on-grid and off-grid hybrid systems to generate electricity using various economic methods and tools. Researchers are introduced different methods worldwide for using renewable energy in EV charging. Many countries have looked into using renewable energy for EV charging stations [3, 17-20]. Here's a summary of their findings. Muna Y.B. and Kuo C.-C evaluated EV charging stations powered by hybrid renewable systems in three Ethiopian cities. It tested three battery types (Lead-acid, Flow-Zince-Bromine, Lithium-ion) individually and compared them in terms of system size, cost, performance, and environmental impact. The results showed that Flow-Zince-Bromine batteries are the most cost-effective choice [17]. Another study examined the financial feasibility of using solar-powered EV charging stations in Ngawi City, Indonesia, known for its abundant solar energy potential. It considered factors like energy demand, system capacity, and costs. Using HOMER software, the analysis described that solar PV systems can meet the power needs of EV charging stations, even generating extra energy for potential profit [18]. In Vietnam, The best setup for PV-powered EV charging stations is analyzed with considering technical and economic factors . Results suggested that areas with higher solar irradiation, like Ho Chi Minh, are more favorable for investing in these stations compared to regions with lower irradiation, such as Hanoi [3]. whether a hybrid solar PV and battery energy storage system (BESS) is examined with economically viable for EV charging at Chulalongkorn University in Thailand. According results, level 2 solar PV stations is more favored than BESS due to cost. Lower BESS costs could improve project returns. The study aims to promote environmentally friendly EV charging using renewable energy [19]. A standalone renewable EV charging station in Qatar is evaluated optimizing its configuration using HOMER software. It compared the optimal solution with grid extension options across four cities. This methodology can be applied anywhere, considering local weather conditions[20].

In this paper, HOMER software is used to analyze the costs and profits of utility grid, PV+utility grid+battery, PV+utility grid and utility grid+battery models. The net present cost (NPC) and cost of energy (COE) are checked in four setups to find the cost-effective solution. Cite location is selected Mandalay city.

Mandalay city, located in the central region of Myanmar, is experiencing rapid urbanization and economic growth, accompanied by an increase in energy demand. The city's transportation sector is relied heavily on conventional fossil fuel-powered vehicles, which contribute to air pollution and environmental degradation. The government of Myanmar has expressed its commitment to promoting sustainable development and reducing carbon emissions, making

Mandalay city an ideal candidate for the implementation of clean transportation solutions such as EVs.

In this paper, the input datas are based on sunlight, electricity prices, EV charging needs, and grid reliability parameters to Mandalay city in Myanmar. The software is evaluated various system configurations, considering the sizing of PV arrays, battery storage capacity, and grid interaction. Economic metrics such as levelized cost of electricity (LCOE), net present value (NPV), and payback period are calculated to assess the economic viability of the proposed charging station over its operational lifespan.

The rest parts of these paper is organized like this: Section B described the required parameters of exisiting charging station, Section C showed the results methods, Section D is explained configuration and working principle of the proposed PV-utility grid EV charging station and Section E presented the results and discussion and Section F concluded this paper.

B. Existing Charging Station Grid System of Mandalay

Selected Site Description

Mandalay Region is a very suitable location for solar PV production due to its tropical climate and consistent sunshine throughout the year. Located in the tropical region of Myanmar, Mandalay Region is a good place to generate solar energy all year round. This is because it gets consistent sunlight most of the year and its seasons are more about wet and dry periods rather than drastic changes in sunlight.

Situated at 21.9747 north latitude and 96.0836 longitude, Mandalay experiences more wet and dry seasons than temperature fluctuations between seasons. Consequently, there are no predominant weather patterns that would significantly hinder solar PV power generation in this area [7]. EV charging station at 78 st & 101 st is choosed for this research. Because of these roads are main roads in Mandalay city. And, these roads are the most incoming and outing cars places compared to the other roads.

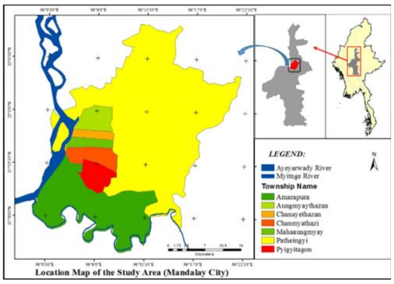

Figure 1. Location Map of Mandalay City

Situation of Existing Grid Tied EV Charging Stations at Corner of 78 th & 101 st, Mandalay

In existing utility grid charging station, the current installed power is 500kW. The charging power, often measured in kilowatts (kW), depends on the charging equipment. Select a Level 3 (DC Fast Charging) 50 kW to 350 kW (High-speed public charging stations)charger with a 60 kW charging power.

Table 1. Charging Station Characteristics

Charging Station Characteristics	
Charging Level	Level 3(DC Charging)
Capacity	50KWh
Power Level	500kw(100KW*5number)
Voltage	380 V
Pile	5 pile (10 ports)

The charging number of electric vehicle is calculated according to the following Table 2. Table 2 and Figure 3 are described the hourly traffic of (101st) street and (78th) street, Mandalay City. It is observed that the number of incoming and outgoing vehicle is high at 6:00 AM to 8:00 AM and 4:00 PM to 6:00 PM. Therefore, the number of charging vehicle is assumed full load (10 vehicles) at these times which is shown in Table 2.

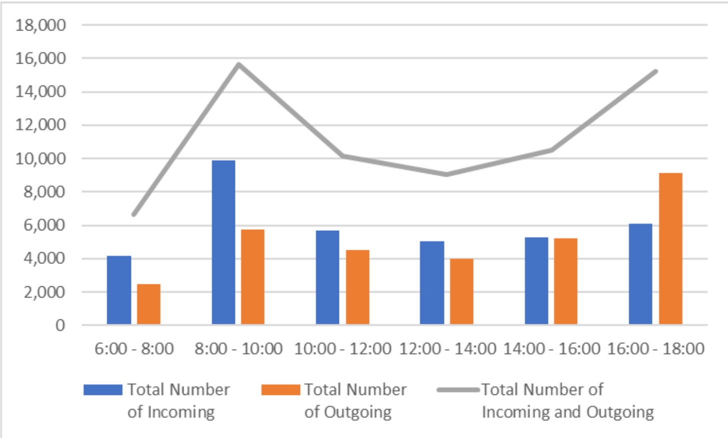

Figure 2. Total Number of Incoming and Outgoing Vehicle to Mandalay City at 101st Road and 78th Road

Table 2. Total Number of Incoming and Outgoing Vehicles to Mandalay City at 101st (Theikpan)Road and 78th Road

No	Time Interval	Total Number of Incoming	Total Number of Outgoing	Total Number of Incoming and Outgoing
1	6:00 - 8:00	4,184	2,470	6,654
2	8:00 - 10:00	9,893	5,725	15,618
3	10:00 - 12:00	5,681	4,495	10,176
4	12:00 - 14:00	5,030	3,990	9,020
5	14:00 - 16:00	5,255	5,243	10,498
6	16:00 - 18:00	6,120	9,123	15,243

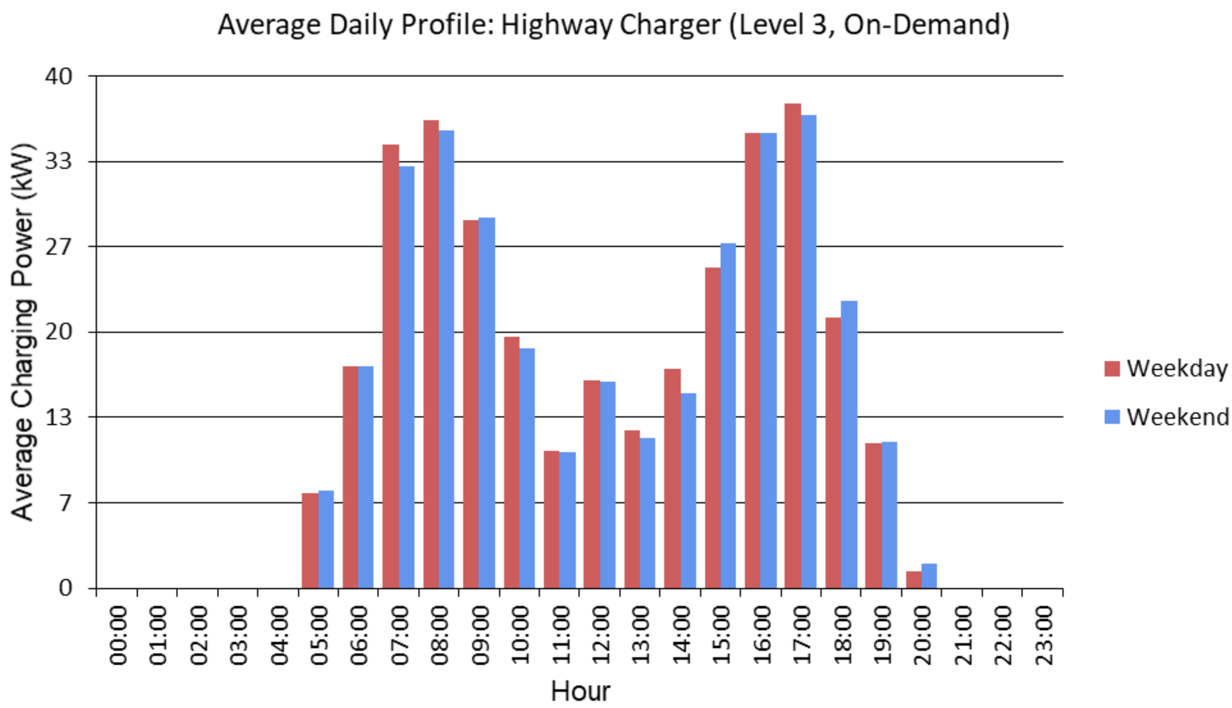

Figure 3. Daily Load of Charging Station

From the Homer data, the monthly average solar global horizontal irradiance in Mandalay city is 5.12 kWh/m^2.day in Figure 4. The highest irradiation month is Apirl (6.37 kWh/m^2/day) and the lowest irradiation month is November (4.39 kWh/m^2/day).

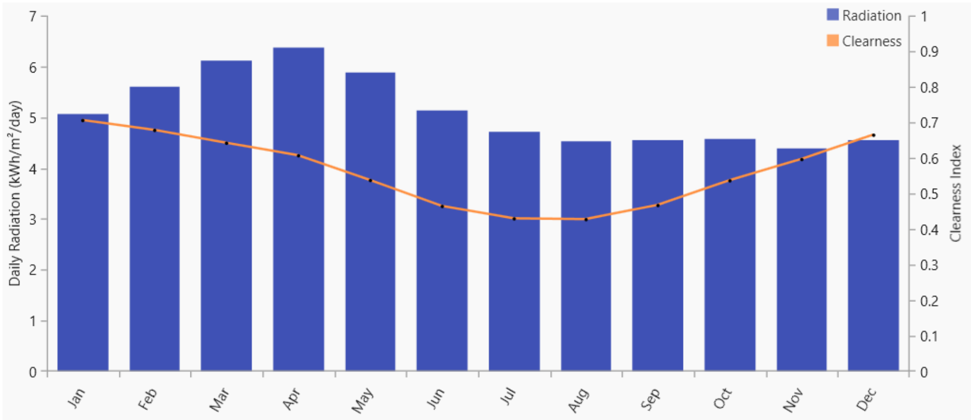

Figure 4. The Monthly Average Solar Global Horizontal Irradiation In Mandalay City

C. Research Methods

In this paper, HOMER Grid software is used to design and optimize a PV-Utility grid electric vehicle (EV) charging station. HOMER Grid is a microgrid simulation program that supports grid-connected renewable power systems and employs algorithms to optimize the utilization of solar, wind, and storage, thereby minimizing overall energy costs. This software also enables modeling of EV charging stations combined with clean power sources like PV and wind energy, facilitating the design of optimal renewable energy and storage systems to reduce utility costs and demand charges associated with EV charging[3].

Technical-economic parameters are described using equations within HOMER, such as those determining solar panel output and maximum battery system charge power[11]. The optimization process aims to reduce the net present cost (NPC) over the project's lifetime, considering factors such as total annualized cost, annual real interest rate, and number of years[12]. Additionally, HOMER calculates the cost of energy (COE) as the average cost per kWh of useful electricity generated by the hybrid power system. In HOMER, the main techno-economic parameters are defined by equations. The output of the solar panel[4]:

$$P_{PV} = Y_{PV} f_{PV} \frac{\overline{G_T}}{G_{T,STC}} [1 + \alpha_P (T_C - T_{C,STC})] \quad (1)$$

Where, P_{PV} = Solar panel output power (kW)

Y_{PV} = The rated capacity of the solar array

f_{PV} = PV derating factor (%)

GT = Solar radiation incident on the solar array (kW/m^2)

$G_{T,STC}$ = Incident solar radiation under standard test conditions (kW/m^2)

α_p = Temperature coefficient of power (%/C)

TC = Solar cell temperature (C°)

$T_{C,STC}$ = solar cell temperature under standard test conditions (25°C)[6].

The maximum battery system charge power is calculated by Equation 2:

$$P_{batt,Cmax,mcc} = \frac{N_{batt} I_{max} V_{nom}}{1000} \quad (2)$$

where N_{batt} = The number of batteries in the storage bank

I_{max} = The storage's maximum charge current (A)

V_{nom} = The storage's nominal voltage (V)[9].

Net present cost (NPC) is the current cost value of installation and operation of the system during the project lifetime. The aim of the optimization process is to reduce the net present cost with the following Equation 3[5]:

$$NPC = TAC,[(1+i)^n - 1]/[i^n[(1+i)^n]] \quad (3)$$

Where, TAC = The total annualized cost ($)

I = The annual real interest rate (%)

n = The number of years.

In HOMER, the cost of energy (COE) is describe as the average cost per kWh of electricity generated by the hybrid power system. The Equation 4 for the COE is as follows[8]:

$$COE = \frac{TAC}{E_{useful}} \quad (4)$$

Where, TAC = the total annual cost ($)

E_{useful} = The production electricity per year (kWh/year).

In terms of environmental impact, HOMER assesses CO_2 emissions by determining net grid purchases and multiplying them by the emission factor of the Myanmar electrical grid. The optimization design process for the PV-Utility grid EV charging station in Myanmar follows a structured framework, including steps for importing input data, simulating feasible system configurations, evaluating technical and economic results, and presenting optimized configurations based on net present cost.

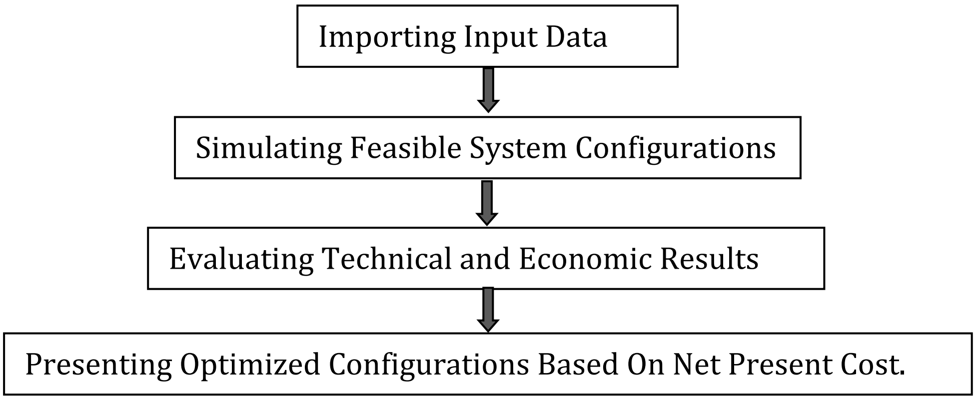

Figure 5. The Framework of Optimization Design of PV-Utility Grid EV Charging Station Using HOMER

D. Components of the Proposed PV-Utility Grid EV Charging Station

Configuration and Working Principle

This setup included the main components of the PV system, bi-directional converters for DC-AC and AC-DC conversion, connection to the utility power grid, backup batteries, and electric vehicles[13]. This configuration optimized the cost of electrical energy supply, lowers the expenses associated with solar power systems and batteries, and reduces carbon emissions[14]. In this model, electric vehicles are charged directly from the solar power system during the day or from the utility grid at night or during adverse weather conditions. Any surplus electricity generated by the solar power system is sold back to the local utility grid as per Myanmar government policies supporting rooftop solar power[15]. Consequently, the batteries installed in the EV charging station are sized to fulfill minimum energy storage requirements and provided backup power when neither solar nor grid power is available, thus minimizing the overall investment cost of the system[16].

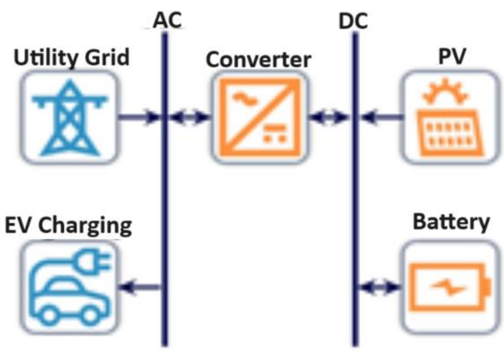

Figure 6. Block Diagram of PV-Utility Grid EV Charging Station

System Parameters

Technical parametera of the main equipment in the PV-Utility grid hybrid EV charging station system in the HOMER Grid are described in Table 3. Electricity purchase price from the utility grid is determined according to the regulations of Myanmar Electricity Corporation, by which the company bought the electricity from the utility grid with an average price of about 0.16 $/kWh and sell to EV charging customer about 0.29 $/kWh, while the selling solar power price from company to Myanmar Electricity Corporation about 0.04 $/KWh.

Table 3. Sizing Components and Other Parameters

Component	Size and Unit Number	Life	Other Information
PV system	1500 kW	25 years	Derating factor: 80%
Bidirectional Converter	32 kW	10 years	Converter efficiency: 98% Rectifier efficiency: 95%
Utility grid	500 kW		Purchase from Utility Grid: 0.16 $/kWh Sellback to EV Charger Customer : 0.29 $/kWh
Battery	36 units	10 years	Properties per unit: Voltage: 3.7 V Capacity: 167 Ah
EV charging	10 units of EV 50 kW		Max charger output power: 48 kW

The costs of the PV-Utility grid hybrid EV charging system are shown in Table 2 persumed on the actual costs of the solar power market in Myanmar, where the Operation and Maintenance (O&M) cost of PV system includes the O&M cost of the bidirectional converter.

Table 4. Cost of Energy Supply Resources

Component	Capital Cost	Replacement Cost	O&M Cost
PV system	3000 $/kW	3000 $/kW	20 $/kW/year
Bidirectional Converter	300 $/kW	300 $/kW	
Lithium Battery	700 $/unit	700 $/unit	10 $/unit/year

The annualy EV charging station operating frequency is described in Figure 7 with an average daily charging of 332 kWh/day.

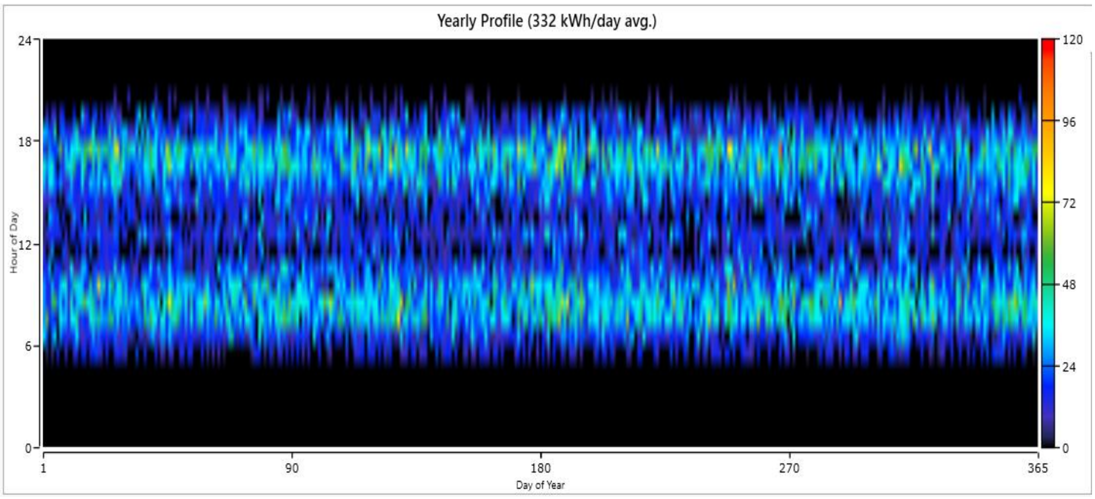

Figure 7. Yearly Profile of EV Charging

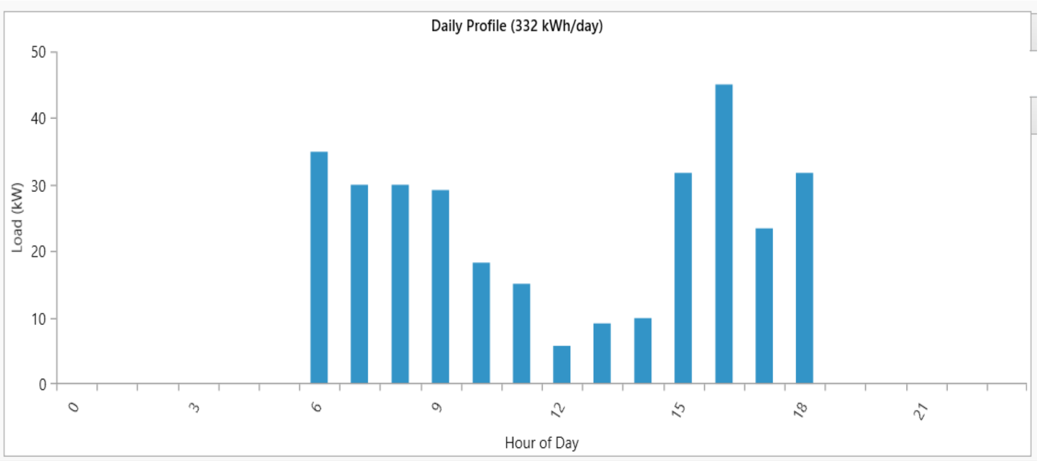

Figure 8. Daily Profile of EV Charging

E. Result and Discussion

HOMER Grid software is employed to assess the most efficient technical and economic setup for PV-Utility grid hybrid EV charging stations in Mandalay cities, Myanmar. This evaluation is conducted under in four setups conditions, while the solar power feed-in tariff (FIT) price decreases from selling price to customer of 0.267 $/kWh to the lowest estimated FIT price of 0.217 $/kWh.

Table 5 showed the best setups for PV-powered EV charging in Mandalay. The grid + PV setup had the lowest cost per kWh, while the grid + battery setup had the highest. The grid + PV + battery setup had the lowest net present cost. However, it had the highest initial cost. The grid + battery setup had the lowest initial investment cost. The grid-only setup had the highest operating cost, where as the grid + PV + battery setup had the lowest. Overall, the grid + PV and grid + PV + battery setups are the most cost-effective according to Table 5. When PV is integrated, the cost of energy (COE) for the EV charging station of Mandalay is reduced by ($0.05/kWh) compared to the existing system, as shown in Table 5.

Table 5. Optimal Configuration of PV-Utility Grid Hybrid EV Charging Stations in Mandalay

	Base Case Exisiting System (Utility Grid Only)	Proposed System		
		PV + Battery Storage: + Utillity Grid	PV + Utillity Grid	Battery Storage + Utillity Grid
Costs and Savings				
CAPEX	$0	$136,011	$117,601	$8,870
OPEX	$32,370	$19,748	$21,857	$31,898
Annual Total Savings ($)	$0	$12,622	$10,513	$472
Annual Utility Bill Savings ($)	$0	$14,469	$10,992	$709
Annual Demand Charges ($/yr)	$9,231/yr	$6,057/yr	$8,634/yr	$8,517/yr
Annual Energy Charges ($/yr)	$23,139/yr	$11,844/yr	$12,744/yr	$23,145/yr
Economic Metrics				
Discounted payback time (yrs)		17.7	19.1	
Simple payback time (yrs)		9.7	10.9	12.5
LCOE ($/kWh)	$0.267/kWh	$0.226/kWh	$0.217/kWh	$0.269/kWh
IRR %		7.99%	7.47%	2.16%
Net Present Cost ($)	$418,465	$391,299	$400,163	$421,231
Environmental Impact				
CO_2 Emissions* (metric ton/yr)	76.6 t/yr	33.5 t/yr	32.7 t/yr	76.6 t/yr
Annual Fuel Consumption (L/yr)	n/a	n/a	n/a	n/a

The monthly generated electricity per year from the solar power system is shown in Figure 9 and the utility grid to ensure the operation of the EV charging stations. Firstly, solar power is applied to charge the EV and the shortage bought from the local power grid. The PV systems in Mandalay city produced the highest electricity from January to Apirl while the period from June to September supplied the lowest electricity.

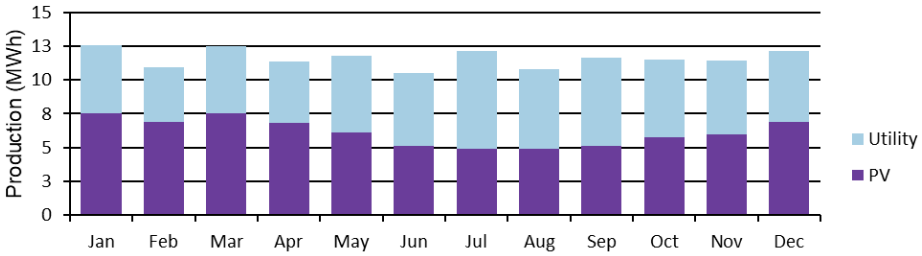

Figure 9. Monthly generated electricity per year from the solar power system and utility grid in Mandalay, Myanmar

Figure 10 is based on the findings, the propose case for saving on monthly utility bills with the PV-Utility Grid-Battery Storage hybrid EV charging station in Mandalay is better than the current one because it costs less.

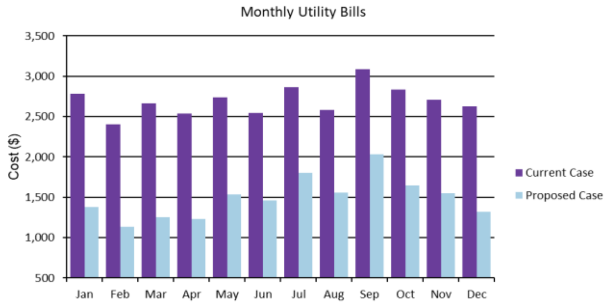

Figure 10. Monthly Utility Bill Savings by Month EV Charging Stations In Mandalay.

The key input parameters have been modified for sensitivity analysis to perform. Figure 11 is shown as a bar chart with a different type representing each of the components in the system. According to this Figure.11, when comparing cost results of PV arrays, PV + Utility Grid + Battery, PV + Utility Grid, and Base Case system, the cost of base case is the highest and that of solar system is the lowest.

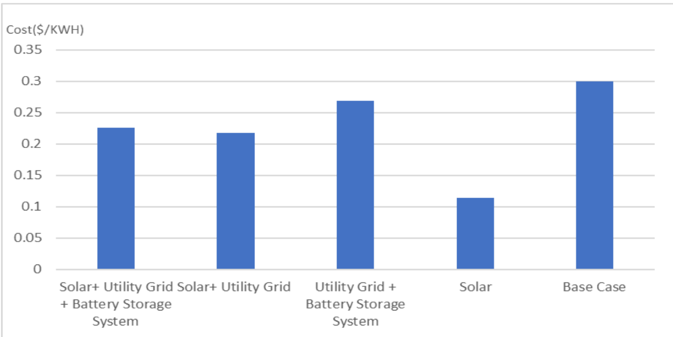

Figure 11. Cost Summary Categorized by Component

Figure 12 shows the nominal cash flow for each year over a 25-year period. Each cash flow is displayed by cost type as a bar chart with each color representing one of four cost types: capital, replacement, operating and salvage. The salvage value appeared as a positive value at the end of the system lifetime.

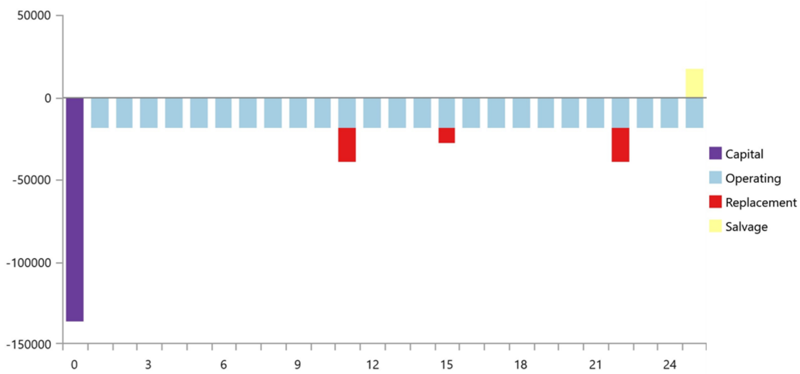

Figure12. Yearly Nominal Cash Flow for the Proposed System

Table 6 is clearly showed that integrating PV sources with the grid is reduced dependency on the grid. The Grid+PV system is produced more energy compared to the Grid+PV+Battery system. This excess electricity is sold to the grid, as indicated by the grid sold data. Despite being grid-connected, all systems still be emitted emissions. The payback period is the time taken for a project to recover its initial investment, and this project's lifetime of 25 years. The grid+PV+battery system had the shortest payback period at 9.7 years, followed by the grid+PV system at 11 years, and the grid+battery system at 13 years.

Table 6. Comparison of Existing and Proposed System

Performance	Systems			
	Grid-only System	Grid-PV-Battery System	Grid-PV System	Grid-Battery System
Grid purchase (kWh/yr)	121,154	65,712	73,237	121,182
Energy Production (kWh/yr)		73,553	75,767	
Grid Sold (kWh/yr)	0	12,693	21,510	0
Total emission (kg/yr)	76,600	33,500	32,700	76,600
Payback (yr)		9.7	11	13

F. Conclusion

In Myanmar, grid electricity operated almost all electric vehicle charging infrastructure, causing increased power demand, cost, and carbon emissions. The feasibility and techno-economic analysis of electric vehicle charging station using utility grid systems combining with PV and battery technology in Mandalay, Myanmar, are focused on in this paper. HOMER software is utilized to analyze the costs and profits of utility grid, utility grid+PV+battery, utility grid+PV, and utility grid+battery models. The net present cost (NPC) and cost of energy (COE) are examined in four setups to determine the best cost-effective solution. These setups considered factors such as load requirements, renewable energy potential, system capacity, levelized cost of electricity, payback period, NPC, and COE. The time required for capital repayment is predicted by combining utilization costs and payback periods in the techno-economic analysis. The findings of this analysis are indicated that the PV-based power generation system is capable of meeting the energy needs of EV charging stations. Additionally, the system generated surplus energy, potentially leading to profitable sales and enhancing its economic feasibility. Moreover, the national grid is strengthened by reducing the additional burdens of electric vehicle charging. Furthermore, installing a solar PV system at an EV charging station reduced the amount of CO_2 emitted by the utility grid. The proposed EV charging station is also contributed to the improvement of reliability and quality service in the energy sector towards sustainable development.

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