Economic Feasibility of Solar PV System for Buildings

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Abstract

A system design optimization and economic feasibility of a solar PV system for self-consumption is studied using long-term system performance simulation. The electric heater is used to replace part of battery storage to reduce the cost. Three parameters, R_{pL}, R_{hb} , t_{bp} , are derived to correlate the long-term system performance. It is found that there is an optimal design and the solar PV system is economical if it was used to replace partial demand which is paid at higher grid electricity price. This is the partial grid-parity.

Keywords: PV for self-consumption; solar PV system; optimal design of solar PV

1. Introduction

Solar PV system for self-consumption with energy storage should be used if solar penetration is high. The installation of conventional grid-tied solar PV systems requires approval from the grid authority. The cost of approval application becomes relatively high for small solar home systems.

Hsu *et al* (2016) developed a so-called "hybrid solar PV system (HyPV)" which is a distributed energy system for self-consumption. HyPV operates in stand-alone PV mode or grid mode automatically according to the weather and battery conditions, as shown in Fig. 1. HyPV uses switching technique. It operates in either solar or grid mode. No excess solar power is fed into grid. The installation of HyPV dos not requires approval of grid authority. Since no solar PV power is fed into the grid, the system match between the load pattern and the storage capacity needs to be optimized in order to avoid PV generation loss. To reduce the system cost, an electric water heater is installed to replace part of battery storage (Huang *et al*, 2017). In this paper, a system design optimization is carried out and economic feasibility is studied through long-term system simulation.

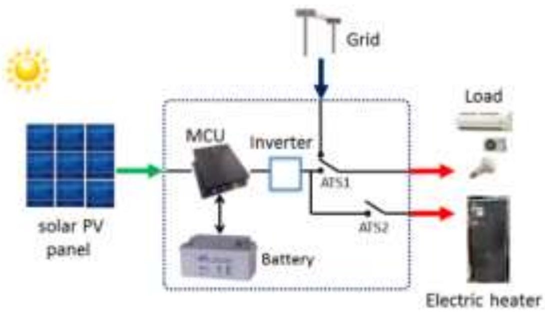

Fig. 1: Hybrid solar PV system (HyPV).

2. System simulation

The long-term system simulation is carried out using the performance model of HyPV and meteorological data. The long-term simulation is performed with different system design parameter and load pattern.

The incident solar radiation (I_T) is absorbed and converted into electricity P_{pv} which drives the load (P_L) and charges the battery (P_{bat}), as shown in Fig. 2. The energy balance equation, eqn (1), is derived (Hsu *et al*, 2016).

$$P_{bat} = P_{pv} - P_L \qquad (1)$$

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The battery will be cut off and the PV power generation approximates the load power, if it is fully charged. That is, there are two operating states in PV power generation as described in eqn(2).

$$\frac{dE_{bat}(t)}{dt} \approx \begin{cases} P_{mp} - P_L, \text{ battery not fully charged} \\ 0, \text{ battery fully charged} \end{cases} \quad (2)$$

Where E_{bat} is the energy storage level (i.e. state of charge SOC).

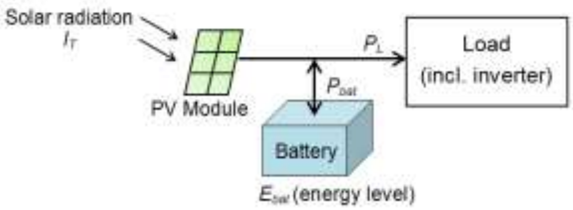

Fig. 2: Schematic of system energy balance of HyPV in PV mode.

3. System design analysis

3.1. System design parameters

The long-term system simulation for different design parameters is carried out using the local meteorological data. Four load patterns are used in the present study: Load Pattern A (100% energy used in daytime), Load Pattern B (75%), Load Pattern C (50%), and Load Pattern D (25%). Total PV energy generation over 20 years was calculated. The total investment cost includes initial and maintenance costs (Li battery replacement). Three parameters are defined, eqn(3), to correlate the long-term system performance.

$$R_{pL} = \frac{P_{mp}}{P_{L\max}}; \; R_{hb} = \frac{C_{hs}}{C_{bat}}; \; t_{bp} = \frac{C_{bat}}{P_{mp}} \quad (3)$$

R_{pL} is defined as the ratio of maximum PV power generation to maximum load; R_{hb} is the ratio of thermal storage to battery storage; t_{bp} is the charge time for solar PV to fully charge the battery.

3.2. Performance simulation results

Fig.3 is the variation of PV generation cost with R_{pL}. It shows that there is an optimal design for PV generation cost. Fig.4 is the variation of PV generation cost with R_{hb}. An optimal design for PV generation cost can be found. The optimal ratio of thermal to battery storage capacity R_{hb} is 1~4, depending on the battery size

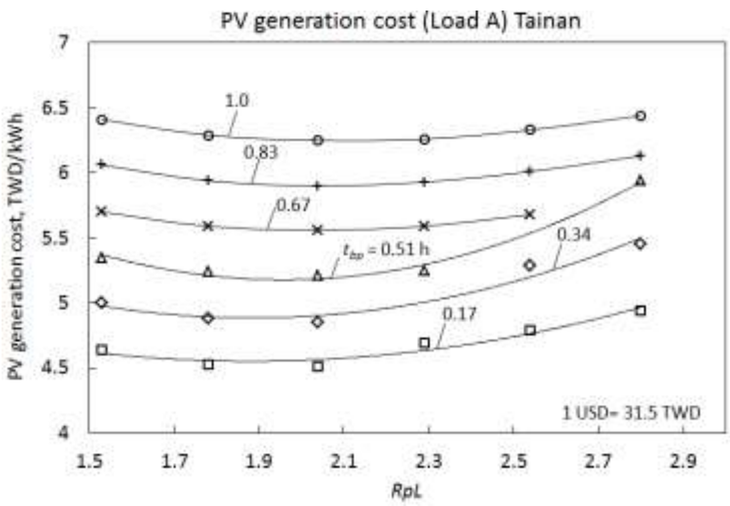

Fig. 3: Variation of PV generation cost with R_{pL}.

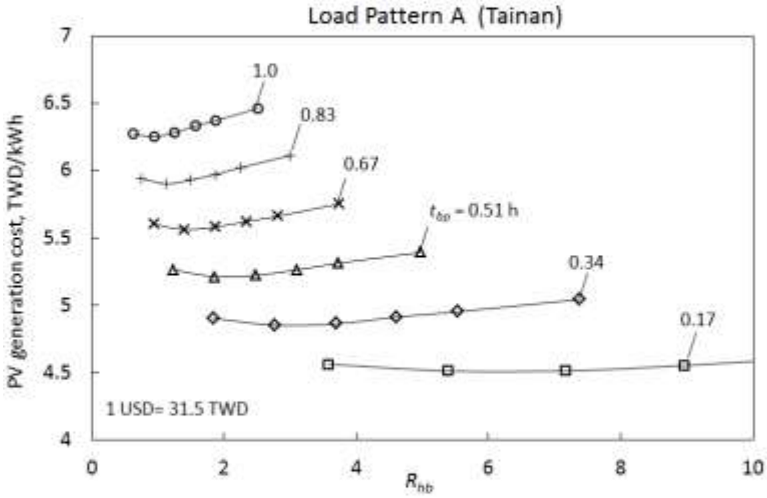

Fig. 4: Variation of PV generation cost with R_{hb}

3.3 PV energy generation cost

The PV generation cost is compared with the grid electricity price as shown in Fig.5. The categorized grid electricity price in Taiwan is in staircase structure.

	Present price, TWD/kWh	Monthly consumption, kWh/mon	Yearly price increase, %/y	Price after 20 years, TWD/kWh	Average price, TWD/kWh
Category 6	6.12	>1000	4.6	15.04	10.58
Category 5	5.42	701-1000	4	11.88	8.65
Category 4	4.64	501-700	3.4	9.06	6.85
Category 3	3.52	331-500	2.8	6.12	4.82
Category 2	2.38	121-330	2.2	3.68	3.03
Category 1	1.63	<121	1.6	2.24	1.93

Fig. 5: Categorized grid electricity price. (1 USD=31.5 TWD)

Tab.2 shows the optimal design for four load patterns in three cities of Taiwan. The PV energy production cost is among 4.66-7.24 TWD/kWh (1 USD=31.5TWD). For the electricity bill paid in Category 3 or 4, solar PV replacement is economical. That is, solar PV is economical if it was used to replace partial demand which is paid at higher grid electricity price. This is the partial grid-parity should be arranged to the left, with characters similar to that of the body text and should be numbered.

Tab. 2: Optimal design and economic feasibility.

	R_{hb}	R_{pL}	t_{bp} (h)	Battery capacity (Wh)	Solar PV panel (Wp)	20-year energy saving (TWD)	20-year total investment (TWD)	PV energy generation cost (TWD/kWh)	Return on investment (%/year)	PV generation loss (%)	Ratio of PV energy supply (%)	Lowest electricity price category for PV to be economical
Load Patten A												
Taipei	2.77	2.04	0.34	1,360	4,000	595,627	425,322	6.65	2.00	0.67	44	4
Taichung	3.69	2.04	0.34	1,360	4,000	834,713	429,172	4.65	4.72	1.66	59	3
Tainan	2.77	2.04	0.34	1,360	4,000	802,813	425,322	4.85	4.44	1.79	58	4
Load Patten B												
Taipei	3.16	2.38	0.34	1,190	3,500	517,232	371,538	6.68	1.96	1.21	36	4
Taichung	3.69	2.04	0.34	1,020	3,000	629,168	326,004	4.66	4.65	0.81	44	3
Tainan	3.69	2.04	0.34	1,020	3,000	606,425	326,004	4.9	4.30	0.61	44	4
Load Patten C												
Taipei	4.92	3.05	0.34	1,020	3,000	447,375	321,604	6.74	1.96	1.07	28	4
Taichung	3.69	2.03	0.34	680	2,000	416,473	222,836	4.78	4.34	0.77	30	3
Tainan	3.69	2.03	0.34	680	2,000	415,211	222,836	5.03	4.32	0.58	29	4
Load Patten D												
Taipei	5.9	5.09	0.34	850	2,500	369,075	283,120	7.24	1.52	2.84	17	5
Taichung	7.38	5.09	0.34	850	2,500	504,338	286,970	5.09	3.79	4.07	20	4
Tainan	5.90	5.09	0.34	850	2,500	493,874	283,120	5.35	3.72	5.14	20	4

4. Conclusion

Solar PV system for self-consumption with energy storage should be used if solar penetration is high. The conventional grid-tied solar PV systems is not suitable for small solar home system since it requires high approval cost from the grid authority. The installation of HyPV dos not require approval of grid authority.

A system design optimization and economic feasibility of a solar PV system for self-consumption is studied using long-term system performance simulation. The electric heater is used to replace part of battery storage to reduce the cost. Three parameters, R_{pL}, R_{hb} , t_{bp} , are derived to correlate the long-term system performance. It is found that there is an optimal design and the solar PV system is economical if it was used to replace partial demand which is paid at higher grid electricity price. This is the partial grid-parity.

5. References

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6. Acknowledgment

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