AN OPTIMAL DESIGN AND USE OF SOLAR HOME SYSTEM IN MONGOLIA

Amarbayar Adiyabat* and Kosuke Kurokawa*

*Tokyo University of Agriculture and Technology (TUAT)
Naka-cho 2-24-16, Koganei, Tokyo 184-8588, Japan, Fax: +81-423-85-6729
E-mail: amar@cc.tuat.ac.jp, kurochan@cc.tuat.ac.jp

ABSTRACT

This paper presents the results of study related into optimal design and use of Solar Home System (SHS) in Mongolia.

Over recent years, SHS becomes widely used by nomadic households in Mongolia. In the other hand, there exists an increasing problem of system component failure, low battery lifetime and users' dissatisfaction.

To overcome the present problem, a user training manual and demand-side load management seems to be necessary for enhance lifetime and minimize failures of SHS.

The time-serial simulation results shows possibilities to gain more performance ratio of SHS, which sized design parameter method. The optimal load table to support DSM for user proposed in the case of Mongolian central area.

Keywords: Solar Home System (SHS), optimal sizing, Demand-side-Management (DSM)

1. INTRODUCTION

Solar Home System (SHS) is the best way for sustainable surviving and development in rural area of developing countries.

Over recent years SHS becomes widely used by nomadic households in rural areas, it is based on the implementation influence of "100,000 Solar Ger" National program and demonstrative research project of portable PV systems by NEDO of Japan. It is expected that spread progresses from now on.

On the other hand, there exists an increasing problem of system component failure. Problems like fusing of light bulbs, inadequate charging of batteries, low battery life and need for continuous maintenance have been some of technical problems with SHS. From authors' detailed performance analysis [1], many functional failures of the batteries and the increase in battery loss, array capture loss, and high load mismatch losses, user's bad managements of load were observed.

2. WHAT IS A PROBLEM OF SHS

From the purchasing ability and electricity demand, the solar home system get into to small size in the developing country. An array capacity determined to fixed size at commercial PV module rate, like one module 55W or 75W. Therefore, SHS designing become an issue to calculate the capacity balance of a storage battery and load consumption under consideration of an installation environments and user's electricity demand.

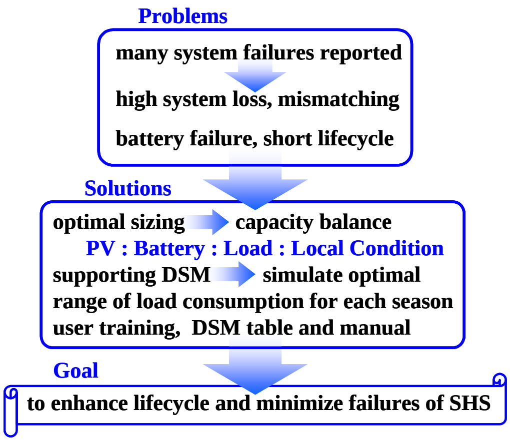

Fig.1: The problem and solution of this study

A charge cycle of SHS will stretch as time go on by lack of solar irradiation causing different installation conditions and high exceed electricity consumptions. This leads to low battery SOC (State-of-Charge), frequent disconnections and brings early degradation of storage battery.

It is not desirable for a SHS that it is also less too much as well as demand exceeding from designed energy consumption load.

An overcharge protect function of charge regulator frequently operates at the low consumption. It is reported that the battery efficiency near the top-of-SOC was low [4]. From field test data, the electrolyte of the batteries decreased very much due to effects of gassing, a result of the oscillation of the charge controller which serves as an over charge protection.

To overcome the present problem, a user training manual and demand-side load management are indispensable to enhance lifecycle and minimize failures of SHS.

This paper presents the results of study related into optimal design and use of SHS in Mongolia.

3. METHODOLOGY

3.1 DESIGN PARAMETER METHOD FOR SHS

The PV system sizing tasks usually start from the definition of daily consumption load. In the designing of small-scale stand-alone PV systems, the capacity of storage battery (6) and the available load consumption (4) calculated from the local irradiation data and the fixed array capacity (1 or 2 module), based on the energy balance equations (1) [2].

In sizing tasks, there have to tend constant daily consumption all along the year. In order to calculating the optimum balance of battery capacity and an available load at each season or month, system performance ratio K (5) was introduced to following equations (1)-(7).

$$H_A \cdot A \cdot \eta_{PS} \cdot K = E_L \cdot D \cdot R \quad (1)$$

$$\eta_{PS} = P_{AS} / (G_S \cdot A) \quad (2)$$

$$D = (N_d + N_{rc}) / N_{rc} \quad (3)$$

$$E_L = P_{AS} \cdot (H_A / G_S) \cdot K / (R \cdot D) \quad (4) \text{ from (1), (2)}$$

$$K = K_H \cdot K_P \cdot K_B \cdot K_C \quad (5)$$

$$B_{kWh} = E_{LBd} \cdot N_d \cdot R_B / (C_{BD} \cdot U_B \cdot \delta_{BD}) \quad (6)$$

$$E_{LBd} = \frac{\eta_{BA}\gamma_{BA}}{(1+\eta_{BA}\gamma_{BA}-\gamma_{BA})} \cdot E_L \quad (7)$$

H_A : in-plane irradiation [kWh/m^2/period]
A : array area [m^2]
η_{PS} : PV efficiency under STC
K : performance ratio
E_L : load energy consumption [kWh/period]
D : solar energy dependence, in the case of SHS $D=(N_d+N_{rc})/N_{rc}$
N_d : assumed non-sunshine days [d]
N_{rc} : recovery days of battery state of charge [d]
R : design redundancy
P_{AS} : PV array maximum power under STC [kW]
G_S : irradiance at STC [1kWh/m^2]
B_{kWh}: battery capacity [kWh]
E_{LBd}: load of dependency on battery [kWh/d]
R_B : battery design redundancy
C_{BD} : factor of battery capacity reduction
U_B : depth-of-discharge / DOD
δ_{BD} : decreasing rate of voltage dropping at discharge
γ_{BA} : dependency of load on battery
η_{BA} : battery efficiency

3.2 SYSTEM LOSS FACTORS

Operation characteristic parameters and performance indices of SHS are expressed in equations from (1)-(12).

Some of the major factors (as shown **Fig.2**) to reduce the performance ratio are the loss caused array capture, the loss caused by mismatching and the loss caused by lowered efficiency of degraded battery.

In the calculation, the values of parameters are taken as the average value from the authors' detailed performance analysis on demonstrative research project of portable PV systems by NEDO[1].

The array losses are possible to minimize by careful installation. Therefore, orientation, shadow, dust factors calculated in the default value 1.

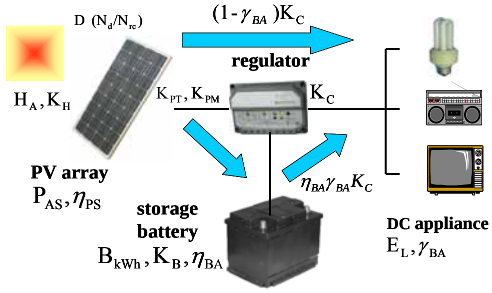

Fig.2: Relationship of the major parameters for SHS designing

$$K_H = K_{HD} \cdot K_{HS} \cdot K_{HCTr} \quad (8)$$

K_H : irradiation modification factor
K_{HD}: irradiation movement factor
K_{HS}: shading factor 1.0
K_{HCTr}: gain factor of tracking 1.0-1.22: if tracking by hand

$$K_P = K_{PD} \cdot K_{PT} \cdot K_{PA} \cdot K_{PM} \quad (9)$$

K_P : PV conversation efficiency factor
K_{PD} : deterioration factor with age
K_{PDS}: soiling factor 1.0
K_{PDD}: degradation factor
K_{PT} : temperature factor 1.0 in winter, 0.93 in summer
K_{PA} : array circuit factor 1.0
K_{PM}: load mismatch factor 0.85 （control of regulator based on a battery voltage）

$$K_B = (1-\gamma_{BA}) \cdot \eta_{BD} + \gamma_{BA} \cdot \eta_{BA} \quad (10)$$

$$\eta_{BA} = K_{B,OP} \cdot \eta_{BTS} \quad (11)$$

$$K_{B,OP} = K_{B,sd} \cdot K_{B,ur} \cdot K_{B,au} \cdot \eta_{BC} \quad (12)$$

K_B : battery efficiency modification factor
η_{BD} : bypass energy efficiency
$K_{B,\ OP}$: modification factor of operation efficiency
η_{BTS}: stack test efficiency of battery
$K_{B,\ sd}$: self-discharge loss factor
$K_{B,\ ur}$: unbalance factor of battery cell
η_{BC} : efficiency of charge regulator

3.3 SIMULATION FOR DSM SUPPORT

Demand Side Management (DSM) is playing important role in the maximizing lifecycle of SHS. There is need a support for user implementing DSM at SHS.

We developed the simulation program that to calculate the available consumption load by each month, to support DSM for SHS user. The simple battery model (13)-(15) based on state of charge (SOC) added in to simulation program, which was used in the performance analysis [1].

$$V_{bat,i+1} = 12.51 - 0.72 \cdot (1 - SOC_i) - \frac{I_{bat,i}}{C_{rate}} \cdot \left[\frac{24.0}{1 + I_{bat,i}^{1.3}} + \frac{1.62}{SOC_i^{1.2}} + 0.12 \right] \quad (13)$$

$$V_{bat,i+1} = V_{bat,i} + 0.76 \cdot (1.57 + Sin^{-1}\left(\tfrac{SOC_i - 0.5 \cdot SOC_0 - 0.5}{0.5 - 0.5 \cdot SOC_0}\right) \quad (14)$$

$$SOC_{i+1} = SOC_i \pm I_{bat,i} \cdot T_{step} / C_{rate} \quad (15)$$

In this simulation, the maximum available load has calculated from maintain rate of SOC in every settled loads. This is allowing to determinate seasonal optimum load range. Also, the sensibility simulation of maintain rate performed at various depth-of-discharge.

4. RESULT AND DISCUSSION

The results calculated by design parameter method shown in **table 1** and **2**. The optimum (cost-effective) balance of fixed array vs. various battery calculated at N_d/N_{rc} =2/3 (see table 1). The battery capacity is less than common design value, caused by few no sunshine days.

The average seasonal load consumption values at the optimum balance of fixed array and battery capacity are indicated in **table 2**. The load value of summer is approximately two-fold than winter available load.

The maximum available load from the time-serial simulation in case of the NEDO portable SHS[1], indicated at 600Wh/day (see **Fig. 3**). This value is 1.8 times larger than the value of design parameter method.

The **Fig. 4** shows the seasonal optimum load range from the simulation of SOC maintain rate. Also, the sensibility of seasonal optimum load range at degraded battery efficiency (**Fig. 5**).

There is necessary additional function in charge regulator, to supporting DSM, like signaling about a SOC, auto-calculating I/O energy or interface for reservation future demand.

Table 1:The optimum (Cost-effective) balance of fixed array vs. battery capacity calculated by the design parameter method

PV array [W_p]	VRLA/Deep-cycle Battery [Ah] 20HR			Vehicle SLI Battery * [Ah] 5HR		
N_d/N_{rc}**	3/3	2/3	1/2	3/3	2/3	1/2
12.0	10.9	8.7	4.8	14.5	11.6	12.9
22.0	19.9	15.9	8.9	26.6	21.3	23.6
50.0	45.3	36.2	20.1	60.4	48.3	53.7
55.0	49.8	39.9	22.1	66.4	53.1	59.0
75.0	67.9	54.3	30.2	91	72.5	80.5
102	92	73.9	41.1	123	99	109
204	185	148	82.1	246	197	219

* max depth-of-discharge DoD U_B: VRLA=60%, SLI=30%
** N_d/N_{rc}: no sun day/recovery day

Table 2: The average seasonal load consumption at the optimum balance of fixed array and battery capacity for N_d/N_{rc}= 2/3

PV array [W_p]	Vehicle SLI Battery [Ah] 5 HR	Average Load [Wh /d] at seasonal reference yield [h]		
		Summer 6h	Spring 4.8h	Winter 3.2h
12.0	11.6	24.5	19.6	13.1
22.0	21.3	44.9	35.9	23.9
50.0	48.3	102.0	81.6	54.4
55.0	53.1	112.2	89.8	59.8
75.0	72.5	153.0	122.4	81.6
102	98.5	208.1	166.5	111.0
204 with Inv.	197.1	333.0	213.1	142.1

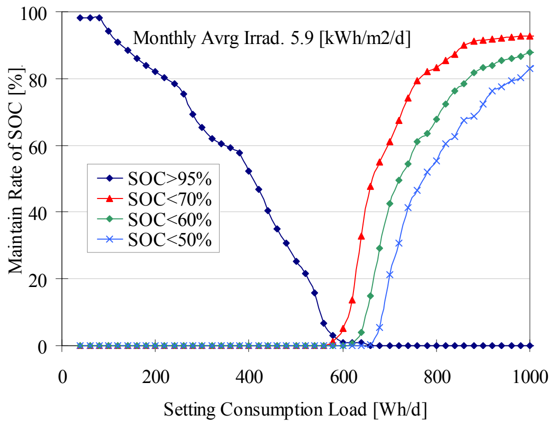

Fig. 3: Sensibility simulation of SOC Maintain Rate vs. Setting Loads at reference yield Y_r=5.9 h

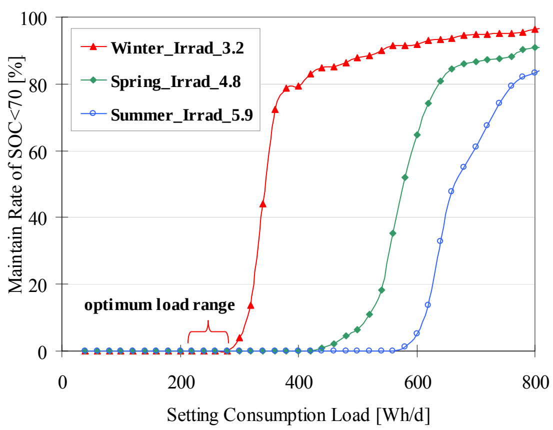

Fig. 4: Determination of seasonal optimum load range from time-serial simulation of SOC maintain rate

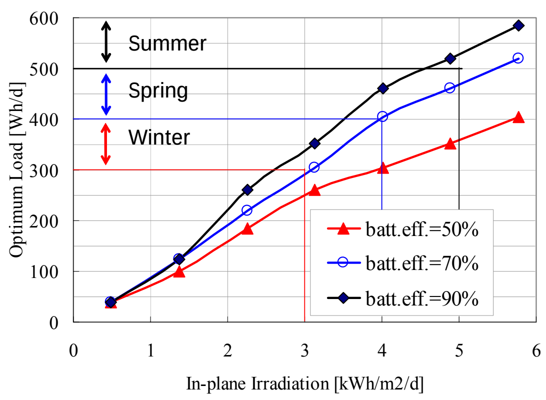

Fig. 5: Sensibility simulation of seasonal optimum load range at degraded battery efficiency

5. CONCLUSION

- The detailed design parameter sizing method for SHS improved with feedback experimental loss parameters from field data.
- The simulation model developed, to calculate available maximum consumption value from the typical commercial PV module and battery capacity at install environments.
- The time-serial simulation results shows possibilities to gain more performance ratio of SHS, which sized design parameter method.
- The optimal load table to support DSM for user proposed in the case of Mongolian central area.

6. REFERENCE

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