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Power dispatching control of pyramid solar micro-grid

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Abstract

The hybrid PV system (HyPV) is a solar PV system for self-consumption which operates at stand-alone PV mode or grid mode automatically without feeding access PV power into the grid. To reduce power generation loss due to mismatch between load capacity and size of battery and PV modules, a networking technique called "pyramid solar micro-grid" is proposed. The binary-connection hierarchy of HyPVs is adopted. Solar PV power of HyPVs can be shared each other through a power dispatching control. However, the system reliability due to data transmission and the power dispatching control method becomes an important issue. In the present study, we developed a transmission and communication technique using RS-485 interface combined with MODbus and CANbus protocols. A power dispatching control utilizing mobile-commander scheme was also studied. The long-term performance test of a 2+2 pyramid solar micro-grid with 4 individual HyPVs shows that the micro-grid works very well without any failure over 9 months.

Keywords: solar micro-grid, solar PV, micro-grid, distributed generation

1. Introduction

Most grid-tied solar PV systems installed today feeds all the PV power into the grid, according to feed-in-tariff (FIT) policy. If solar PV is in high-penetration ratio, the solar power feed-in will cause grid instability. Solar PV with battery storage is thus very important in high penetration of solar energy [1-2]. Many micro-grids or distributed energy systems (DG) in different structure have been proposed and studied for optimum design [2], system control [3-5], field test [6] and reliability technique [7]. The solar micro-grid was built to supply electrical power to a community as a distributed-energy system. However, conventional solar micro-grid was usually designed according to the concept of centralized power system except in smaller scale [6]. Solar panels, power control system, battery bank and charger/discharger, inverter etc are put together to create a small centralized power system. The generated power is then separately sent to many users. The construction of such a solar micro-grid is quite expensive and difficult due to non-technical problems such as land search and wiring in the grid.

National Taiwan University have developed a solar PV system called "hybrid solar PV (HyPV)", which is in a simple structure as shown in Fig. 1 [8]. HyPV does not use MPPT (maximum-power-point tracking controller) and regular battery charger. Instead, the nMPPO (near-maximum-power-point design) was adopted to match the voltage of battery and PV module in the system design [9]. And the battery is directly charged by solar PV power before overcharging [10]. This can reduce the cost and improve the system reliability.

HyPV operates at stand-alone PV mode or grid mode automatically by switching technique using ATS (automatic transfer switch) and does not feed power into grid. HyPV operates at PV mode when solar PV power generation or battery storage is high enough. It switches to grid mode when battery storage is low.

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The switch scheme from grid to PV mode determines the system performance, including the life of battery and switching device (ATS), and PV energy generation loss [8].

HyPV is a solar PV power system for self-consumption without feeding PV power into grid. This will lead to PV generation loss if the system match between load capacity and sizes of battery and PV modules is not very well. To cope with this problem, we proposed a networking technique, called "pyramid solar micro-grid", which connects individual HyPVs and shares solar PV power each other through a switching or power dispatching control [11,12]. A pyramid solar micro-grid constructed based on the binary connection of HYPVs at 3 levels is shown in Fig.2. In this pyramid solar micro-grid, solar PV power of eight HyPV units can be shared each other through a smart control. The binary connection of HYPVs is the simplest design to build a pyramid solar micro-grid.

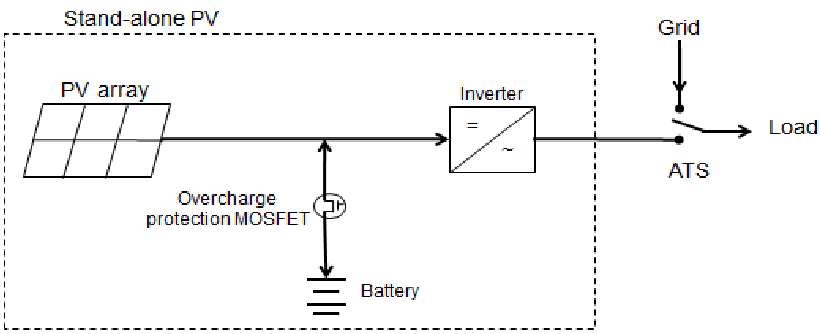

Fig. 1. Hybrid PV system (HyPV).

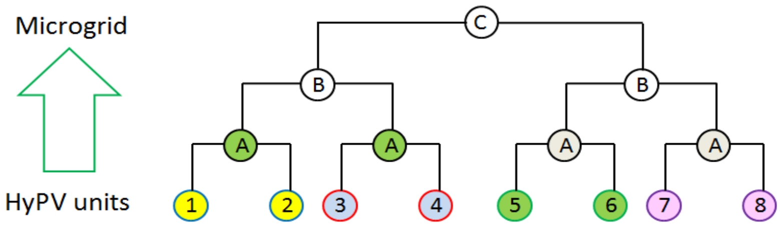

Fig. 2. Pyramid solar micro-grid based on binary connections.

Two pyramid solar micro-grids were built for test [10,11]: one from two HyPV systems connected at Level-A, called "Hynet-2A"[10], and the other from four HyPV systems connected at Level-B, called "Hynet-2B" [11]. The conventional RS485 technique was adopted for data transmission and communication in the pyramid solar micro-grid. The long-term field test shows that data transmission and signal communication problem could cause malfunction of the pyramid solar micro-grid during power dispatching control. This can be very serious if a larger micro-grid was built. Besides, the method of power dispatching control also affects the performance of pyramid solar micro-grid.

The present study focuses on the improvement of system reliability, especially on data transmission and communication protocols. The power dispatching control scheme was also modified in order to keep the system efficiency close to that of FIT PV systems.

2. Experimental Setup of 2+2 Pyramid Solar Micro-grid

2.1. Design of 2+2 pyramid solar micro-grid

The individual HyPVs can be connected in a binary structure (Level-A) in order to share the solar PV power each other when one of the HyPVs is at low load and battery full. Two pairs of HyPVs can be further connected in binary form as Level-B for 4 individual HyPVs to share excess solar power each other. See Fig.3 for a 2+2 pyramid solar micro-grid.

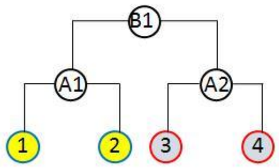

Fig. 3. Binary connection of 2+2 pyramid solar micro-grid.

The central control units (CCU: B1,A1,A2) connecting the HyPVs at different levels are all the same in hardware, but with different control logic and software. CCU will dispatch power flow between two individual HyPVs within Level-A or two Level-A groups in the Level-B and above. Hynet-2B consists of two pairs of 1+1 HyPV systems, A1 and A2.

The design specifications of Hynet-2B in the present study is shown in Table 1. Fig.4 shows the concept of Level-A and Level-B connection.

Table 1. System design specification of 2+2 pyramid solar micro-grid Hynet-2B.

Top level (Level-B)	**B1**			
Bottom level (Level-A)	**A1**		**A2**	
HyPV ID	**D0**	**D2**	**T1**	**T2**
PV size, kWp	0.49	0.49	1.47	1.47
Average PV energy generation, kWh/day	1.27	1.27	3.82	3.82
Battery				
Type	LA	Li	LA	Li
Capacity, kWh	2.4	1.44	4.8	1.824
Load				
Type	Cooling	lighting	lighting	lighting
Load power, kW	0.1~0.7	0.15~0.25	0.2~0.5	0.2~0.5
Load pattern	daytime	24h a day	24h a day	24h a day

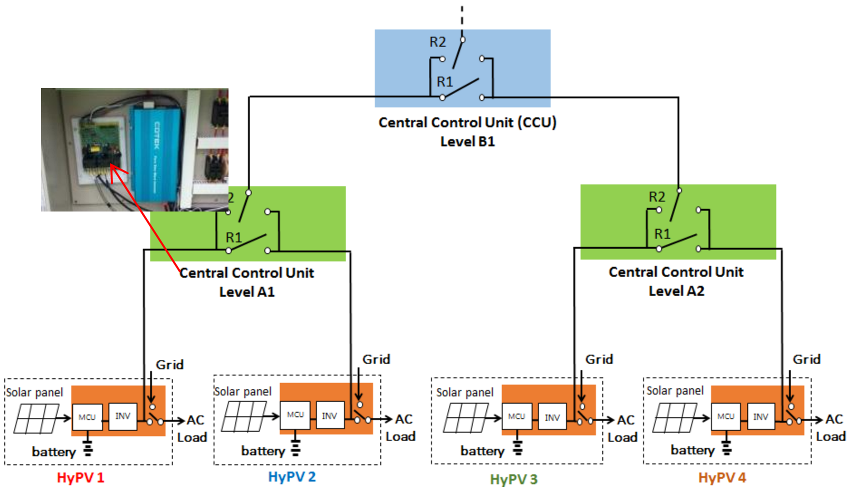

Fig.4. Level-B binary connections of 2+2 pyramid solar micro-grid.

2.2. Data transmission and communication protocols

The data transmission of each HyPV utilizes RS-485 interface. MODbus and CANbus protocols are used at different levels. For binary connection of two HyPVs, the CCU (central control unit) is used as shown in Fig. 5. The CCU connecting the two HyPVs at Level-A is assigned as Master and two MCU in the two HyPVs are the Slave in data transmission. MODbus protocol is used for the communication within Level-A, directly with two individual HyPVs. Fig. 6 shows the RS-485 wiring within Level-A binary connection of 1+1 HyPVs.

For data transmission between the CCUs of Level-A, Level-B and above, CANbus protocol is used. The connection is shown in Fig.7. Only CCUs at upper levels are communicated through CANbus.

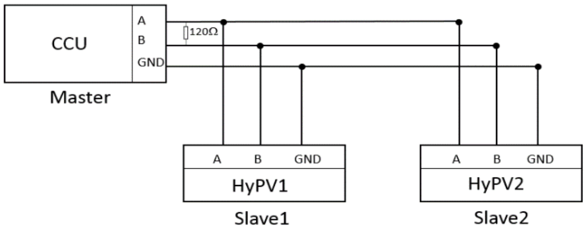

Fig.5. RS-485 data transmission structure within Level-A binary connection of 1+1 HyPVs.

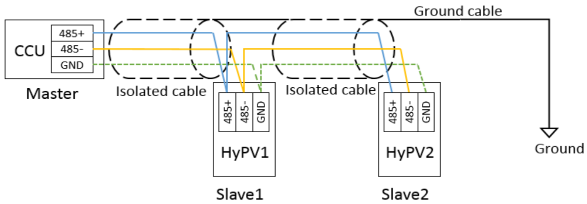

Fig.6. RS-485 wiring within Level-A binary connection of 1+1 HyPVs.

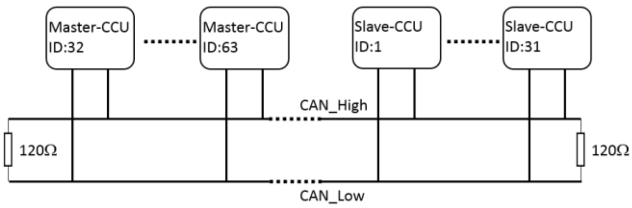

Fig.7. CANbus protocol between CCUs of Level-A and the above.

2.3 Mobile-commander power dispatching control

Within Level-A power dispatching

Level-A CCU performs the power dispatching between two connected individual HyPVs. Power flow is controlled using the following parameters as the indicator:

V_H: battery voltage at full charging, V

V_L: battery voltage at full discharging, V

D_B: battery discharge limit for energy sharing, Wh

Each HyPV will transmit the above parameters to the CCU of Level-A. The CCU then makes decision on power flow control between the two individual HyPVs. The power dispatching flow is activated according to the following logic [9,10]:

State I: Searching the seller and the buyer for PV energy sharing

(1)Measure the battery voltage of each HyPV.

(2)Assign the HyPV with full-charge voltage V_H as the seller.

(3)Assign the HyPV with low voltage V_L as the buyer.

State II: Starting PV sharing when buyer and seller co-exists (R1 ON in Fig.4)

(1) Activating PV sharing when buyer and seller co-exists.

(2) Monitoring the battery discharge of the seller.

State III: Stopping PV sharing (R1 OFF in Fig.4)

(1) When the seller battery has discharged an amount of energy D_B, the PV sharing operation is terminated.

(2) The system returns to State I.

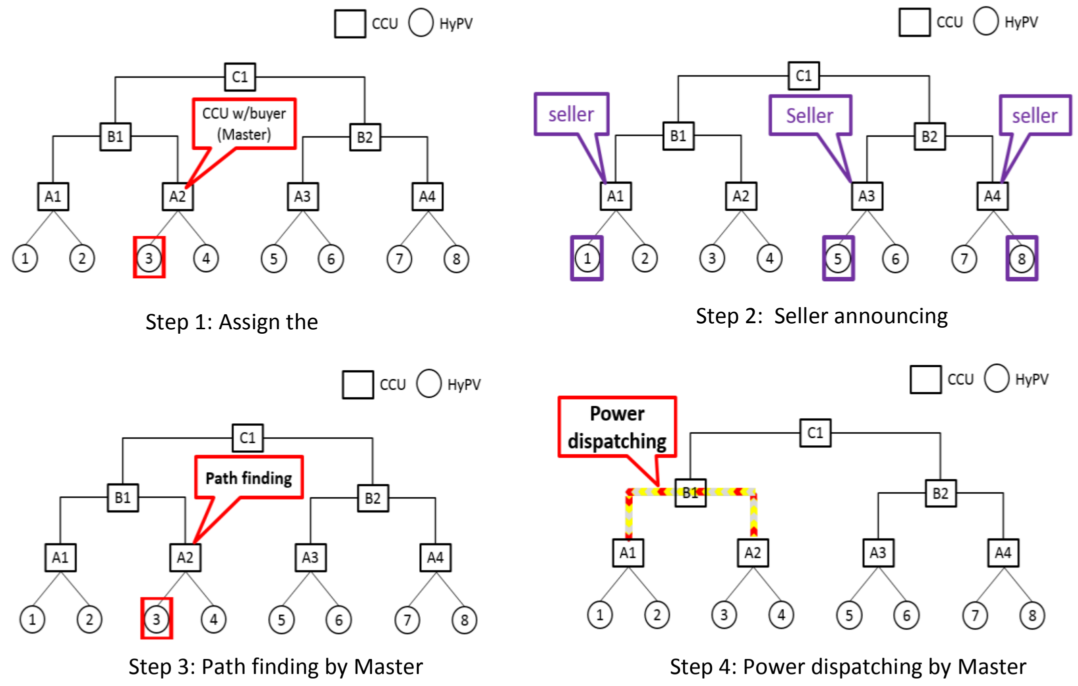

Fig. 8. Power dispatching control.

<u>Above Level-A power dispatching</u>

If the power dispatching between two individual HyPVs at Level-A cannot be activated, Level-A CCU will detect and claim which HyPV is acting as the buyer or the seller. The status of Level-A HyPVs is reported to Level-B CCU through CANbus. CANbus will chose one of the CCU with buyer status as the commander (master) for power dispatching control within the micro-grid. The chosen Master CCU will find the optimal path for power dispatching. The master may be changed after executing a power dispatching control command. This is called "mobile-commander power dispatching control" as shown in Fig.8. The status of buyer/seller and path finding can be simplified through a flagging as shown in Fig.9.

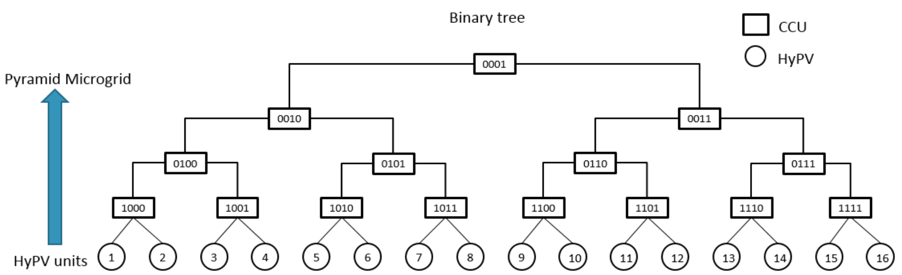

Fig.9. Flagging process for status and path finding of power dispatching.

3. Long-term Test Results

The 2+2 pyramid solar micro-grid (Hynet-2B) was tested outdoor. Data were collected by a PC for analysis. Table 2 is the long-term continuous test results of 2+2 pyramid solar micro-grid Hynet-2B. It is seen that the average daily PV generation per kWp PV installation is 3.53 kWh/kWp which is above the average value of FIT (feed-in-tariff) system (2.61 kWh/kWp) in the same location. Table 3 shows the power dispatching flow within Level-A and Level-B. It is seen that the power dispatching in A1 is within

Level-A only. No power dispatching above Level-A is found. For A2, power dispatching is both within Level-A and Level-B.

Table 4 shows the signal loss of MODbus sand CANbus in long-term test. The average signal loss of MODbus is 37 times per day in A1 group (D0+D2). This corresponds 1 signal loss every 38 minutes since RS-485 transmits 2 data in every 5 seconds. For CANbus, the data loss is about ten times less than MODbus. This is acceptable since the long-term continuous test is free of system malfunction. In the previous experience, the signal loss using conventional RS-485 protocol causes system malfunction or breakdown very often, about once or twice a month. Hynet-2B has been run continuously for more than 9 months without any malfunction due to data transmission and communication.

Table 2. Long-term continuous test results of 2+2 pyramid solar micro-grid Hynet-2B.

Level-B		B1								Specific PV generation (kWh/kWp)
Level-A		A1				A2				
HyPV unit		D0		D2		T1		T2		
2018	Solar irradiation (Wh/m²day)	PV unit generation (kWh/kWp)	PV daily generation (Wh)	PV unit generation (kWh/kWp)	PV daily generation (Wh)	PV unit generation (kWh/kWp)	PV daily generation (Wh)	PV unit generation (kWh/kWp)	PV daily generation (Wh)	
5/18	6212	7.18	3520	4.95	2428	6.36	9350	5.33	7833	5.90
5/19	4576	5.20	2549	3.84	1883	4.13	6078	3.51	5155	4.00
5/20	5788	6.13	3005	4.79	2345	5.15	7563	2.99	4399	4.42
5/21	4397	5.15	2522	3.72	1822	3.94	5788	1.38	2026	3.10
5/22	5355	4.97	2436	4.49	2199	4.80	7056	4.56	6696	4.69
5/23	5358	6.70	3283	4.48	2196	4.83	7097	4.61	6770	4.94
5/24	5750	4.52	2215	4.36	2136	4.18	6150	4.58	6733	4.40
5/25	4689	4.90	2399	3.56	1746	3.82	5612	3.91	5754	3.96
5/26	5741	5.56	2726	4.42	2166	5.09	7482	2.54	3731	4.11
5/27	6338	5.64	2764	4.43	2171	4.16	6111	4.82	7082	4.62
5/28	4473	4.38	2147	3.62	1772	3.20	4703	2.72	3996	3.22
5/29	4557	4.47	2192	3.57	1751	2.90	4260	3.10	4554	3.25
5/30	5018	4.86	2383	3.92	1919	1.57	2303	3.66	5377	3.06
5/31	5223	5.30	2595	4.09	2005	3.30	4848	3.67	5399	3.79
6/1	2364	3.17	1553	2.00	982	1.96	2886	2.10	3081	2.17
6/2	4386	3.94	1931	3.75	1839	2.67	3924	3.41	5017	3.24
6/3	4551	4.60	2254	3.68	1803	1.47	2158	3.43	5041	2.87
6/4	6242	6.15	3015	4.61	2261	1.66	2446	3.69	5425	3.35
6/5	4940	4.57	2241	3.84	1883	2.97	4372	3.57	5251	3.51
6/6	4431	3.15	1543	3.59	1757	2.89	4251	3.32	4886	3.17
6/7	6480	4.16	2039	4.01	1965	2.24	3288	4.36	6410	3.50
6/8	6302	6.81	3335	4.83	2367	4.10	6028	5.06	7439	4.89
6/9	6384	6.13	3003	4.85	2377	2.91	4279	3.88	5707	3.92
6/10	2696	3.19	1562	2.27	1114	2.45	3602	2.37	3480	2.49
6/11	1084	1.36	669	0.86	422	0.96	1404	0.95	1390	0.99
6/12	6992	5.09	2496	5.98	2932	3.63	5332	4.76	7003	4.53
6/13	4382	4.35	2133	3.67	1801	3.09	4546	3.31	4859	3.40
6/14	2297	2.70	1321	1.97	964	1.63	2397	1.84	2700	1.88
6/15	1561	2.10	1030	1.39	683	1.53	2247	1.45	2134	1.55
6/16	5383	6.23	3053	4.37	2142	3.16	4640	3.89	5713	3.97
6/17	5696	6.09	2986	4.76	2334	2.90	4267	3.54	5201	3.77
6/18	3889	4.63	2267	3.32	1626	3.01	4429	2.98	4375	3.24
6/19	4076	4.60	2253	3.43	1679	2.97	4364	3.07	4520	3.27
6/20	2881	3.76	1842	2.54	1246	2.71	3984	2.53	3719	2.75
average	4720	4.76	2331	3.76	1845	3.19	4684	3.38	4966	3.53

Table 3. Power dispatching energy flow within and above Level-A.

Level-B		B1							
HyPV		D0 selling (Wh)		D1 selling (Wh)		T1 selling (Wh)		T2 selling (Wh)	
2018	Solar irradiation (Wh/m²)	Within Level-A	Within Level-B	Within Level-A	Within Level-B	Within Level-A	Within Level-B	Within Level-A	Within Level-B
5/18	6212	0	0	179	0	0	0	1627	0
5/19	4576	0	0	140	0	0	0	0	0
5/20	5788	0	0	250	0	0	0	0	0
5/21	4397	158	0	0	0	0	0	0	0
5/22	5355	0	0	0	0	0	0	699	153
5/23	5358	166	0	0	0	453	0	598	0
5/25	4689	873	0	0	0	732	0	1698	7
5/26	5741	204	0	16	0	345	0	766	0
5/27	6338	0	0	111	0	299	0	3066	34
5/28	4473	0	0	0	0	0	0	0	0
5/29	4557	0	0	0	0	0	1809	734	0
5/30	5018	0	0	0	0	0	324	1465	690
5/31	5223	0	0	0	0	0	2005	1386	243
6/1	2364	0	0	0	0	0	450	0	352
6/2	4386	498	0	0	0	0	0	1450	12
6/3	4551	114	0	0	0	0	175	1400	126
6/4	6242	138	0	121	0	0	135	1017	545
6/5	4940	0	0	0	0	0	1447	978	527
6/6	4431	0	0	0	0	0	1099	766	458
6/7	6480	402	0	114	0	0	402	2344	276
6/8	6302	0	0	36	0	0	1270	4108	609
6/10	2696	0	0	0	0	0	2099	0	0
6/11	1084	0	0	0	0	0	0	0	0
6/12	6992	0	0	320	0	0	1221	960	895
6/13	4382	0	0	0	0	0	2170	827	331
6/14	2297	0	0	0	0	0	1970	448	0
6/15	1561	0	0	0	0	0	1249	0	0
6/16	5383	0	0	147	0	0	0	1481	1226
6/17	5696	0	0	706	0	0	178	1297	890
6/18	3889	0	0	0	0	0	2072	399	511
6/19	4076	0	0	0	0	0	3157	332	326
6/20	2881	0	0	0	0	0	1824	282	0
average	4636	80	0	67	0	57	783	941	257

Table 4. Signal loss of MODbus sand CANbus in long-term continuous test.

2018	Signal loss in MODbus (times/day)		Signal loss in CANbus (times/day)	
	D0&D2	T1&T2	D0&D2	T1&T2
5/29	49	68	4	0
5/30	42	24	6	0
5/31	16	20	8	0
6/1	34	58	3	0
6/2	50	57	0	0
6/3	98	51	3	0
6/4	82	61	4	0
6/5	34	41	2	0
6/6	65	23	4	0
6/7	32	17	4	0
6/8	59	46	4	0
6/9	47	51	5	0
6/10	9	1	0	0
6/11	12	2	1	0
6/12	32	8	11	0
6/13	9	4	5	0
6/14	10	2	3	0
6/15	0	0	4	0
6/16	37	8	6	0
6/17	25	5	4	0
6/18	54	10	7	0
6/19	14	4	5	0
6/20	34	31	6	0
average	37	26	4	0

4. Conclusion

The hybrid PV system (HyPV) is a solar PV system for self-consumption which operates at stand-alone PV mode or grid mode automatically and does not feed access PV power into the grid. HyPV operates at PV mode when solar power generation or battery storage is high. It switches to grid mode when battery storage is low. There may be a PV generation loss if the system match between load and sizes of battery and PV modules is not proper. A networking technique called "pyramid solar micro-grid" is proposed, which connects individual HyPVs, and allows solar PV power sharing each other. The binary-connection hierarchy of HyPVs is used to build a pyramid solar micro-grid. Solar PV power generation of HyPVs can be shared each other through a power dispatching control. However, the system reliability due to data transmission and communication and power dispatching control among each individual HyPV becomes an important issue. In the present study, we developed a transmission and communication technique using RS485 interface combined with MODbus and CANbus protocols. A power dispatching control utilizing mobile-commander scheme was also studied. The long-term performance test of a 2+2 pyramid solar micro-grid built from 4 individual HyPVs shows that the micro-grid works very well without any failure over 9 months. The average signal loss of MODbus is 37 times per day in A1 group (D0+D2). This corresponds to one signal loss in every 38 minutes since RS-485 transmits 2 data in every 5 seconds. For CANbus, the data loss is much less than MODbus. There is no solar PV generation loss since the solar PV energy generated approaches that of FIT PV system.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Zi-Ming Dong conducted the experiment and data analysis; Hsin-Yi Hsu conducted the controller design; Bin-Juine Huang was the supervisor and conducted the research and wrote the paper; Min-Han Wu conducted the CCU design; Wei-Hao Wu conducted the MOD bus design; Po-Chien Hsu conducted the central control system design; Kang Li and Kung-Yen Lee are the co-supervisor,

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