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Time Response-Based Model Estimation of a Laboratory Photovoltaic Power System

R. Sabiu Shehu[1], A. Bayo Yusuf[2], I. Farouq Ibrahim[2]

Senior Lecturer, Dept. of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna, Nigeria[1].

Lecturer, Dept. of Electrical and Electronics Engineering, Kaduna Polytechnic, Kaduna, Nigeria[2]

Lecturer, Dept. of Electrical Engineering, Federal Polytechnic Bauchi, Bauchi, Nigeria[3]

ABSTRACT: The usage of solar power is far less damaging to the environment than burning fossil fuels to generate electric power. In comparison to other renewable energy resources, solar has unmatched portability and thus flexibility. These characteristics make solar power a key energy source as we move toward more sustainable and clean ways to meet our energy needs.One of the ways of improving solar based power system efficiency was by incorporating sun tracking control mechanism, availability of a representative solar power systems models is important for the controller design. In the paper,an approximate linear model of a laboratory photovoltaic power system was developed. First the system output voltage at fixed step input of 7.05V to a light source was collected and plotted in time, from the plot time indices are read and translated into natural frequency and damping constant, with these a second order transfer function model was developed. Simulation of the model produces time response result showssome acceptable level of closeness with that of the data plot of the physical system.

KEYWORDS: Solar Power System, Transfer Function,Time Response, Input-output Data.

I.INTRODUCTION

Energy is vital for dynamic systems such that their ability to perform any work depend onenergy availability. Solar power is becoming an important form of renewable energy source. The system composed basically of three stages- the photovoltaic (PV) array; boost converter and grid side inverter stage. Many works have been reported dealing with development and efficiency enhancement of PV array.

Analytical modelling techniques needed to develop control scheme for effective energy generation and utilization in solar based powersystems and other renewable energy methods have been reported. System identification techniquethat involves generating model from input-output datawas used in building a model for a given photovoltaic based power system. Time response has been a tool for assessing dynamic systems behaviour. Damping and natural frequency defined in the domain of general second order transfer function translatesinto and gives meaning to a system transient performance. Inferring speed of response (rise time) from a given system time response could yield through relational process the amount of damping and natural frequency, and thus, a builds a transfer function model, detail of this principle can be found in the relevant literatures.

In this paper, second order model of a given laboratory solar power systemobtained from the empirically time response data, would be investigated for transient and steady state performances.

II.PROBLEM STATEMENT

We consider a laboratory solar power system (shown in Fig.1) consisting of a 12Vlight bulb representing sunshine source and a four series connected solar panels. The light bulb unit mounted on a dc motor shaftcan bemoved by varying a potentiometer voltage provided on the system module over an angle range of $0^o$to$\pm 40^o$. Voltage produced by the panels is directly proportional to the amount volt to the bulb, keeping bulb angle constant. For educational and research purposes, a mathematical model of the system is needed.

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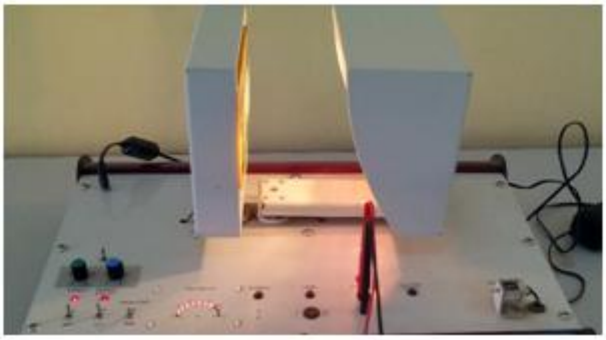

Fig.1:Laboratory solar power System

III.MATHEMATICAL PRELIMINARY

Consider a plant to have a linear model

$$G_g(s) = \frac{\omega_n^2}{s^2+\zeta_{\omega_n}s+\omega_n^2} \quad (1)$$

Where ω_n is natural frequency, $\zeta$the damping ratio. Let a = $\zeta\omega_n$, b = ω_n^2 and if a = 0, the plant poles are purely imaginary; $j\omega_n = \pm j\sqrt{b}$, giving$b = \omega_n^2$. Considering an under damped system; the poles arecomplex conjugates, the real partis σ=$-\frac{a}{2}$, and the damping is

$$\zeta = \frac{|\sigma|}{\omega_n} = -\frac{a/2}{\omega_n}(2)$$

System output expression as function of the natural frequency, damping level and independent variable- time considering (2) above when excited by a unit step input is written as

$$c(t) = 1 - \frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\cos\left(\omega_n\sqrt{1-\zeta^2}t - \phi\right)(3)$$

Where $\phi = \tan^{-1}\frac{\zeta}{\sqrt{1-\zeta^2}}$.

Theory discussions behind (2) and (3) are given in [13]. Transient performance of a system plot in (3) is characterized by the time indices –rise and settling times as[14]

$$T_r = \frac{\pi - tan^{-1}\sqrt{1-\zeta^2}/\zeta}{\omega_n\sqrt{1-\zeta^2}} \cong \frac{0.8}{\omega_n} (4)$$

$$T_s = \frac{4}{\zeta\omega_n}, \quad \text{for 2\% criterion}(5)$$

Equations (4) and (5) can be used to build a model giving a system time response of second order type.

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IV.METHOD

The solar power system under study has two variable dc sources, one supplying the motor for moving the light source unit over an angle range, other one for supplying energy to the bulb. To develop a model of the system, time response data (voltage, time) are first collected in the next section.

A.TIME RESPONSE DATA ACQUISITION

The TPS-3270 solar power module light source unit was fixed at an angle of about 7^o incidence. It is energizedfrom on-board variable dc source with 7.05V. At 10 seconds time interval, the photovoltaic output in volt was measured up to about 1900 seconds. The first 15 datasamples arerecorded in Table 1.

Table 1: Solar system time response data

time(s)	0	10	20	30	40	50	60	70	80	90	100
Output(v)	1.22	4.00	3.99	3.98	3.99	3.99	3.97	3.96	3.98	3.97	3.96

B. Time indices determination

Time response plot of the data in Table 1 above is shown in Fig.2

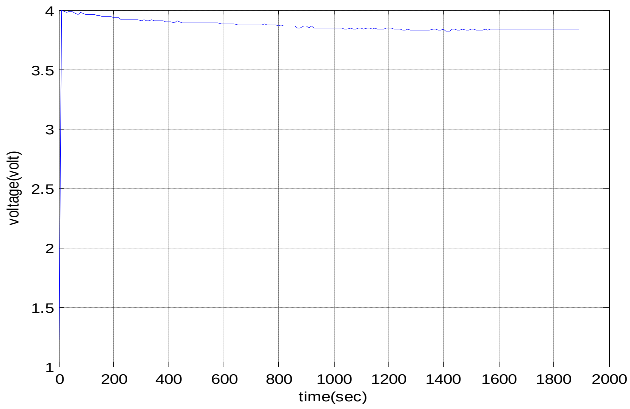

Fig.2: Time response data plot

Concentration of the data line as shown in the initial transient stage of the responseindicates some level of oscillations, the data peaking and subsequent falling and settling of the response signify a model of second order system. The steady state value of the response can be obtained as follows

$$V_{ss} = \frac{\Delta V}{v_{unit}} = 0.05 \times 6 = 0.3 \text{ and } V_{ss} = 3.5+0.3 = 3.8\text{V}.$$

Taking 2% around the final value of 3.8 would yield a boundaries of approximately +3.9 and -3.7, this established the settling time boundary. To determine the rise time, 90% of the final value is 3.42, drawing these times values on the response as shown in Fig.3, we read rise and settling times of10 and 200 seconds respectively.

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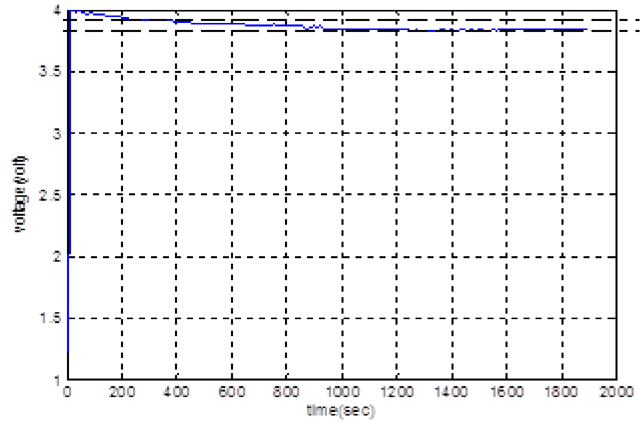

Fig.3: Response plot with 2% Band

Using (4) and (5)the system's natural frequency and damping ratio are 0.08rad/sec and 0.25. The model in form of (1) is

$$G(s) = \frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2} = \frac{0.0064}{s^2+0.04s+0.0064} \qquad (6)$$

Including the effect of the system dc gain $K = \frac{3.8}{7.0} = 0.54$The approximate linear transfer function model of the system is

$$G(s) = \frac{0.0064K}{s^2+0.04s+0.0064} = \frac{0.00345}{s^2+0.04s+0.0064} \qquad (7)$$

V. RESULTS AND DISCUSSION

The simulation model is shown in Fig.4. And in studying the performance of the model we consider the following cases :

Case 1: model relative stability condition.
Case 2: model response to 7.05 steps input
Case 3: response to 7.05 steps input with ± 0.5 saturation nonlinearity.

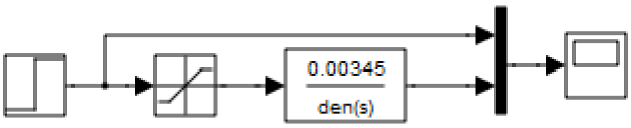

Fig.4: Simulation model

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Relative stability of the modelin gain and phase margins are obtained as shown in Fig.5

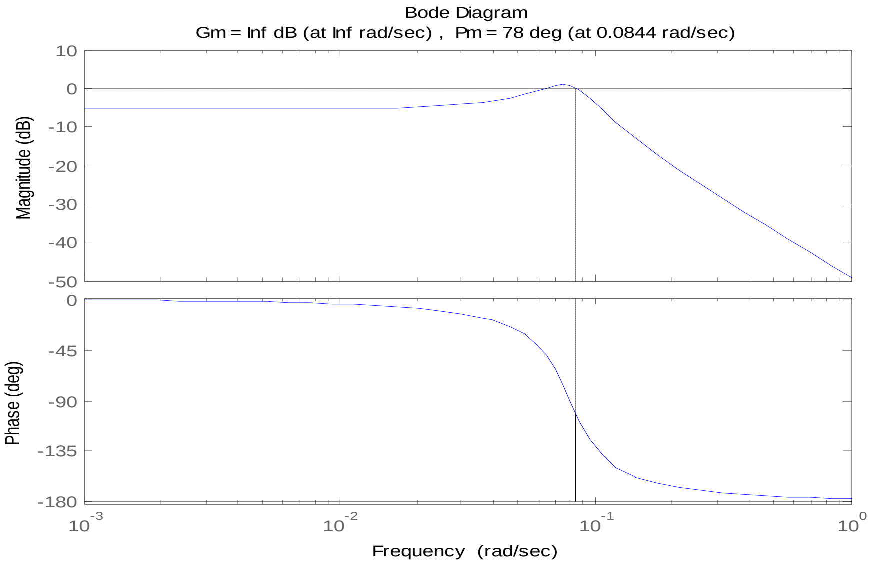

Fig.5: Model relative stability plot

In Fig.2 a good relative stability is indicated by having infinite gain margin, this shows the model's ability to withstand large amplifier gain in the feed forward signal path.The solar power system model response to 7.05 step input is shown in Fig.6.

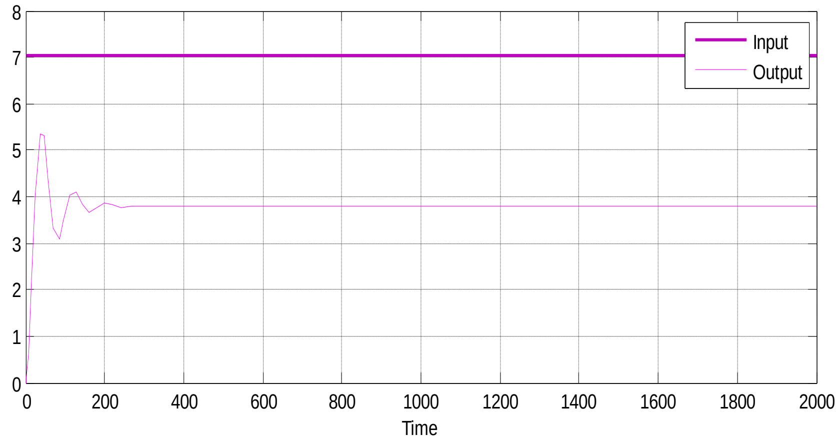

Fig.6: Model response to 7.05 step input

The model response in Fig.6 characterized by some level of oscillations at initial time of the response indicates it to be an under damped model (damping less one), in the steady state an error of about 2.85 can be observed. The response of the model at 7.05V step input agrees in transient and stead state with the performance exhibited by the time response data plot obtained in Fig.3, though an additional overshoot of about 1.2V was observed in the response. Result from case 3 condition is shown in Fig.7.

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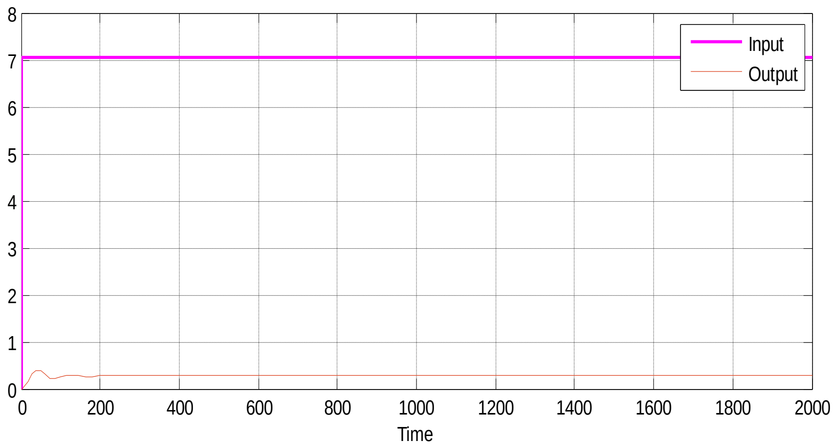

Fig.7: Response under 7.05 step input with saturation nonlinearity

The effect of saturating attenuation (± 0.5) in the photovoltaic system resulted in the system mode exhibiting an undesirable steady state error of about 6.65V as shown (see Fig.7).

VI.CONCLUSION

The paper develops a second order transfer function model of a giving laboratory solar power system. The model estimated from the systemtime response was simulated, the transient and steady state performances obtained very much agrees with those of the original data collected from the physical system. Under attenuating saturation, the model suffers in steady state performance; the transient performance was not that bad.

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