PERFORMANCE ANALYSIS OF PORTABLE PHOTOVOLTAIC POWER GENERATION SYSTEMS BASED ON MEASURED DATA IN MONGOLIA

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ABSTRACT

The New Energy and Industrial Technology Development Organization (NEDO) of Japan has performed demonstrative research on movable type photovoltaic (PV) power generation systems from 1992 to 1996 in Mongolia. The main purpose of this project was to improve compactness, portability, and reliability of portable PV systems including peripheral equipment such as batteries and inverters, by using the portable PV system for nomadic life of people living in the nomadic society.

This paper describes the performance analysis of PV systems based on measured operation data from NEDO's project systems. We have performed experiments using a sample system and DC current circuit resistance, inverter efficiency curve, and the whole system losses will be clarified. Since humidity is very low in Mongolia, the electrolyte of the batteries decreased very much due to evaporation. Also taking into account the effects of gassing, a result of the oscillation of the charge controller which serves as an over charge protection, lowers the batteries lifetime.

KEYWORDS

Portable PV system – 1: Performance – 2:

INTRODUCTION

In Mongolia, about 33% of its total population, that is, 808,500 people are engaged in agriculture or stock-farming, and most of them are nomads living in traditional movable tents called "GER" [4]. They move 4 to 5 times a year together with their livestock in search for pasture. They do not have any access to electricity. Providing them by stable power supply will play a key role in maintaining the basic social services for these people living in rural areas of Mongolia. It will greatly affect the education of rural people when they have access to modern information technology through use of radio, TV.

The New Energy and Industrial Technology Development Organization (NEDO) of Japan has performed demonstrative research on movable type photovoltaic (PV) power generation systems from 1992 to 1996 in Mongolia. The main purpose of this project was to improve compactness, portability, and reliability of portable PV systems including peripheral equipment such as batteries and inverters, by using the portable PV system for nomadic life of people living in the nomadic society [1].

This paper describes the performance analysis of PV systems based on measured operation data from NEDO's project systems. We have performed experiments using a sample system and DC current circuit resistance, charge/discharge efficiency, inverter efficiency curve, and the whole system losses will be clarified.

SYSTEM CONFIGURATION

The system consists of a PV unit, control unit, and battery unit (see Fig. 1) hooked up by connectors. The PV unit consists of a panel block and leg block. The control unit consists of a charge controller, inverter, and data logger. The PV output (rated 204W) is stored in the batteries via the charge controller and output as 220V AC power by the inverter (see Table 1). For easy replacement, the storage batteries used were automotive lead-acid batteries available in Mongolia.

Two batteries of 12V, 70Ah (100Ah for the 1992's system) were used in series. Radio, television, incandescent electric lamp and fluorescent light were used as load of about 280Wh consumption per day.

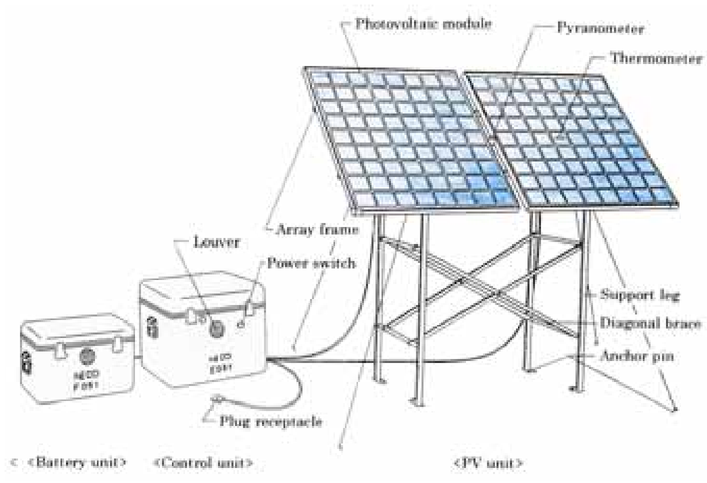


Fig.1: Overall appearance of the system.

TABLE 1: SYSTEM SPECIFICATIONS

			1992's System	1993's System	1994's System
PV Unit	Array Rated Power		204W (51W x 4)	204W (102W x 2)	
	Structure	Panels	Angle Variable	Two-split table	
		Array angle	30 ° ,45 ° ,60 °	45 °	
		Legs	Built-in type		
	Frame material		Array frames, support legs: Aluminum		
			Braces: Stainless steel		
	Assemled dimensions (mm)		L1832xD800xH2070	L1786xD700xH1700	L1786xD700xH1701
	Weight	Panels	26.6 kg	13.5 kg x 2	13.1 kg x 3
		Legs	11.3 kg	6.5 kg	5.7 kg
		Total weight	40.9 kg	33.5 kg	31.9 kg
Control Unit	Input Voltage		DC 24V		
	Output Voltage		AC 220V 50Hz		
	Output Capacity		300VA		
	Dimensions (mm)		L476xD426xH555	L470xD420xH465	
	Weight		43.0 kg	41.7 kg	35.6 kg
	Functions		Overcharge/overdischarge prevention, Overcurrent/Overvoltage protection, and timer		
Battery Unit	Storage battery	Type	Lead-Acid battery for car		
		Voltage	24V (12V x 2 in series)		
		Capacity	100Ah	70Ah	
	Dimensions (mm)		L476xD426xH555	L415xD315xH320	
	Weight		65 kg	40.1kg	
Total weight			148.9 kg	115.3 kg	107.6 kg

The 200 systems were installed from fiscal year 1992 to 1994. 100 sets of initial systems were installed in the area centering around Harhorin in Uvurhangai aimag, and 50 sets of 2nd, 3rd systems each were installed in the area around Undur-Ulaan in Arhangai aimag in 1993 and the southern district of Uvurhangai aimag in 1994.

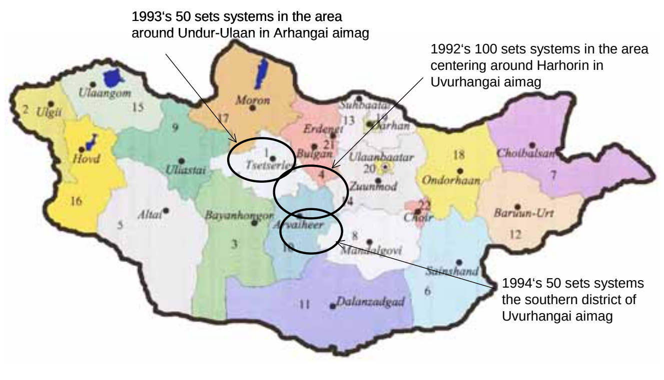


Fig.2: Installation areas of Portable PV systems

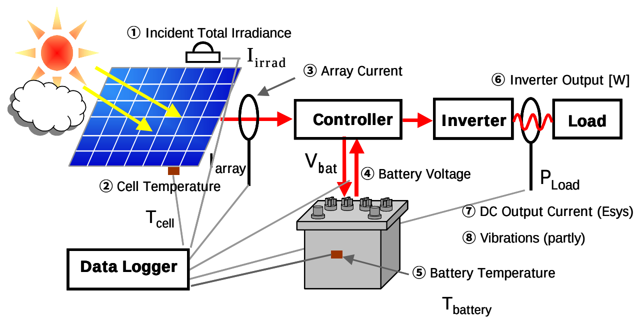


Fig.3: Measurement Items and Points

The operation data have been measured every 10 minutes (initial systems) and 20 minutes (2nd and 3rd systems) and stored in the data loggers. Measurement items were as follows: incident global irradiance in array-plane, cell temperature, array output current, battery voltage, inverter output power, unit internal temperature, DC output current (3rd systems), vibrations (partly) (Fig.3). It was reported that data collecting was very problematic, because the systems were installed over a wide range, many systems installed in total, their installation sites (Gers) moved due to the nomadic lifestyle, and traffic services were poor [1].

ANALYSIS METHOD

First, raw data was checked and correctable noise was filtered. Continuous operation data for two weeks or more was analyzed. Fig. 4 shows the performance ratio and the various losses [in %] of the away output at STC per month. Gain part includes system performance ratio and PV efficiency increase by temperature fall. In the following sections we describe the method in detail. Battery losses are difficult to determine. The value obtained by the deduction of the load consumption, inverter loss and DC circuit resistance loss from array input energy was defined as storage battery loss.

System performance indices

All system performance data have been evaluated in terms of operational performance and reliability. The evaluation procedures are based on the IEC Standard 61724 [2].

$$Y_r = H_A / G_S \quad (1) \qquad Y_A = E_{A,d} / P_{max} \quad (2)$$
$$Y_f = E_{load,d} / P_{max} \quad (3) \qquad K = Y_f / Y_r \quad (4)$$

The <u>*reference yield* Y_r</u> is based on the in-plane irradiation and represents the theoretically available energy per day and kW_p. The <u>*array yield* Y_A</u> is the daily array energy output per kW and represents the number of hours per day that the array would need to operate at its rated output power P_{max} to contribute the same daily array energy to the system as was monitored. The <u>*final yield* Y_f</u> is the energy delivered to the load per day and kW_p. This yield presents the number of hours per day that the array would need to operate at its rated power P_{max} to equal its contribution to the load. The <u>*performance ratio K*</u> is the ratio of PV energy actually used to the energy theoretically available (i.e. Y_f/ Y_r). It is independent of location and system size and indicates the overall losses on the array's rated output due to module temperature, incomplete utilization of irradiance and system component inefficiencies or failures [3].

PV array simulation

Array simulation model was used to calculate the array output degradation due to temperature change and Pmax mismatch. The array output can be computed using the fundamental equation (5) of the equivalent circuit.

$$I = I_{ph} - I_0\left[\exp\left\{q\left(\frac{V + R_s I}{nkT_c}\right)\right\} - 1\right] - \frac{V + R_s I}{R_{sh}} \quad (5)$$

$$I_{ph} = I_{ph0}\left\{1 + 7.9736\times10^{-4}\cdot(T_C - 25)\right\}\times\left[0.94G_A + 0.06\{1 - \exp(-8G_A)\}\right] \quad (6)$$

$$I_0 = I_{o0}\cdot\exp\{0.14132\cdot(T_c - 25)\} \quad (7)$$

$$R_s = R_{s0}\left\{1 + 3.4158\times10^{-3}\cdot(T_C - 25) + 2.5324\times10^{-5}\cdot(T_C - 25)^2\right\} \quad (8)$$

$$R_{sh} = \frac{R_{sh0}}{1 + 4.449\times10^{-2}\cdot(T_C - 25) + 8.0575\times10^{-4}\cdot(T_C - 25)^2} \quad (9)$$

Where, I is current of PV cell, I_{ph} is generating current, I_0 is diode saturation current, q is charge of electron, V is cell voltage, R_s is series resistance, R_{sh} is parallel resistance, n is diode constant, k is Boltzmann constant, T_c is PV cell temperature. The diode constant n is assumed to be 1.2.

The I-V characteristics is largely influenced by the cell temperature. The following approximation equation for each term were derived experimentally by STC.

The operation voltage of the PV array is uniquely decided in such a composition depending on the state of charge (SOC) [4].

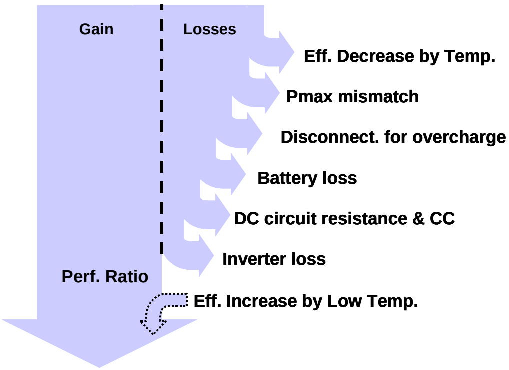


Fig.4: Energy flow (Sankey diagram of losses)

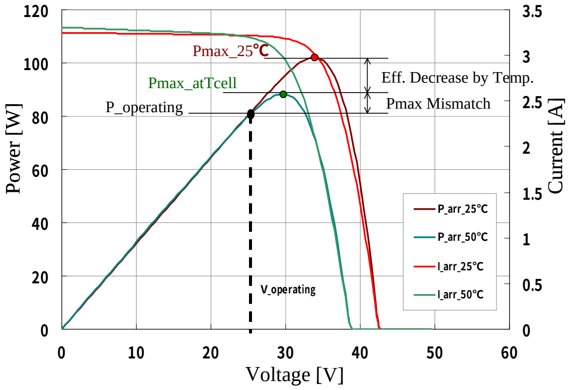


Fig.5: I-V curves of modeled array.

As shown in Fig. 5, the losses due to increase in temperature and Pmax mismatch were computed from the simulated results taken at 25℃ and at measured cell temperature. The loss due to array disconnection from a full charged storage battery was also calculated.

Inverter efficiency curve

Recently we have performed experiments sample system and DC current circuit resistance, inverter efficiency curve (Fig.6). Using the curve-fitted data and measured real load, the inverter and DC circuit resistance losses were calculated. The ratings capacity is 300W.

RESULTS

The results may be summarized as follows: degradation was not observed with the pyranometer and the efficiency of array. Yearly average in-plane irradiance of older systems was 4.88 kWh/m^2 per day and newer systems was 4.71 kWh/m^2 per day. In spite of decrease in the monthly average energy demand, the monthly average energy output of the array increased every year (see Fig.7).

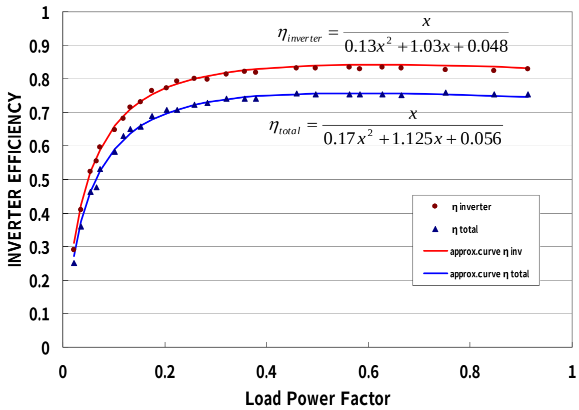


Fig.6: Inverter efficiency vs load power factor

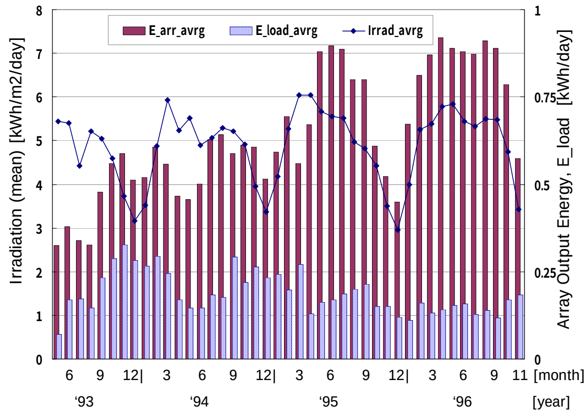
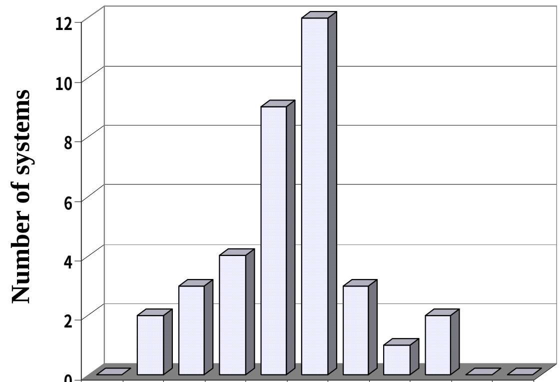


Fig.7: Initial systems monthly average values of Irradiation, Array and Inverter

As shown in Fig.8, the performance ratio distribution concentrated on 0.24 for 37 sites. Fig.9 shows the breakdown of the gain and the losses for the A019 system in the 1994 fiscal year. The energy consumption is high in winter, and since there is little irradiation, disconnection loss is low. However, this loss is increasing during summertime.



Perform. Ratio	0.04	0.08	0.12	0.16	0.2	0.24	0.28	0.32	0.36	0.4	0.44
No. of systems	0	2	3	4	9	12	3	1	2	0	0

Fig.8: Distribution of annual performance ratios

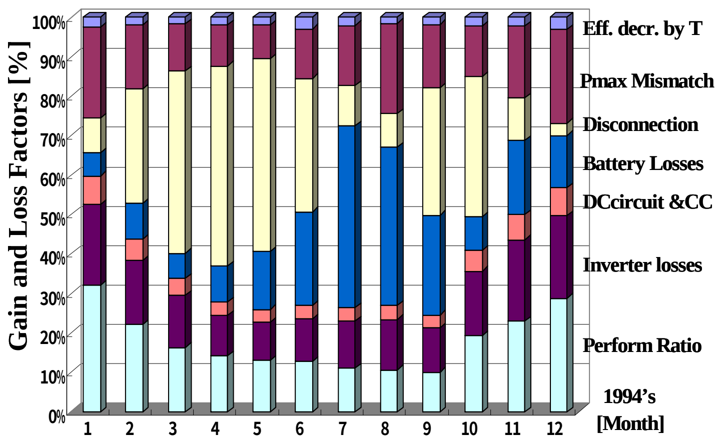


Fig.9: Monthly average performance ratio and losses for A019 systems

CONCLUSIONS

The following became clear after the investigation on many functional failures of the batteries and the increase in battery loss, and high load mismatch losses. Since humidity is very low in Mongolia, the electrolyte of the batteries decreased very much due to evaporation. Also taking into account the effects of gassing, a result of the oscillation of the charge controller which serves as an over charge protection, lowers the batteries lifetime. Therefore, it is necessary to fill up electrolysis liquid periodically.

Storage battery temperature is maintained above 10 degrees under -20 degrees of outside temperature, and it turns out that there is no influence of temperature in the lifetime of a storage battery. We are performing the optimum design and empirical study of small PV system using car battery and with a 3-stage PWM charge controller.

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