Design of PV-"Single Phase Grid" Electric Vehicle Charging System

FADHIL YOUSIF[1], M.A. ALGHOUL[1]*, EBRAHIM ALFEGI[2], NILOFAR ASIM[1], AND K. SOPIAN[1]
[1]Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, MALAYSIA
[2]Mechanical Engineering Dept, Azzawia University, LIBYA
*Corresponding author: dr.alghoul@gmail.com

Abstract: Electric vehicle (EV) and its infrastructure takes significant concerning in the civilized societies around the world. Solar assisted EV charging stations are effective element in the successful initially infrastructure installing and EV deployment. In this paper HOMER software simulation was employed to design and assess solar assisted EV charging system, connected to low voltage, limited 3kW single phase grid connection. The system's PV panels designed as canopy with battery storage capability for solar radiation condition of Kuala Lumpur, Malaysia. The system found suitable to accompany with level 2 chargers to use as public canopy, work place or shopping center car park. The system storage capability and the limited grid power are very effective to mitigate the stress of the numerous EVs that charge simultaneously over the utility grid. PV penetration in this system effectively reduced harmful emissions in overall system operation. PV panels produces feasible amount of energy sufficient to serve during power outage or in disasters when grid disrupted. PV in this system produces 1.82 times lifeline band, monthly consumption of Malaysia TNB, which economically profitable to sale electricity to the grid when no charging service in use. Solar energy that induced by the system PV panels show highly effective operation despite its little renewable energy fraction.

Keywords: electric vehicle, charging system, solar PV, single phase grid, HOMER, Malaysia

1 Introduction

Solar assisted EV charging stations are world widely unrolled via it's relying on clean solar electricity. Single phase grid connection of 50 kW rapid charger station is actually made and announced by Nichicon Japanese Company [1]. Nichicon's low-voltage EV charging station utilizes combination of solar power with single phase commercial grid power source of 3kW maximum value. Storage battery bank is necessary for solar assisted EV charger that connected to low-voltage grid line to store the limited and slowly drawn electricity (from PV and grid). After that this electricity will be ready to discharge fastly in EV battery pack by the charger as needed. The installation of high voltage electrical equipment (that required usually in EV chargers without storage function) is unnecessary and that will be reduced initially costs as well as running costs. Using storage battery bank in charger systems are effective solution for matching between the grid utility and high electric demand that imposes on the grid whereas high penetration of EVs are deployed [2]. Also, storage batteries are common use with intermittent renewable energy systems to be dispatchable electricity power sources [3]. In this paper, design and assessment of 3kW maximum value of single phase low-voltage grid sources solar assisted EV charging station was performed. HOMER simulation used to achieve this design and assessment in terms of Kuala Lumpur solar incident radiation condition.

2 Materials and Method

National Renewable Energy Lab (NREL), a division of the U.S. Department of Energy (DOE), developed Hybrid Optimization Model for Renewable Energy systems (HOMER) software [4].

HOMER models a particular system design by performing an hourly time series simulation of its operation over one year. HOMER calculating through the year, the available renewable power, comparing it to the electric load, and deciding what to do with surplus renewable power in times of excess, or how best to generate or drawn from the grid additional power in times of shortage [5]. PV panels with capacity of 3.17 kW were utilized to extend over 24m2 area canopy with deep cycle lead acid battery pack as electricity power storage. This canopy area is enough to 2 car park spaces with system cabinet in the middle. Battery bank connected to the PV panels via DC-DC converter and charging controller to matching between PV output and battery charging voltage. Also, battery bank connected to the low-voltage grid line via AC-DC converter.

Solar panels total capacity constrained by 3.17 kW for the systems while electricity that drawn from the grid constrained by maximum value of 3kW grid line source.

Level 2 charger used to match the power transfer from the charging system storage battery to the EV battery pack (tab.1).

Mid size EV efficiency of 4.66 km/kWh or 2.9 mile/kWh [6] used to compare system performance for different capacities.

Table 1: SAE J1772TM standard level 2 charger power (kW) and charging time (hour) [4].

AC level 2 (SAE J1772™)	PEV*	BEV**
3.3 kW	3 h	7 h
7 kW	1.5 h	3.5 h
20 kW	22 min	1.2 h

*PEV= plug-in hybrid electric vehicle.
**BEV= battery based electric vehicle = EV.
This table considers charging of PEV with state of charge (SOC) as 0% to full and BEV as 20% to full.

3 System components

3.1 Solar panel

CS6X-295M Solar module [5], 72pcs of 6" mono-crystalline solar cells used in this design (Table 2).

Table2. CS6X-295M Solar module specifications

Specification	Remarks
PTC rating	263.6w
Cell Efficiency	17%
Pmax	295W
Vmp	36.4V
Imp	8.11A
Voc	44.9V
Isc	8.63A
Size (m)	1.95 x 0.98 x 0.04

The capacity of total solar panels that used in this system selected as 3.17kW in order to benefit from a greater share of renewable energy in this design. 3.17kW solar panels correspond to 12 modules of CS6X-295M covers approximately 24m2, i.e. a canopy of (6 X 4) meters or (6 X 2) modules.

3.2 Battery

RA12-260D, AGM Deep cycle Lead Acid battery [6] specifications shown in (table 3).

Table 3: RA12-260D, AGM Deep cycle battery specifications.

specification	remarks
Voltage	12V DC
Capacity	260Ah @ 25˚C
Power	3.12 kWh
Weight	Approx. 74 Kg
Max. Discharge Current	2600 A
Internal Resistance	Approx. 3.5 mΩ
Normal Operating Temp. Range	25˚C±5˚C
Recommended Maximum Charging Current Limit	78 A

Lead acid battery has a cheaper cost and a longer cycle life than Li-ion and other battery types like Ni-MH [7]. Thence, and despite its large size and heavy weight compared to Li-ion battery, Lead Acid battery more adequate in this system assuming that bulky feature does not affect of the system performance.

3.3 Grid

The electric power that drawn from the grid limited by maximum value of 3kW and constrain HOMER not to exceed this capacity in all cases. 3kW are equivalent to maximum electric power that available from residential single phase grid outlet. This feature make the system can install in all rural and urban places and connected to residential electricity outlet point even with limited grid access. Also, this limitation feature contributes in mitigate the detrimental impact of high level EV deployment on the grid utility.

The cost of purchasing electricity from public grid according to the fee schedule for the commercial value of electricity [8] is equivalent to 0.143 US $ / kWh which is above 200 kWh per month (200kWh/month represent the lifeline monthly residential consumption in Malaysia [9]) for Malaysia electric company (TNB).

3.4 Load

Load that considered in this work is an EV that charged from system battery bank through level 2 (>3kW) EV charger [10]. Load profile distributed equally in all day hours assuming that the system continually charging throughout the day.

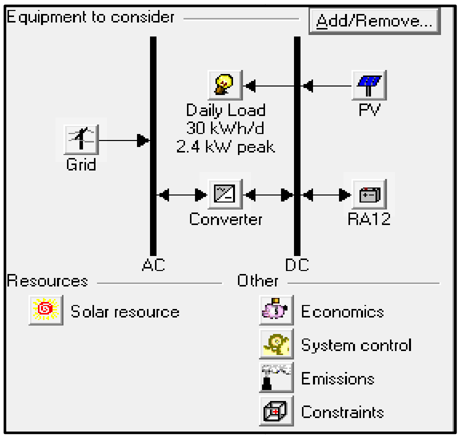

Fig.1 Equipment to consider front of HOMER with first assumed daily load value 30 kWh/d.

Symmetric load profile has been used to determine the maximum system capacity which equal to the maximum load that the system can serve per day. HOMER will change the daily load value shown in (Fig. 1) (30 kWh/d) and replace it (for each row shown in table 5) by assumed values that considered in sensitivity daily load inputs shown in (table 5). HOMER keeps the equally distribution load profile in all calculation steps and change the daily load values according to the inputs that considered in daily load Column in (table 5) [11].

4 Solar Radiation

Annually average of daily incident solar energy data over Kuala Lumpur city of Latitude 3.14 / Longitude 101.68 are collected from NASA's Surface meteorology and Solar Energy Data [12] (Fig. 2). The same data available in NREL sponsored Solar and Wind Energy Resource Assessment (SWERA) [13]. (Fig. 2) shows that average daily radiation of each month take the highest value in Feb., Mar. and Apr. while take the lowest value in Nov. and Dec. The mean output solar energy produced by the solar panels per day is (12.4kWh/d) and the total production of electricity are (4543 kWh/yr) (Table 4).

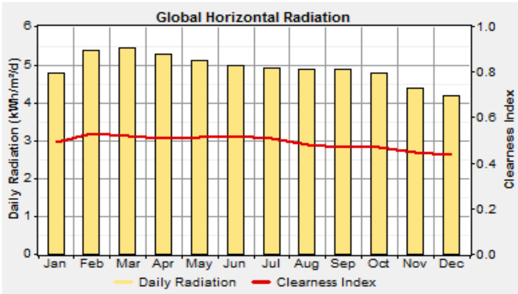

Fig.2 Daily solar radiation over Kuala Lumpur in all year months.

Table 4. The mean output of daily solar energy produced by solar panels.

Quantity	Value	Units
Rated capacity	3.17	kW
Mean output	0.52	kW
Mean output	12.4	kWh/d
Capacity factor	16.4	%
Total production	4,543	kWh/yr

5 Results and discussion

HOMER optimized results are shown in table 5 for the hybrid system of PV-3kW maximum grid line, as maximum daily load that the system can serve. Each row in tables 5 represents an optimized configuration that HOMER evaluated for each daily load value that assumed in daily load column. The yellow colored configuration is the optimized design that corresponds to 77 kWh/d daily loads. This design consists of 3.17kW PV capacity, 12 batteries, 3kW converter capacity to convert AC 3kW grid line maximum capacity to DC electric current. The initial cost of the optimized system is US$17,673 and the net present cost is US$124,976 with cost of energy of 0.178 $/kWh.

Table 5: sensitivity results of HOMER designs for charging system.

Daily Load (kWh/d)	PV (kW)	RA12	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
30.000	3.170		3	3	$ 6,873	1,171	$ 36,159	0.132	0.36
40.000	3.170		3	3	$ 6,873	1,643	$ 47,942	0.131	0.29
50.000	3.170	1	3	3	$ 7,773	2,188	$ 62,465	0.137	0.24
60.000	3.170	1	3	3	$ 7,773	2,752	$ 76,579	0.140	0.20
70.000	3.170	2	3	3	$ 8,673	3,535	$ 97,049	0.152	0.17
71.000	3.170	3	3	3	$ 9,573	3,594	$ 99,411	0.153	0.17
72.000	3.170	3	3	3	$ 9,573	3,686	$ 101,721	0.155	0.16
73.000	3.170	3	3	3	$ 9,573	3,780	$ 104,069	0.156	0.16
74.000	3.170	4	3	3	$ 10,473	3,841	$ 106,486	0.158	0.16
75.000	3.170	6	3	3	$ 12,273	3,868	$ 108,985	0.159	0.16
76.000	3.170	10	3	3	$ 15,873	4,133	$ 119,199	0.172	0.15
77.000	3.170	12	3	3	$ 17,673	4,292	$ 124,976	0.178	0.15
78.000	3.170	20	3	3	$ 24,873	4,729	$ 143,109	0.201	0.15
79.000	3.170	40	3	3	$ 42,873	5,752	$ 186,673	0.259	0.15
80.000	3.170	60	3	3	$ 60,873	6,770	$ 230,120	0.315	0.15
81.000	3.170	80	3	3	$ 78,873	7,787	$ 273,557	0.370	0.15
82.000	3.170	150	3	3	$ 141,873	11,316	$ 424,774	0.568	0.15
83.000	3.170	150	3	3	$ 141,873	11,327	$ 425,051	0.561	0.15
84.000	3.170	150	3	3	$ 141,873	11,338	$ 425,335	0.555	0.15
85.000	3.170	200	3	3	$ 186,873	13,869	$ 533,610	0.688	0.15

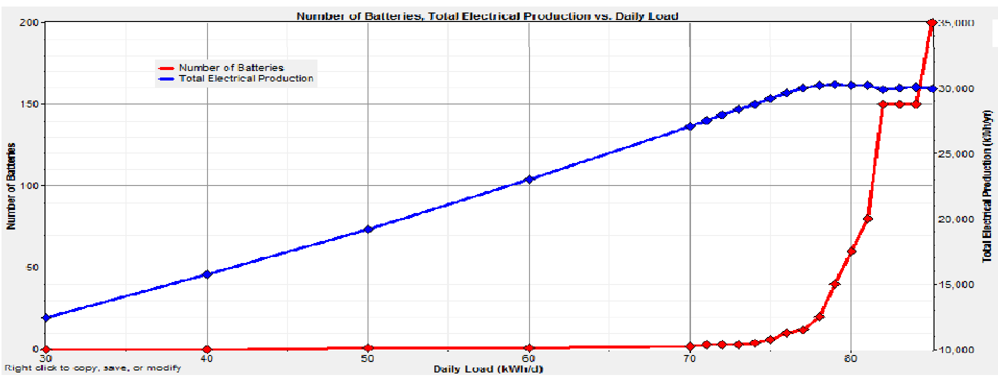

Fig. 3: Total Electrical Production and Number of Batteries vs. Daily Load of charging system.

Fig. 3 shows the relationship between the daily load (kWh/d) in x-axis versus total electrical energy produced in the system (blue curve), and number of batteries that be used in the system (red curve).

Total electrical production is the combination of grid electrical energy plus the electrical energy provided by solar panels. Blue curve shows that any increasing in daily load will led to increase the total electrical production linearly below the "threshold" point (77 kWh/d) on x-axis(blue curve). After this value any increasing in daily load will led to saturate the total electrical production due to that energy sources (solar and grid) provide limited and insufficient amount of energy after that point to serve the excess load. However this saturation point in the blue curve associated with "knee" point in the red curve (12 batteries) that both points corresponding with the threshold point on x-axis. The knee point start the rapid increasing in HOMER simulation batteries number because that HOMER compensate the shortage in produced electricity in the systems by adding extra batteries in order to utilized it's initially stored energy to meet the excess load. This HOMER technique solves the problem for one year only (HOMER analyses electric source-demand balance for one year not for all project life). Because the energy that existing in the batteries will deplete after that and the system stop supplying the excess load after the threshold point. So, the optimum value for daily load that keep the system stabile, is the threshold point (77 kWh/d) which represent the maximum energy that the stabile system can produce per day.

The system produces (77kWh/d) daily electric energy that sufficient to provide 24 hour charging service throughout the day with level 2 charger of 3.3kW power output or 11 hours with level 2 charger of 7kW power output. These results mean that the system can provide whole day charging serves with 3.3kW charger and only day time (Malaysia grid peak hours) charging serves with 7 kW charger. In the other words, such amount of energy are equivalent to 359 km rang for mid size EVs, of 4.66 km/kWh efficiency, which can charge 7 EVs per day for 50 km each. This system is suitable to serve as public canopy, work place or shopping center car park which usually uses level2 charger.

PV system that employed in this hybrid system provide 12.4 kWh/d or 372kWh/month which is 1.82 times more than lifeline (200kWh/month) monthly consumption in Malaysia which indicate that the system can benefit from selling electricity to the grid in case of no EV charging in serve.

Table 6: pollutant emission that prevented by PV system per year.

Load	PV	CO2 Emissions	SO2 Emissions	NOx Emissions
kWh/d	kW	kg/yr	kg/yr	kg/yr
77	3.17	2871	12.44	6.1

The annual green energy that produced by PV panels (4543 kWh/yr) are considerably reduce the toxic emissions that supposed to be emitted by the grid if the system is fully grid dependence (tab 6).

6 Conclusions

Solar assisted EV charger that consisted of 3.17 kW PV connected with single phase 3kW maximum grid source to supply level 2 EV charger through battery storage pack is suitable to use as public canopy, work place or shopping center car park.

The energy storage capability of the system and the limited power that drawn from the grid is very useful to mitigate the unwanted impact of the numerous EVs that charge simultaneously over the utility grid. Also, the charging system can effectively alleviate the stress that imposes on the grid by EV charging that occurs through peak hours demand.

PV system that employed in this hybrid system produces 1.82 times lifeline band, monthly consumption of Malaysia TNB utility company, which is economically profitable to sale electricity to the grid when no charging service in use.

The annual green energy that produced by the PV panels are considerably reduced the toxic emissions that supposed to be emitted by the grid if the system is fully depend on the grid.

References

1. Nichicon. Product News. Nichicon Corporation 2012; Available from: http://www.nichicon.co.jp/english/product_news/new120.html.
2. Buchanan, W.D., J.F. Mohos, and W.E. Rippel, Battery charging system and method, U.P. Office, Editor 2007.
3. Vittal, V., The Impact of Renewable Resources on the Performance and Reliability of the Electricity Grid, in The Bridge, Linking Engineering and Society2010, The Bridge National Academy of Engineering.
4. International, S., SAE Charging Configurations and Ratings Terminology, 2012.
5. Dmsolar. Canadian Solar MaxPower Solar Panel 295w. 2012; Available from: http://www.dmsolar.com/csimosomo29p.html.
6. RITAR. RA12-260D. 2012; Available from: www.ritarpower.com/upload/pdf/2010081115012539042372.pdf.
7. Lowe, M., et al., Lithium-ion Batteries for Electric Vehicles: THE U.S. VALUE CHAIN, 2010, Center on Globalization, Governance & Competitiveness Duke University.
8. TNB. For Commercial Pricing & Tariff. Tenaga Nasional Berhad 2012 July 2012]; Available from: http://www.tnb.com.my/business/for-commercial/pricing-tariff.html.
9. TNB. Residential, Pricing and Tariff. Tenaga Nasional Berhad. 2012; Available from: http://www.tnb.com.my/residential/pricing-and-tariff.html.
10. SAE. SAE Charging Configurations and Ratings Terminology. Society of Automotive Engineers 2011; Available from: http://www.sae.org/smartgrid/chargingspeeds.pdf.
11. HOMER, Primary Load Inputs, Scaled data for simulation, HOMER Help., 2012.
12. NASA. Surface meteorology and Solar Energy. Atmospheric Science Data Center 2012 December 19, 2011 July 2012]; Available from: http://eosweb.larc.nasa.gov/sse/.
13. SWERA. Solar and Wind Energy Resource Assessment. A United Nations Environment Programme facilitated effort. 2012 July 2012]; Available from: http://en.openei.org/apps/SWERA/.