태양광 하드웨어 시뮬레이터의 소신호 안정도 분석

투시타 란디마 웰라와타, 최성진
울산대학교 전기 공학부

Small−Signal Stability Analysis of Solar Array Hardware Simulators

Thusitha Randima Wellawatta and Sung−Jin Choi
School of Electrical Engineering, University of Ulsan, KOREA

ABSTRACT

Due to uncontrollability and non−repeatability of natural irradiation and temperature, the solar array simulator (SAS) is required to conduct the MPPT power processing experiments precisely. However, the nonlinearity of PV curve characteristic is a crucial task for the control of SAS. In the literature, this issue is addressed by many authors and various methods are proposed. However, stability analysis of SAS is not enough to evaluate the control performance. In this paper, the limitations of conventional SAS are studied according to the small signal model. By using the proposed approach, the performance of two different control method for SAS system are analyzed and compared.

1. Introduction

Solar power is one of most eco−friendly power sources in the world. Due to daylight limitations, many kinds of research were conducted to obtain maximum power tracking (MPPT). But, controlling of irradiation and temperature is a difficult task and cannot repeat the same conditions. So, solar array simulator (SAS) consists of DC/DC converter, PWM controller, and the reference generator, where the control reference command is determined by a P−V curve of the PV module. However, the solar array hardware simulators have been invented. The characteristics of the PV module are highly non−linear as shown in Fig.1, and PV equation is an implicit function as (1).

$$I_{PV} = I_{ph} - I_S\left[\exp\left(\frac{V - I_{PV}R_S}{AV_t}\right) - 1\right] - \frac{V_{PV} - I_{PV}R_S}{R_P} \qquad (1)$$

where I_{ph} is the photovoltaic current (A), I_s is the saturation current of the diode (A), V_{pv} is the photovoltaic voltage (V), V_t is the thermal voltage (V), A is the ideality factor, Rs is the series resistance (Ω), and R_p is the parallel resistance (Ω)[1]. Thus, the overall operation is quite complicated and sometimes causes a stability issue, because SAS system contains power converter, multi−feedback loop voltage or current controller, and reference generation algorithm. Most of researchers do not consider the cross relation of multi−loop[1], [2]. Some researches were conducted on this issue[3], but their approach was not systematic to evaluate the performance of the SAS. In

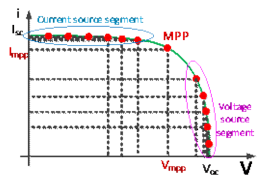


Fig.1 PV curve

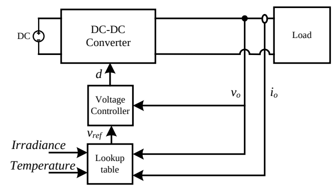


Fig.2 A typical SAS system

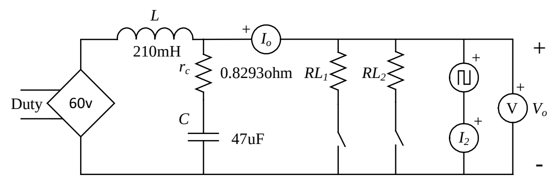


Fig.3 Average model of buck converter with variable loads

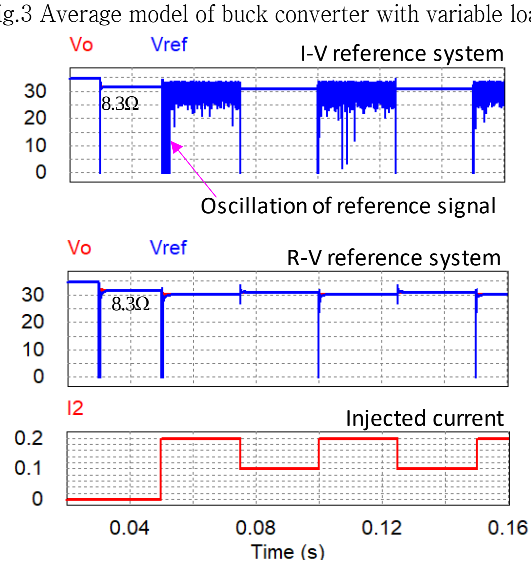


Fig.4 Output voltage of SAS system under 8.3Ω| (t=0.03s) load, +0.2A| (t=0.05s) squire current

this paper, stability of SAS system is analyzed, and existing solar array simulator techniques are compared in viewpoint of small−signal stability.

2. Problem definition of SAS system.

To observe the behavior of SAS, the block diagram shown in Fig.2 is considered. The buck converter is selected for the simulation due to easy operation and average model is used to remove the switching dynamics as shown in Fig.3. RL_1 and RL_2 are used to generate a step change of the load and square wave current ripple is injected as I_2. MSX 120 PV module characteristics are coded into a lookup table.

In simulation, voltage mode (VM) control are used for the inner loop controller and current sensing signals are used to generate the reference signal (V_{ref}). The outer loop contains an I−V lookup table and converts the sensing current into V_{ref} (I−V reference system). On the current source segment, the V_{ref} of the VM mode controller is oscillatory due to the small change of sensing current as shown in Fig.4. It demonstrates that in the current source segment, VM controller get unstable. Some researchers used impedance sensing methods [1], [2] (R−V reference system) to overcome those issues.

3. Small−Signal modelling

To understand this issue, the SAS system is analyzed by two−feedback loop small−signal model [4] and overall block diagram is shown in Fig.5. according to the selection of feedback method k_v and k_{load} is selected (I−V reference system: k_v =1; k_{load} =0 and R−V reference system: k_v =0; k_{load} =$1/\hat{v}$). The transfer function of buck converter ($G_{vd}(s)$) in (2) is used to design the PI controller (C) in (3) with the value of Table 1.

$$Gvd(s)=\frac{\hat{v}_O(s)}{\hat{d}(s)}=\frac{v_S}{R_L}\frac{R_L}{s^2LC+s\frac{L}{R_L}+1} \tag{2}$$

$$C(s)=\frac{k_i\left(s+k_p\right)}{s} \tag{3}$$

Here, the inner loop consists of a voltage controller and reference is generated by the lookup table in the outer loop. Thus, the overall loop gain equation (T) can be written as (4).

$$\begin{aligned} T(s)&=T_1(s)+T_2(s)\\ T(s)&=C(s)\cdot G_{vd}(s)+C(s)\cdot G_{vd}(s)\cdot\frac{1}{R_L}\cdot\frac{1}{\sigma_{LUT}} \end{aligned} \tag{4}$$

Likewise, an impedance sensing system can be modeled as

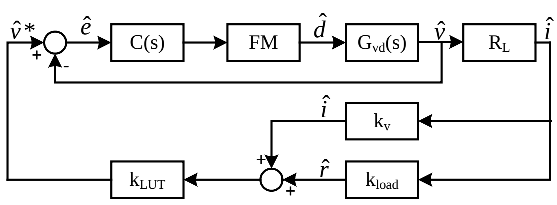
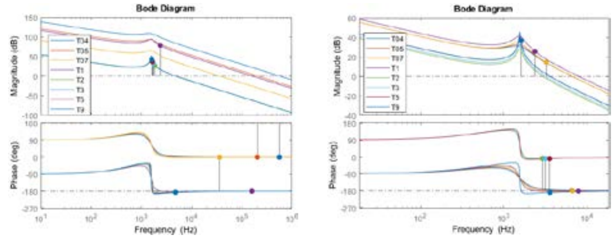


Fig.5 system block diagram

Table 1. Components of model			
Component	Value	Component	Value
R_L	9.5Ω(mpp)	kp	0.14158
L	210uH	ki	3955
C	47uF		



(a) I−V reference system (b) R−V reference system

Fig.6 Bode diagrams each system

$$T(s)=G_{vd}(s)\cdot C(s)+G_{vd}(s)\cdot C(s)\cdot\frac{\frac{d_R}{dv}}{\left(-\frac{v}{(i)^2}\frac{di}{dv}+\frac{1}{i}\right)} \tag{5}$$

For the small−signal simulation, different operating points change the $G_{vd}(s)$ and the k_{LUT}. The gradient values of σ_{LUT}, dR/dv, and di/dv are manipulated from relevant lookup tables. Above (4) and (5) are simulated on Matlab.

4. Simulation results

Bode plots are obtained for 8 different loads (4Ω, 5Ω, 7Ω, 9.5Ω, 20Ω, 30Ω, 50Ω, and 90Ω) and the results are shown in Fig6. According to the simulation results, the impedance method shows less gain change and phase margin deviation under different load condition. When the load impedance close to the zero, gain of the I−V reference system is increase enormously (gain start from 150dB on 4Ω) but R−V reference system is lightly increased (gain start from 60dB on 4Ω).

5. Conclusion

In this study, the small−signal analysis of SAS is based on two feedback loop small−signal model. Two types of SAS are compared, and it is concluded that better performance is shown by R−V reference system.

Reference

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