

# A simple levelized cost of electricity for EV charging with PV and battery energy storage system: Thailand case study

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## ABSTRACT

This paper proposes the calculation of the simple levelized cost of electricity of PV and battery energy storage system for supporting the investment decision of the EV hybrid charging station. The paper introduces the problems of EV charging against the grid power system. Thus, the hybrid charging for EV is suggested. The study provides an architecture of the hybrid EV charging station along with the factor impacting the EV infrastructure for acknowledgment. The cost elements of the station are presented to address the benefits of the investment. Besides, the profit is mainly from the margin of the electricity price, therefore, this study compares the electricity cost of PV and PV equipped with a battery with the commercial on-peak electricity tariff. The results show that the charging cost contributed by PV alone has the lowest amount throughout the study period year 2020 – 2030. In contrast, the hybrid charging cost contributed by PV and battery has a higher value than the on-peak tariff during 2020 – 2025 but it is lower afterward. The result supports the feasibility of charging an EV by solar power and the hybrid power system in the future.

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## NOMENCLATURE

$sLCOEx$	Simple levelized cost of electricity for x technology
$CRF$	Capital recovery factor
$CF$	Capacity factor
$i$	Interest rate, %
$n$	Year of the project
$O\&M$	Operation & Maintenance
$Pc$	Charging price
$Econ$	Converter efficiency

## 1. INTRODUCTION

Electric vehicle (EV) is becoming an effective transportation mode, thus the power supply adequacy and quality are the main concern to prevent the power supply outage [1]. The energy management strategy, therefore, plays a crucial role in maximizing energy utilization [2–7]. In [8], the impact of EV load on the power system in Thailand has been studied and it is found out that the traditional charging period of EV is from 6 PM – 7 AM. The EV load generates high power ramps in the early morning and evening. Besides, in

case of incorporating photovoltaic (PV), the low power can be occurred in the daytime by the reverse power flow generated by PV; this power profile is the so-called “duck curve” [9-11].

A study of practical solutions to mitigate EV load impacts against the distribution power shows that the splitting transformer to two units and relocation closing to the EV loads can reduce the impact of the voltage drop and peak load demand [1, 10]. However, this requires a high investment from utilities. A simple but effective method is the incentive-based charging period using time-of-use (TOU) tariff; the method provides the capability of flattening power and voltage. Though the TOU tariff has not been deployed in many utilities and the charging regime causes the inconvenience against the EV owner [12]. This scenario has also happened the same in Thailand.

Incorporating with PV distributed energy resources for charging EV, the effective socio-economic charging solution can be obtained [13]. The scheme contributes to the low charging price in the daytime, however, without EV load, it may trouble the power system. Thus, the battery energy storage system (BESS) is applied to store the surplus energy and reuse when required; this is an optimized solution in the real-world of EV applications [14]. The composition of PV and BESS for EV hybrid charging becomes an effective solution to maintain power quality, deploy the renewable energy source, and contribute zero-emission electric mobility [15].

In Thailand, there is a need to study the feasibility of the EV hybrid charging station. Therefore, this paper proposes the contemporary key elements for the feasibility study of EV charging station as shown in Figure 1. In section 2, it gives the factor impacting the EV infrastructure with cost elements of the charging station. The architecture of the EV hybrid charging station is presented in section 3. As the electricity price is the important factor designated the possibility of implementation, the simple levelized cost of electricity (*sLCOE*) calculation is proposed in section 4. The cost projection of the PV module and Li-ion battery in China during the year 2020-2030 is used [12]. The engineering, procurement, construction (EPC) cost of PV and battery from suppliers in Thailand year 2020 is compared with China’s cost to find the gain and establish Thailand’s cost projection during 2020-2030 (see Table 1). After that, the *sLCOE* of the PV and hybrid charging is made and compared with the commercial on-peak electricity tariff. The results are used for supporting the investment decision as suggested in section 5.



Figure 1. Key elements for the EV hybrid charging station feasibility study

**2. FACTOR IMPACTING THE EV CHARGING INFRASTRUCTURE**

The penetration of EV is reinforced by the charging network [16]. Besides, the charging infrastructure is influenced by the direct and indirect factors as shown in Figure 2 [17].

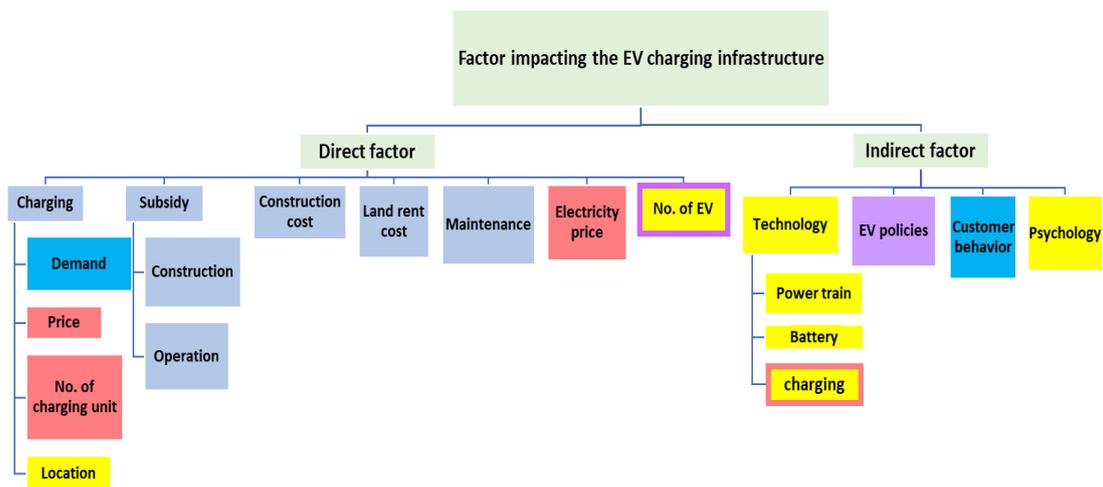


Figure 2. The factors influencing of EV charging infrastructure

The direct factors are mainly based on the financial approach. The charging demand, the subsidy from the government, construction, maintenance, electric tariff, and number of EV are the main concerns of the EV charging infrastructure development. The indirect factor is based on the EV owner perspective; power train and energy source performance, charging technology, support policies, and human factors. The relations of the factors are shown along with their colors highlighted either in/out of the group of factors, for example, the charging demand can be influenced by the customer behavior because the driver may charge the EV accordingly to his convenient time. Therefore, the incentive-based charging period may be ineffective. The psychological factor of the driver is related to the charging location, the number of EVs in the market, technology of the EV system, and charging technic. The improvements of the technology factors mitigate the driver anxiety effectively, i.e. the EV can be conveniently charged until full within a short period or has a long driving range by the improvement of charging and battery technology [16, 18].

Regarding the direct factor that can be evaluated monetarily, the cost elements of the EV charging station in Thailand are suggested as shown in Figure 3.

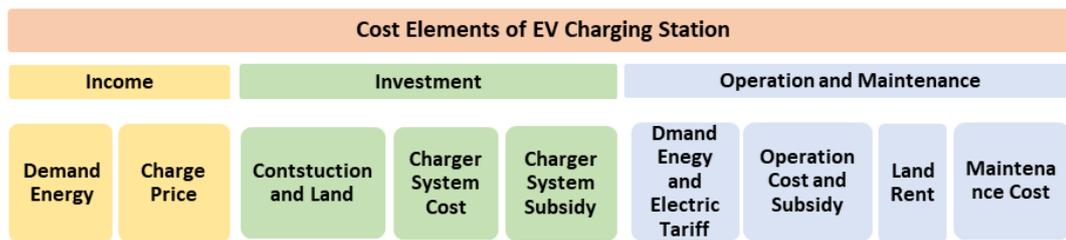


Figure 3. Monetary structure of EV charging station

The profit composes of any financial elements; income, investment, and operation and maintenance, and they are obtained by (1).

$$Profit = Income - Investment - Operation \& Maintenance \quad (1)$$

The (2) shows the income calculation which is derived from charging demand (kWh) and charging price in which the margin is added to the electricity price (baht/kWh).

$$Income = Demand Energy \times EV Charging price \quad (2)$$

The EV charger subsidized by Thai government is required to promote the EV charging station, and it is deducted from the construction and charger system cost to build up the investment cost as in (3).

$$Investment = Construction and land Costs + Charger System Costs - (Unit Charger System Subsidy \times No. of Charger) \quad (3)$$

The operation and maintenance (O&M) cost is developed from the amount of electricity sold, operational cost (supposed to be subsidized by Thai government), land rental cost, and maintenance cost as shown in (4).

$$O\&M Cost = (Demand Energy \times Electricity Price) + (Operation Cost - Operation Subsidy) + Land Rent + Maintenance Cost \quad (4)$$

### 3. HYBRID CHARGING STATION ARCHITECTURE

The hybrid charging station structure in this study encompasses the power from the grid, PV, and BESS which manages via a hybrid inverter as is shown in Figure 4. Because of the Li-ion battery is the suitable technical solution together with commercial availability as suggested in IEEE standard of energy storage, it is the assured choice for this study [19]. Based on the hybrid charging system, the maximum grid power can be decreased by 45% during EV charging and the system can offset the EV daily charging load completely [15, 20]. With the character of the hybrid inverter, the power from the grid and BESS can flow bi-directionally between the EV load while the solar power is controlled to supply only [20]. The PV can be

installed at any available space i.e. building/charging station rooftop or empty land. Without EV load, the surplus solar power is supplied to the BESS for reuse. At the EV charging station, DC fast charger and AC charger level 2 is normally used as the standard chargers for EV [21, 22]. To find the feasibility to implement the hybrid charging system, the electricity price generated by any technologies is evaluated using *sLCOE*.

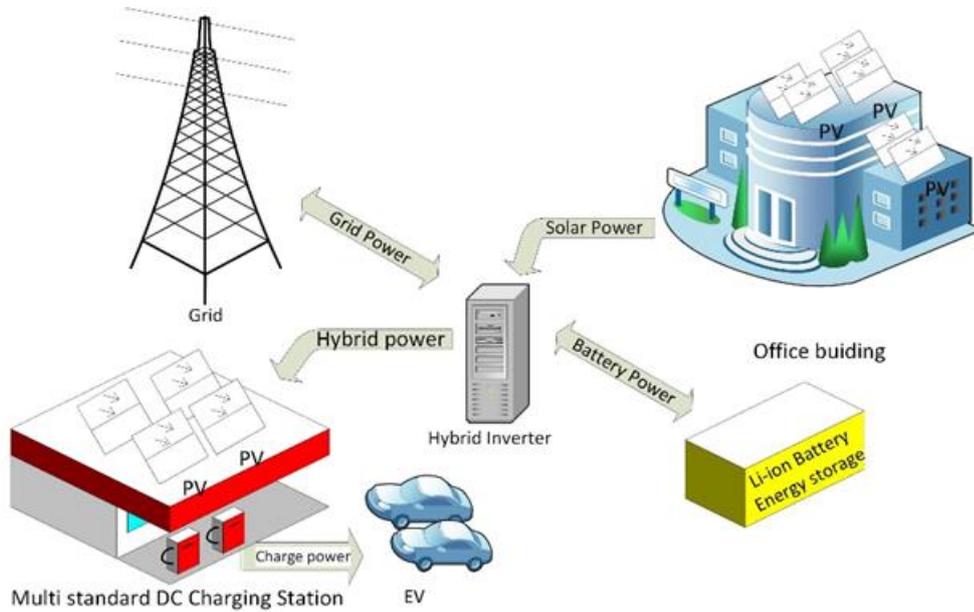


Figure 4. The architecture of an EV charging station incorporating with PV and BESS

**4. SIMPLE LEVELIZED COST OF ELECTRICITY**

The *sLCOE* calculation identifies the commercializing of a power generation technology through its lifetime. The fundamental definition of *sLCOE* is expressed in (5) [23].

$$sLCOE = \frac{\text{Total Lifetime Cost}}{\text{Total Lifetime Energy Production}} \tag{5}$$

The simple levelized cost of electricity of the PV system, *sLCOEPV*, can be obtained by (6).

$$sLCOE_{PV} = \frac{(C_{cap,PV} \times CRF_{PV}) + O\&M_{fix}}{8760 \times CF_{PV}} + O\&M_{vary} \tag{6}$$

It accounts for the combination of capital costs ( $C_{cap,PV}$ ), fixed operation & maintenance ( $O\&M_{fix}$ ) of rooftop PV [24], variable  $O\&M$  ( $O\&M_{vary}$ ) [25], the capacity factor of PV ( $CF_{PV}$ ) which is the ratio of the annual generating power to its capacity. For  $CF_{PV}$ , it is selected based on the small size of the residential solar rooftop, 0.16, as is studied in [26]. Also, the calculation includes the capital recovery factor ( $CRF_{PV}$ ) which is the constant annuity to the present value of the annual receiving for a given year ( $n$ ) along with the interest rate ( $i$ ) as shown in (7). It should be noted that the number of the year using for  $CRF$  calculation for PV and BESS is 20 and 10 respectively as per its normal usage and lifetime. To replace a daily consumption 7.5 kWh of an EV supplied by the power grid, the solar peak power could be well managed by a smart charger to charge an EV efficiently. Thus, the high-cost grid power purchased may not be required [12]. However, in the real world, the charging demand and intensity are random whereby solar energy may not be ready or enough.

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{7}$$

To capture the surplus solar energy when EV is away, the battery is utilized i.e. saving the energy on a weekend. Based on this assumption, the battery will be charged by PV for 6.4 hours/week for 15 kWh that is used by an EV on a weekend [12]. Thus, the simple levelized cost of electricity of BESS, *sLCOEBES*, can

be obtained by (8). The first term presents the discounted of capital investment and running  $O\&M$  yearly cost. They are derived from the battery capital cost,  $C_{cap, bat}$ , considering the capital recovery factor of BESS,  $CRF_{BES}$ , with yearly  $O\&M$  ( $O\&M_{year}$ ) over the yearly discharge hour. The discharge hour is assumed the same as charging time 6.4 hours/week and this is calculated by using a capacity factor of BESS,  $CF_{BES}$ , as of 0.038. Because the battery is charged by solar power,  $sLCOE_{PV}$  is used for the charging price ( $P_c$ ), and it is deducted with the cost of energy conversion loss where the energy conversion efficiency ( $E_{con}$ ) is considered. This second term is to segregate the conversion loss cost out to find the only electricity cost contributed by the battery.

$$sLCOE_{BES} = \frac{(C_{cap,Bat} \times CRF_{BES}) + O\&M_{year}}{8760 \times CF_{BES}} - (P_c \times (1 - E_{con})) \quad (8)$$

The evaluation of  $sLCOE_{PV}$  and  $sLCOE_{BES}$  during 2020-2030 is calculated based on its  $CRF$  aforesaid. The interest rate of 4.7% for Thailand's government project is applied. The capital cost, operation, and maintenance parameter, and other parameters are declared (with references) in Table 2. The purpose of the calculation is to find the  $sLCOE$  of the PV and hybrid charging to compare with the commercial on-peak electricity tariff. The complex calculation such as future replacement or degradation costs is not included in this preliminary study. From the cost projection of EV charging as depicted in Figure 5, one can observe that the  $sLCOE_{PV}$  is the cheapest cost among others and it has a little decrease during year 2020-2030. In contrast, the  $sLCOE$  of hybrid system, PV equipped with BESS, is the highest cost between 2020 and 2025, but it is lower than the on-peak tariff afterward. In [27], we found that the  $sLCOE$  of residential PV-battery system since 2020 has the same agreement as in our study, however, it has a small different of the competed year that the price of hybrid charging is lower than the grid tariff. The discrepancy is mainly from the different interest rate where we use the interest rate for a government project, 4.7%, but the aforementioned study used the discount rate for a residential scale, 2.89%.

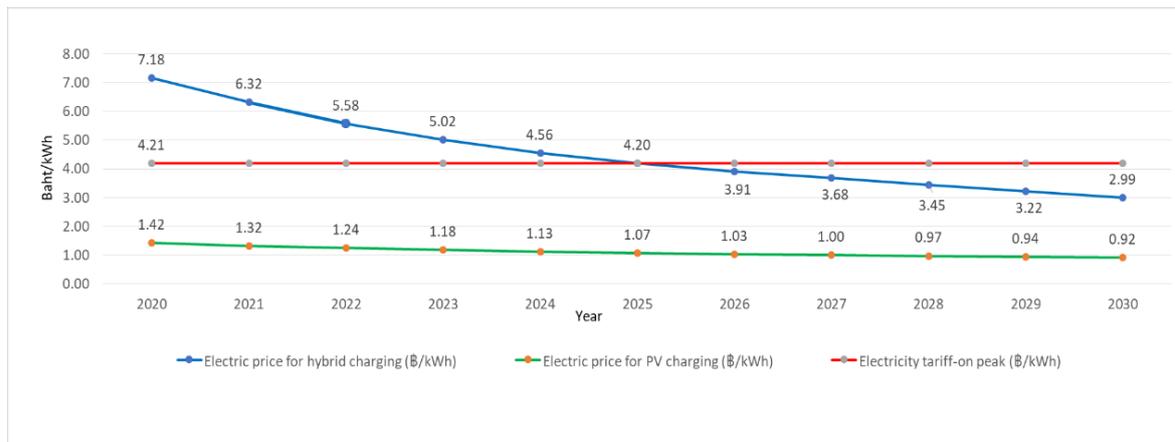


Figure 5. Cost projection of EV charging

## 5. CONCLUSION

This study concludes the basic knowledge for simple levelized cost of electricity calculation of PV and battery energy storage systems. The benefits of renewable energy resources and storage that mitigate the problem of EV charging against the grid power are presented. Moreover, the architecture of the hybrid charging station is illustrated. The factor that impacts the EV infrastructure is declared to seek out the cost element. Thus, the  $sLCOE$  of the power generations has been addressed for observation its suitability. Finally, the electricity cost of PV and hybrid systems which composes of PV and storage are evaluated with the on-peak tariff. Considering only the  $sLCOE$ , PV is the cheapest solution of power generation but, in the real-world condition, other factors may cause the application difficulty, i.e. installation area, available charging period which depends on the solar intensity, etc. To enhance the PV application, the battery storage is studied for its feasibility to implement. Based on the parameters used for the battery and PV in this study, the  $sLCOE$  of hybrid charging will be acknowledged after 2025 compared with the on-peak tariff. Therefore, the grid and solar power could be a worth solution for EV charging presently.

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## APPENDIX A

Table 1. Cost projection of PV and Li-ion battery of Thailand based on China's evaluations

Year	China's annual PV module production (GW)	China's PV cost projection (USD/kW)	China's estimated PV cost including EPC (USD/kW)	Thailand cost, 50% higher than China's EPC (USD/kW)	China's annual Li-ion battery production (GWh)	China's Li-ion battery cost projection (USD/kWh)	China's Estimated Li-ion battery including EPC (USD/kWh)	Thailand cost 50% higher than China's EPC (USD/kWh)
2020	100	205.8	411.6	617.4	129.1	142.8	285.6	428.4
2021	100	187.6	375.2	562.8	199.6	121.8	243.6	365.4
2022	100	172.2	344.4	516.6	275.1	103.6	207.2	310.8
2023	100	161	322	483	355.6	89.6	179.2	268.8
2024	100	151.2	302.4	453.6	441.2	78.4	156.8	235.2
2025	100	141.4	282.8	424.2	525.4	70	140	210
2026	100	134.4	268.8	403.2	614.2	63	126	189
2027	100	128.8	257.6	386.4	707.7	57.4	114.8	172.2
2028	100	123.2	246.4	369.6	142.1	51.8	103.6	155.4
2029	100	117.6	235.2	352.8	217.7	46.2	92.4	138.6
2030	100	113.4	226.8	340.2	297.4	40.6	81.2	121.8

## APPENDIX B

Table 2. Evaluation results of sLCOE for hybrid charging

Parameter of	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
<b>sLCOE<sub>PV</sub></b>											
% interest / 100	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
$n_{PV}$ (yr)	20	20	20	20	20	20	20	20	20	20	20
$CRF_{PV}$	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078
$C_{PV}$ (\$/kW)	617.4	562.8	516.6	483.0	453.6	424.2	403.2	386.4	369.6	352.8	340.2
$O\&M_{fix}$ (\$/kW-yr)	10	10	10	10	10	10	10	10	10	10	10
$O\&M_{vary}$ (\$/kWh)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
$CF_{PV}$ %	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
$sLCOE_{PV}$ (\$/kWh)	0.045	0.042	0.039	0.037	0.035	0.034	0.032	0.031	0.030	0.030	0.029
<b>Parameter of sLCOE<sub>BES</sub></b>											
% interest / 100	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
$n_{BES}$ (yr)	10	10	10	10	10	10	10	10	10	10	10
$CRF_{BES}$	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128	0.128
$C_{Bat}$ (\$/kW)	428	365	311	269	235	210	189	172	155	139	122
$O\&M_{year}$ (\$/kW-yr)	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
$CF_{Bat}$ %	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
Energy conversion efficiency	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
$sLCOE_{BES}$ (\$/kWh)	0.180	0.157	0.136	0.120	0.108	0.098	0.090	0.084	0.078	0.071	0.065
<b>Total sLCOE for PV+BES (\$/kWh)</b>	0.225	0.198	0.175	0.157	0.143	0.132	0.123	0.115	0.108	0.101	0.094

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