Hybrid solar photovoltaic system for self-consumption

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ABSTRACT

The present study develops a hybrid solar PV system (HyPV) which generates solar energy for local self-consumption without feed into the grid. The first system HyPV-1 was designed and installed in a residential house of NTU with 4 residents to run field test under different loads and battery storage capacity. The continuous long-term test in high season shows that two air conditioners (total power consumption 300-1500W) coupled with 1.38 kWp PV module and 1.4 kWh battery pack can be completed powered by solar PV in Taipei (low solar radiation area). HyPV-1 has been run for longer than 14 months.

1. INTRODUCTION

Most grid-tied solar PV systems installed today feeds all the PV-generated power into the grid to make money from high government tariff. This will cause grid transmission problems due to the unbalance of grid power sources in clear weather when solar PV is widely disseminated. It will need additional cost for improving power transmission network or shut down solar PV plants in clear weather. A decentralized solar PV system can generate solar power for self consumption and with storage device to store excess energy without feed to the grid. Most of such kind of PV system is designed in grid-tied type with a grid-tied inverter (two-way inverter) which can import electricity from grid to make up the solar PV power supply when load is large and feed excess solar power back to grid. High quality of electricity syncronize between inverter AC output and grid AC power is required strictly. Some technical regulations and qualification procedures have to be exactly followed. This causes higher cost, especially for solar home system.

In the present study, we have developed the isolated-type hybrid solar PV system (HyPV). Fig.1. A storage device is integrated with the system. The load power supply is divided in two modes: Grid Mode and PV Mode, through a switch control. When solar radiation is high or load demand is low, HyPV operates in PV Mode to supply load from battery and PV modules through an one-way inverter. When solar PV power and battery storate is not enough to supply the load, HyPV is switched to Grid Mode, with all the load power is supplied by grid. There is no feed-in grid operation.

The optimal switching between grid, solar, and battery energy supply, the charge/discharge control of battery, and the energy management of the system etc. is quite complicated. Reliability is the key issue of HyPV in application. The allowed annual blackout time for HyPV is quite short (less than 20 minutes per year per family in Taiwan). The limited battery cycle life also needs to be taken into account. This is a big challenge of decentralized systems with limited maintenance capability and at various operating environments. The HyPV technology was developed by New Energy Center at National Taiwan University. The first system HyPV-1 was designed and installed in a residential house of NTU for field test.

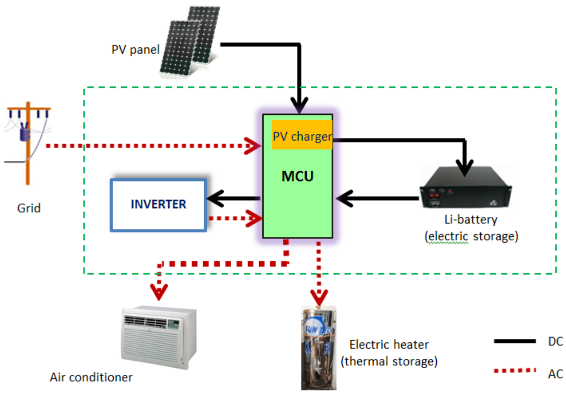


Fig.1 System configuration of HyPV-1.

2. DESIGN OF HyPV-1

The design of hybrid PV system is shown in Fig.1. The special features of HyPV-1 include: (1)using 1A-3P tracker to increase solar energy generation by 25-37% without increasing cost [1]; (2) using nMPPO system design [2] to skip energy loss and cost of MPPT; (3)using advanced Li-Fe-P battery with a solar charging controller; (4) adopting add-on design (in 4 modules for a system) for various system requirement; (5) developing a smart energy management system to control the charge, discharge, and grid-power input for optimal performance. HyPV-1 consists of six 230 Wp PV modules (module efficiency 14.7%), total 1.38 kWp, mounted on 3 sets of 1A-3P (1-axis 3-position) trackers [1]. Fig.2.


Fig.2 1A-3P sun tracker.

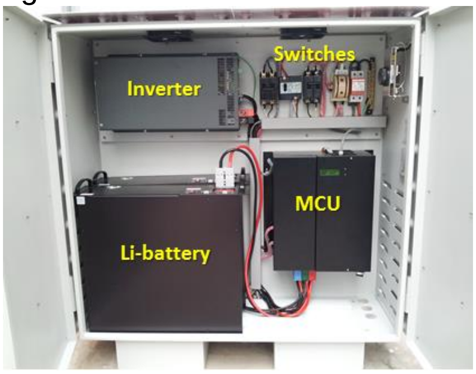


Fig.3 Power system of HyPV-1

A 4.5 kWh/48V Li-Fe-P battery bank was used as storage. To reduce energy loss and increase reliability, no MPPT was used. Instead, nMPPO (near-maximum-power-point operation) system design was used [3].

A 1.5 kW/220Vac one-way inverter was used to drive AC load which includes two high-efficiency air conditioners (total input 200~1500W, COP>5.0), a fresh air exchanger (80W), and a 100W LED street light.

A microprocessor-based main control unit (MCU) was developed to control the energy supply from PV, battery, and grid. Fig. 3 shows the power system of HyPV-1. A remote monitoring system was developed to monitor the long-term system performance.

HyPV-1 was installed August 31, 2012, in a NTU house (only ground floor) with 150 m^2 land area and 4 residents. The house is surrounded by high-rise apartment buildings and trees which creates some shading effects on PV modules.

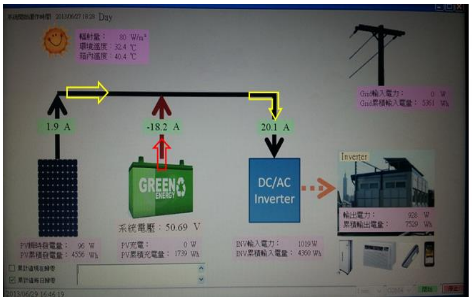
3. TEST RESULTS

HyPV-1 was run continuously in the house to supply electricity for 4 residents. The performance test includes PV energy generation, load variation, battery charge/discharge, system stability, shading effect etc.

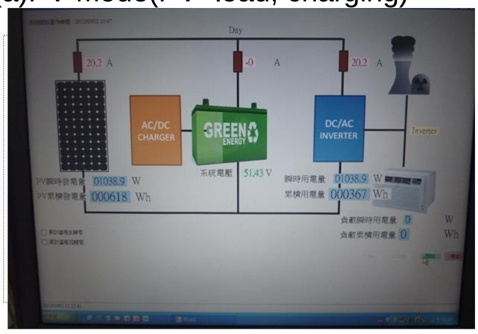
Energy flow of HyPV-1

HyPV-1 operates in different modes according to the PV power generation, load power consumption, and battery SOC (state of charge). Fig.4 shows the energy flow of HyPV-1.

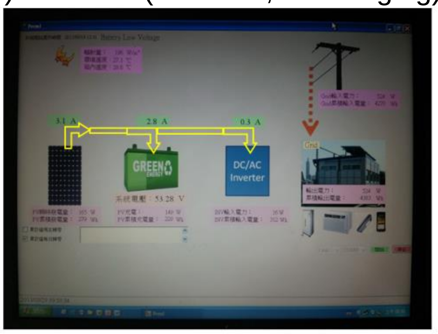
(a)PV Mode(PV>load, charging)



(b) PV Mode(PV<load, discharging)



(c)PV Mode(PV=load,balance)



(d)Grid Mode(PV+battery < load)

Fig.4 Energy flow of HyPV-1.

Performance in typical day

Fig.5 is the performance of a typical day (2012/9/10). The sun is varying. Battery is charged or discharged according to the energy balance between solar power generated and load demand. The battery performance is shown in Fig.6. The voltage varies according to the status of energy demand and solar power generation. For this particular day, the load is applied only in daytime.

At full-load condition with the two air conditioners running at full load all the day, the PV Mode (load supplied by both PV and battery) and Grid Mode (load supplied by grid power) switches interchangeably and smoothly according to the solar radiation intensity, battery SOC (state-of-charge), and load change, as shown in Fig.7. The ATS cycling times is 6 for the day 2013/6/29. Fig.8 shows that the instantaneous apparent PV efficiency based on the solar radiation measured on a fixed tilted surface is about 0.13 in average, and 0.185 maximum. This is due to the variation of PV voltage (battery voltage) and PV temperature which may drive the operating point away from MPP (maximum-power point) of PV module. Shading effect is another unpredictable factor to reduce the PV efficiency.

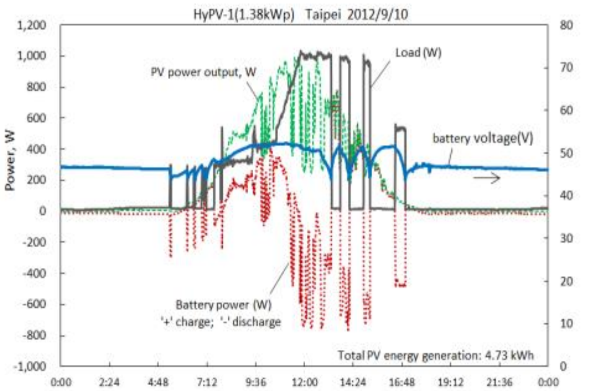


Fig.5 Performance on 2012/9/20

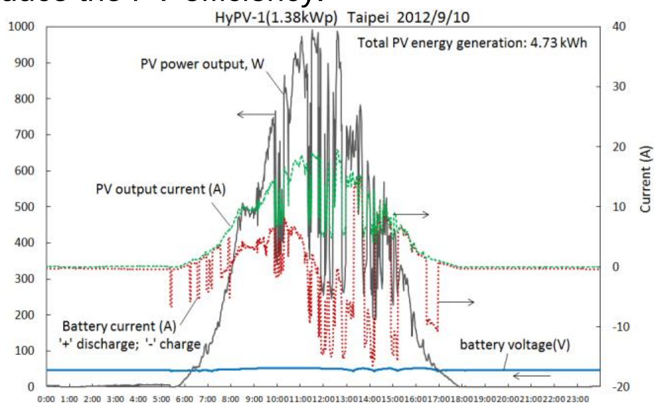


Fig.6 Load variation and battery voltage.

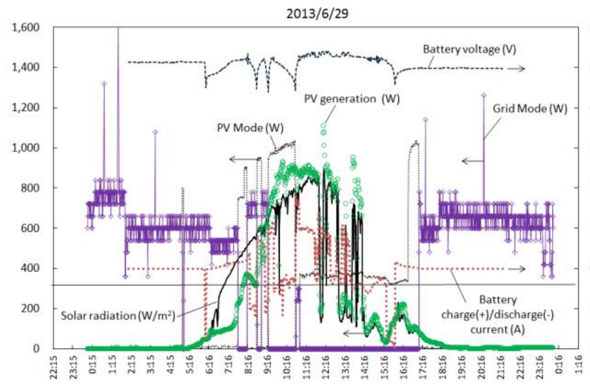


Fig.7 Daily-performance in June 29, 2013.

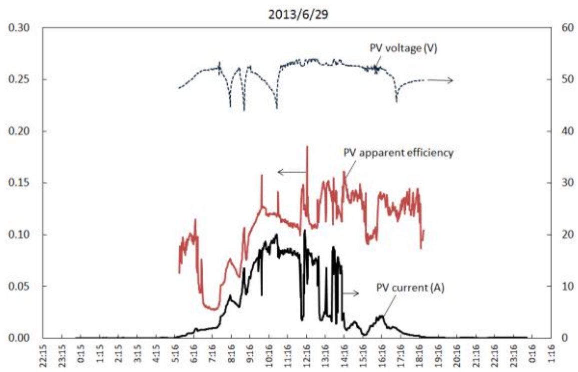


Fig.8 Apparent PV efficiency.

Long-term performance in high season

Long-term test of HyPV-1 was run at normal living conditions with 4 residents, with different combination of air conditioners engaged arbitrarily, battery packages, etc. to observe the system performance and stability. The operating conditions were monitored by the data acquisition system built inside the MCU.

HyPV-1 was run in summer with two air conditioners in full load (300-1,100W, 8-20 kWh/day, running 24 hours/day) to test the performance of solar air conditioning using a buffer storage (only one battery pack 1.4 kWh used). The test result in August, 2013, Fig.9, shows that the daily PV energy generation is 3.78 kWh/day in average and 7.0 kWh/day at maximum or 5.07 kWh/day per kWp PV installation. According to field monitoring data of Taipei, energy generation of PV system in Taipei is around 900 kWh/yr (2.46 kWh/day) per kWp PV installation.

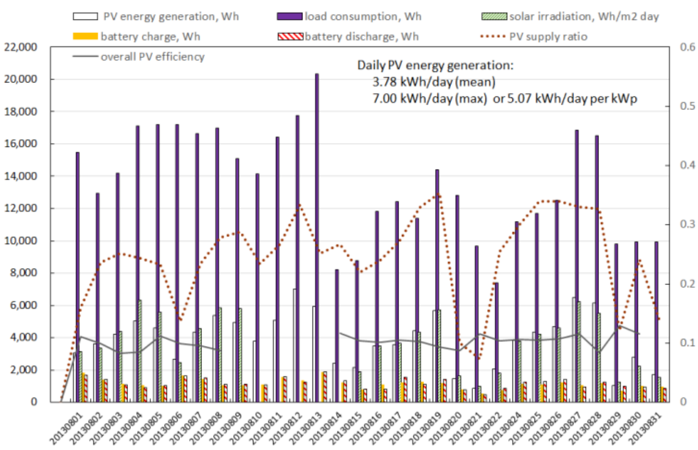


Fig.9 Long-term performance at full-load condition.

The ratio of energy supply from PV is 0.08~0.35 from rainy to clear day. The PV ratio can be increased to >0.7 if the two air conditioners is running 12 hours a day. If the two air conditioners were run 8 hours a day, then HyPV-1 will supply all the energy demand of air conditioners from solar.

The daily energy conversion efficiency of PV system (based on solar radiation measured on a fixed 20^o tilted surface) is from 0.088 in rainy days to 0.130 in clear days. As compared to the rated module efficiency 0.147 (at 1000 W/m^2, 25^{o}C), the measured peak PV efficiency of HyPV-1 at clear days is 0.13 at high ambient temperature (>33^{o}C, <900W/m^2), which is very near the performance using MPPT, about 0.88 approach to the rated maximum-power point (at 1,000 W/m^2, 25^{o}C).

The continuous long-term test in high season shows that two air conditioners (total power consumption 300-1500W) coupled with 1.38k Wp PV module and 1.4 kWh battery pack can be completed powered by solar PV in high season in Taipei (low solar radiation area). The NTU house is surrounded by high-rise buildings with serious shading. The advantage of using 1A-3P sun tracker is offset by the shading effect. The case in the present HyPV-1 is supposed to be the worst case in Taiwan.

Long-term performance over two seasons

HyPV-1 was run since early September, 2012. During November 2012 to March of 2013, PV modules were shaded by a 7-floor building across the street after 1:00PM. The test data is thus not analyzed here. The test result from March to August, 2013, is shown in Fig.10. The daily load consumption increases from March and reaches the maximum in August. It is seen that PV ratio decreases from 0.79 to 0.29. During this period, the system combination was also changed for gathering different experimental data as shown in Table 1.

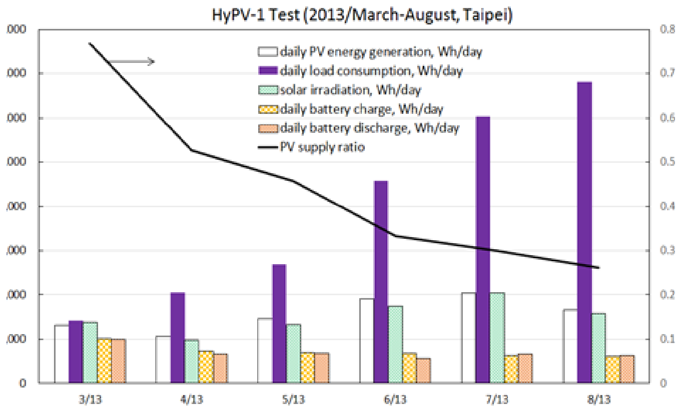


Fig.10 Long-term performance (Mar-Aug, 2013)

Performance of solar air conditioning

HyPV-1 becomes a solar air conditioning system after June using small buffer storage (1.4 kWh) for stabilizing the compressor performance. As shown in Table 1, the ATS frequency increases with decreasing battery capacity and increases with increasing load. The power regulation performance is smooth. No interruption occurs during ATS operation.

Table 1. Power source of load.

2013	Ambient temp °C	PV-Mode supply, kWh	Grid-Mode supply, kWh	Total load, kWh	PV ratio	ATS frequency	Remarks
March	22.1	78.7	20.4	99.1	0.79	61	1 AC, battery 4.3 kWh
April	22.4	54.7	67.5	122.2	0.45	98	2AC, bad weather
May	24	72.1	67.2	139.3	0.52	149	2AC(full-load); bad weather
June	31	83.6	156.6	240.2	0.35	154	2AC (full-load); battery 2.8kWh
July	31	98.0	200.5	298.5	0.33	-	2AC (full-load); battery 2.8kWh
August	31	130.1	312.3	442.4	0.29	320	2AC (full-load); battery 1.4kWh

4. CONCLUSIONS

Most grid-tied solar PV systems installed today are designed to feed all the energy generated into the grid to make money from high feed-in tariff. This will cause serious grid transmission problems when the penetration of solar PV is high, especially the unbalance of grid in clear weather. The present study develops a hybrid solar PV system (HyPV) which generates solar power for local self-consumption and use Li-battery to store excess energy without feeding back to the grid. The first system HyPV-1 was installed in a residential house of NTU to run field test. HyPV-1 consists of a 1.38 kWp PV modules mounted in 3 1A-3P sun trackers, a 4.2 kWh LFP battery, and a power control unit (PCU) for energy management. The load consists of two air conditioners, a fresh air exchanger (80W), and a 100W LED street light. Long-term test of HyPV-1 was run at normal living conditions with 4 residents, with different combination of HyPV to investigate the system performance and stability.

At full-load condition with the two air conditioners running at full load all the day, the PV Mode (load supplied by PV and battery) and Grid Mode (load supplied by grid power) switches interchangeably and smoothly according to the solar radiation intensity, battery SOC (state-of-charge), and load change.

HyPV-1 was run in summer with two air conditioners in full load (300~1,100W, 8~20 kWh/day, running 24 hours/day) to test the performance of solar air conditioning using a buffer storage (only one battery pack 1.4 kWh used). The test result in August, 2013, shows that the average daily PV energy generation is 3.78 kWh/day per kWp PV installation which is higher than the published data in Taipei, 900 kWh/yr (2.46 kWh/day) per kWp PV installation. The ratio of energy supply by PV is 0.08~0.35 from rainy to clear day. If the two air conditioners were run 8 hours a day, then HyPV-1 will supply all the energy demand of air conditioners.

The continuous long-term test in high season shows that two air conditioners (total power consumption 300~1500W) coupled with 1.38 kWp PV module and 1.4 kWh battery pack can be completed powered by solar PV in high season in Taipei (low solar radiation area). The NTU house is surrounded by high-rise buildings with serious shading. The advantage of using 1A-3P sun tracker is offset by the shading effect. The case in the present HyPV-1 is supposed to be the worst case in Taiwan.

HyPV-1 has been run continuously since August, 2012. The performance is quite satisfactory. Further commercialization of HyPV is underway.

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