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Improving Solar PV System Efficiency Using One-Axis 3-Position Sun Tracking

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Abstract

The energy conversion efficiency of commercial solar PV is around 15-19%. Millions of dollars are spent in order to gain a small percentage in energy conversion efficiency. The power generation of solar PV can be increased using sun tracking technology. However, the design of the sun tracker is usually very complicated and expensive. Units are heavy and prone to breakdown and installation is difficult. In the present study, one-axis three-position (1A-3P) low-cost sun tracking PV as a BIPV was developed and tested. The comparative test of a 1A-3P tracking PV system started from 2010/3/01 was carried out. The single-day increase of energy generation is 39% in clear days. The overall increase of total energy generation from March 1, 2010 to May 31, 2012, is 24.2% in Taipei. The expected overall increase of total energy generation with respect to fixed PV is 37.5% in high solar radiation areas. The installation cost of 1A-3P sun tracking PV is about the same as the regular mounting cost of a conventional rooftop PV system, but providing 25-37% higher PV energy generation efficiency. For cost reduction in structural design, the wall mounting of 1A-3P tracker may cause PV not facing south exactly. A long-term comparative field test was carried out to study the effect of misalignment using three identical 1A-3P tracking PV module facing south, southeast 45^{o}, and southwest 45^{o}. The measured energy loss is 4.42~6.82% for southeast orientation and 4.31~6.79% for southwest orientation. The test result shows that the energy loss of 1A-3P PV due to misalignment of south is negligible. Many samples of 1A-3P trackers were manufactured and installed for field test. The longest test is over 30 months with satisfactory performance.

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Keywords: Sun tracking PV; sun tracker; solar PV system; solar PV power generation

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1. Introduction

The improvement of energy conversion efficiency using new material or new manufacturing process of solar cell seems approach its limit, around 15-19%. Millions of dollars are spent in order to gain a small percentage in energy conversion efficiency. The power generation of solar PV can be increased using sun tracking technology. However, the design of the sun tracker is usually very complicated and expensive. Units are heavy and prone to breakdown and installation is difficult.

Many theoretical studies have been conducted for the past several decades to show the improvement of PV power generation using 1-axis or 2-axis sun tracking PV [1-2]. Kacira *et al* [3] experimentally investigated the effect of a dual-axis solar tracking on energy gain compared to a fixed panel in Sanliurfa of Turkey, and found that the daily average gain is 29.3% in solar radiation and 34.6% in power generation, for a particular day in July. Mazen *et al* [4] performed an experimental investigation on the effect of using two-axis sun-tracking systems under Jordanian climate. It was experimentally found that there was an increase of about 30–45% in the output power compared to the fixed PV system, for particular days.

Huang *et al* [5] developed a novel 1-axis 3-position (1A-3P) sun tracking PV with 3 fixed angles at morning, noon, and afternoon. A controller was developed to control sun tracker to the 3 fixed positions at the designated time (10:20 to turn horizontal, 13:40 to turn west, 18:30 to turn east). A comparative test using a fixed and a 1A-3P tracking PV was carried out with two identical stand-alone solar-powered LED lighting systems (Fig. 1).

Fig. 1. Comparative test of 1A-3P sun tracking PV.

The 1A-3P sun tracker consists of a supporting frame, a PV mounting frame, and a moving screw as described in [5]. A DC motor is used to turn the PV mounting frame. The turning of the 1A-3P tracker is made by a timer IC which is used to provide the time signal to trigger the motor to turn at the turning angle (or time). The motor consumes 5 W power and it takes about 15 s for each turning. The energy consumption of the driving motor is thus negligible. A rotating-type resistor was installed on the rotating axis as the position sensor to detect the angular position of the tracker to control the stopping angle. All the control algorithms, measuring functions for tracker motion and PV power generation, was implemented by a micro-processor PIC. The instantaneous solar irradiation on the fixed PV with tilt angle 25^o (I_T) was measured every 4 s. The daily-total solar irradiation on the fixed PV tilt (H_T) was integrated from measured I_T.

The field test in the particular days shows that the 1A-3P tracking PV can generate 35.8% more electricity than the fixed PV in a partly-cloudy weather with daily-total solar irradiation H_T =11.7 MJ/m^{2}day, or 35.6% in clear weather with H_T=18.5 MJ/m^{2}day [5]. This indicates that the present 1A-3P tracking PV can perform very close to a dual-axis continuous tracking PV. The long-term outdoor test results have shown that the total power generation increase in the test period from March 1, 2010 to June 30, 2011, is 24.5% in Taipei [5]. The expected increase of total long-term power generation with respect to fixed PV will be higher than 30% in Taichung and 35% in Kaohsiung.

The 1A-3P tracker is a kind of BIPV (Building-integrated-PV) which can be easily mounted on the building walls. The cost of the sun tracker including controller is about the same as the regular mounting cost of a conventional rooftop PV system. This means that there is no extra cost for 1A-3P sun tracking PV, but with 25-35% more energy conversion efficiency. In the present study, we continue to monitor the long-term comparative performance test and further conducted another comparative test to study the effect of the misalignment of the sun tracker if not mounted exactly toward south.

2. Comparative test of 1A-3P sun tracking PV

Figure 2 shows the long-term test results from 2010/3/01 to 2012/5/31. The overall increase of PV energy generation from 2010/3/01 to 2012/5/31 is 24.2% in Taipei, which is about the same as the test result from 2010/3/01 to 2011/6/30 [5]. The increase of 1A-3P tracking PV energy generation is between 17.2% and 29.3% on monthly basis as shown in Table 1.

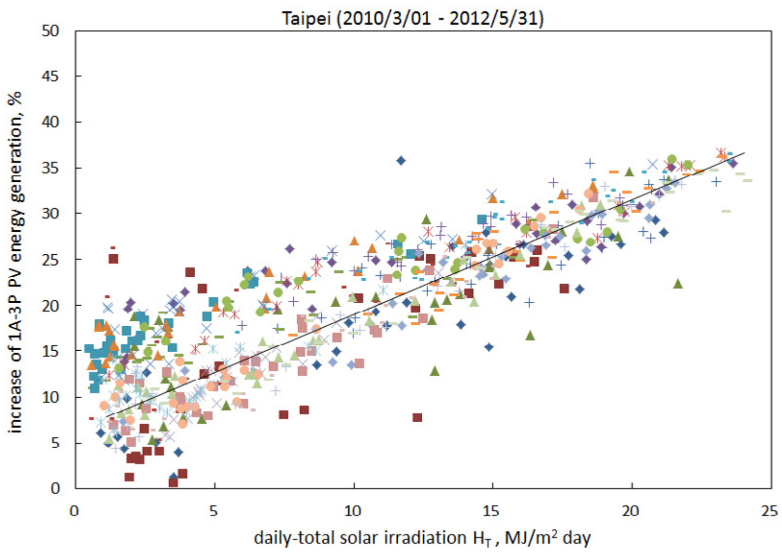

Fig. 2. Comparative test results of 1A-3P tracking PV.

Table 1. Test results from 2010/3/01 to 2012/5/31.

Month	monthly-mean irradiation	energy generation, kWh/month		increase of 1A-3P (%)
(2010-2012)	H_T, MJ/m^2 day	fixed	1A-3P	
Mar-10.2010	11.21	22.783	28.044	23.1
April	7.96	14.466	17.136	18.5
May	10.41	20.464	25.082	22.6
August	14.89	14.427	17.604	22.0
September	14.42	26.930	33.867	25.8
October	6.86	13.162	15.908	20.9
November	6.53	12.041	14.654	21.7
December	11.76	22.451	28.733	28.0
January-11, 2011	3.32	6.911	8.386	21.3
February	6.76	11.958	15.100	26.3
March	5.16	10.067	12.527	24.4
April	12.74	19.152	24.768	29.3
May	11.26	17.636	22.361	26.8
June	13.45	25.476	32.560	27.8
July	14.87	28.731	37.128	29.2
August	17.98	26.668	33.959	27.3
September	14.15	27.179	34.092	25.4
October	7.19	15.025	17.611	19.2
November	8.38	16.733	20.150	20.4
December	6.32	14.000	16.089	14.9
January.2012	3.89	8.379	9.591	14.5
February	8.3	16.015	19.505	21.8
March	10.15	20.453	25.354	24.0
April	9.11	18.309	22.080	20.6
May	14.49	27.697	35.280	27.4
Total	10.14	457.113	567.569	24.2

3. Effect of 1A-3P mounting misalignment to exact south

The 1A-3P tracker will be arbitrarily mounted on the wall of a building which may not always make the PV module facing south direction exactly. An auxiliary mounting structure may be needed to correct the orientation of PV module. In the previous analysis [6], it was theoretically shown that the energy loss due to alignment error to south direction installation will be around 8% for the maximum misalignment 45^o. We thus performed another comparative field test to verify this.

Three identical 1A-3P tracking PV systems (130W$_p$ PV, 100Ah/12V battery, 25W LED) were built for PV module facing three orientations: south, southeast 45^o, and southwest 45^o (Fig. 3). The test results (Fig. 4) shows that the daily power generation loss compared to 1A-3P tracking PV facing south is 1-9%, the high the solar irradiation, the higher the energy loss. The overall energy loss is 4.42~6.82% for southeast orientation and 4.31~6.79% for southwest orientation at mean irradiation 7.19~14.15 MJ/m^2 day (Table 2). This is the largest loss since the solar irradiation is high in the test period. The experimental result has shown that the 1A-3P tracker can be mounted on walls toward a rough south direction. The energy loss due to misalignment error is negligible as predicted [6].

Fig. 3. Comparative test on the effect of misalignment of 1A-3P installation direction.

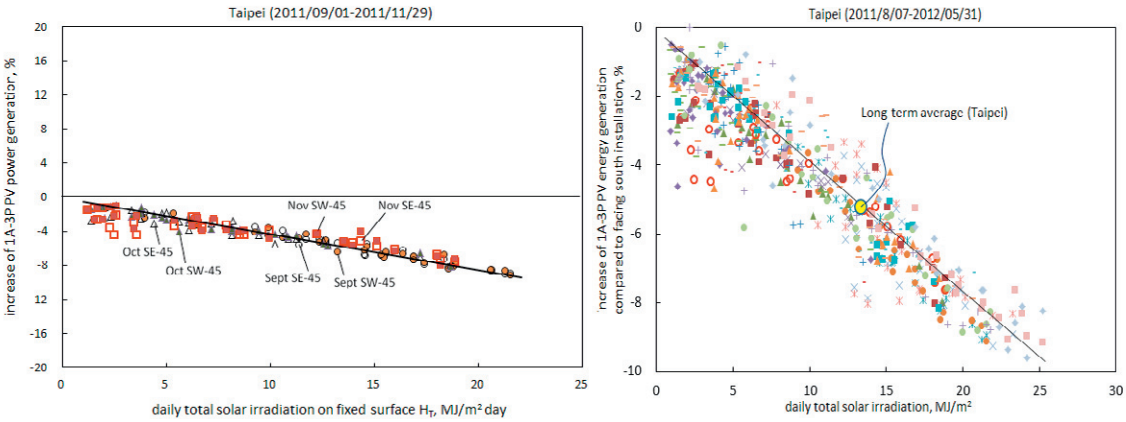

Fig. 4. Comparative test results on the effect of misalignment of 1A-3P installation direction.

Table 2. Effect of misalignment from south direction.

Month	Monthly-total PV energy generation					
	facing south	Facing SE-45deg		Facing SW-45deg		Irradiation H_T
(2011-2012)	kWh/month	kWh/month	loss(%)	kWh/month	loss(%)	H_T, MJ/m^2 day
07-August.2011	16.54	15.47	-6.45	15.49	-6.34	15.26
September	19.27	17.95	-6.82	17.96	-6.79	14.15
October	9.95	9.51	-4.42	9.52	-4.31	7.19
November	10.97	10.42	-4.98	10.43	-4.88	8.30
December	9.09	8.77	-3.51	8.75	-3.68	6.32
January.2012	5.42	5.25	-3.08	5.24	-3.19	3.89
February	11.04	10.47	-5.13	10.48	-5.04	8.30
March	14.49	13.64	-5.87	13.63	-5.92	10.15
April	12.48	11.87	-4.82	11.88	-4.80	9.11
May	19.65	18.37	-6.52	18.36	-6.56	14.49
Total	128.92	121.77	-5.55	121.79	-5.53	9.59 (mean)

4. Application of 1A-3P sun tracking PV

The 1A-3P sun tracker consists of a supporting frame, a PV mounting frame, and a moving screw. A microprocessor-based controller was developed to control the rotation of the tracker 3 times a day, on 10:20 to horizontal, 13:40 to west position, and 18:00 return to east position (Fig. 5). Each motion takes about 10 s. The reliability is the majopr issue in the product design. The tracker is designed for 25 years outdoor use. Hence, the tracker does not use solar sensor. An intelligent control system was developed to correct the clock automatically (Fig. 6). The mounting distance between adjacent 1A-3P trackers is 2.8 meter to avoid shading. This is acceptable since the 1A-3P tracker was developed as a BIPV for small solar home system. Usually, three to six 1A-3P trackers is enough for 1.5 kW_p to 3 kW_p installation, with each tracker holding two PV modules (250 W_p each).

Fig. 5. Atitude of 3 positions

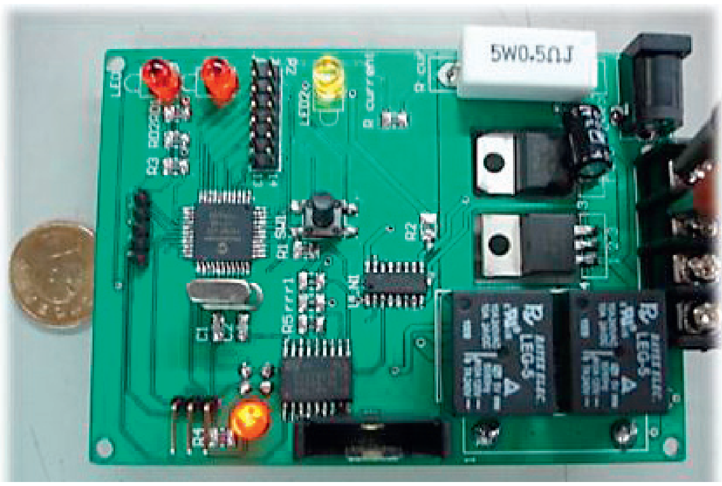

Fig. 6. Controller of 1A-3P tracker.

Many samples of 1A-3P trackers were manufactured and installed for field test as shown in Fig. 7. The longest performance is over 24 months. No failure was found.

Fig. 7. Real application of 1A-3P PV systems.

5. Conclusions

The comparative test of a 1A-3P tracking PV system started from 2010/3/01 was carried out. Each of the two identical sLED systems tested consists of a 230Wp PV module, a lead-acid battery 100 Ah/24V, and a 100W LED lighting fixture. The total power generation increase in the test period from March 1, 2010 to November 30, 2011, is 25.4% in Taipei (an area of low solar energy resource). If the 1A-3P tracking PV is used in the area of high solar energy resource with yearly-average $H_T > 17$ MJ/m^{2}day, the expected increase of total long-term power generation with respect to fixed PV will be higher than 37.5%. This is very close to that of dual-axis continuous tracking PV. The 1A-3P tracker can be easily mounted on the wall of a building as BIPV. The tracker cost is about the same as the regular mounting cost of a conventional rooftop PV system, but having 25-37% more energy generation.

In practice, the 1A-3P tracker will be arbitrarily mounted on the wall of a building which may not always make the PV module facing south direction exactly. An auxiliary mounting structure may be needed to correct the orientation of PV module. In the previous analysis, it was theoretically shown that the energy loss due to alignment error to south direction will be around 8% for the maximum misalignment 45^o. Another comparative field test was thus carried out.

Three identical 1A-3P tracking PV systems (130Wp PV, 100Ah/12V battery, 25W LED) were built and installed for PV module facing three orientations: south, southeast 45^o, and southwest 45^o. The test result shows that the daily power generation loss compared to 1A-3P tracking PV facing south is 1-9%. The overall energy loss is 4.42~6.82% for southeast orientation and 4.31~6.79% for southwest orientation at mean irradiation 7.19~14.15 MJ/m^2 day. This will be the largest loss since the solar irradiation is high in the test period. The experimental result has shown that the 1A-3P tracker can be installed on a wall toward roughly south. The energy loss due to misalignment error is negligible.

Many samples of 1A-3P trackers were manufactured and installed for field test. The longest test is over 24 months. The performance was satisfactory. The 1A-3P sun tracking PV is ready for commercialisation.

Acknowledgements

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Nomenclatures

I_T instantaneous solar irradiation on PV slope, W m^{-2}
H_T daily-total solar irradiation on PV slope, MJ m^{-2}

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