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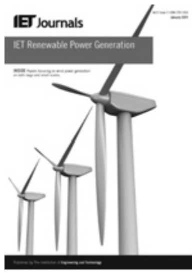

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Binary-based tracer of photovoltaic array characteristics

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Abstract: Conventional photovoltaic (PV) *I–V*-curve tracer uses a lot of resistors and switches to produce a smooth curve. We propose a binary *I–V*-curve tracer with an adjustable-resistance load, which means fewer switches and resistors to achieve the same smooth curve. The prototype was built in an ATMega 8535 microcontroller and then tested in various shade conditions of the PV array.

1 Introduction

Photovoltaic (PV) counts among the more important and effective renewable-energy solutions to environmental problems [1–3], with ongoing work continuing to improve it [1, 2, 4]. Measuring the limits of PV-system performance, degradation and failure requires monitoring and data processing of the PV-array *I–V* curve [5]. Monitoring tools have been developed [5–13], with temperature and solar irradiance the commonly monitored parameters [5, 6, 8, 9]. PV-array *I–V* curve changes with fluctuations in the PV-source temperature and solar irradiance (among several others) [4, 8, 9]. Tracing it is necessary as field conditions fluctuate [5, 9].

Monitoring allows determining of a PV module's actual power in field conditions [5] and of fault in a string-based PV array [14], also evaluating of module degradation [15]. It has also been proposed for use in designing of power converter systems and effective harvesting of solar power [16].

The *I–V* curve is traced by sweeping the load on a PV source through a range of currents and voltages. The load could be resistive, reactive or electronic (as in [9, 13, 16]). The electronic load in [13] has several transistors in Darlington combination, and a battery compensates the current generated by the PV source; the *I–V* curve is traced in <5 s. The one in [9, 16] has a linear metal oxide semiconductor field effect transistor, whose gate-to-source voltage (V_{GS}) is varied to produce the *I–V* curve. Herman *et al.* [17] uses a reactive load (capacitor-based *I–V* tracer), measuring the *I–V* curve during charging of the connected load capacitor. van Dyk *et al.* [5] uses a resistive load and an array of resistors and mechanical relays (the system is similar with a variable resistive load); the resistors are switched on and off to sweep the *I–V* curve from short circuit to open circuit, and one resistor value produces one point on the *I–V* curve; a smooth curve needs many points, thus the resistors and relays are many.

We propose a simple *I–V*-curve tracer with an array of binary-numbered resistors. A few resistors suffice to produce a smooth curve quickly (540.2 ms). The tracer has been verified by simulation and experiment.

2 *I–V*-curve tracer

An *I–V*-curve tracer extracts PV-panel power. Fig. 1*a* schemes the *I–V*-curve tracer of [5]. To trace in short circuit, switch $(\mathrm{SW})_1$ must close, and in open circuit, switches $\mathrm{SW}_{n+1} \ldots \mathrm{SW}_1$ must open. The switches $\mathrm{SW}_{n+1} \ldots \mathrm{SW}_2$ connect to individual resistors. They connect and disconnect alternately, varying the resistance. One resistor produces one trace point. A conventional *I–V*-curve tracer with N measurement points needs N–2 resistors and N–1 switches (Table 1 lists the switching combinations). The sequence of bits in Table 1 represents the states of the switches.

A binary-numbered variable-resistance load reduces the number of resistors. Fig. 1*b* shows resistors $R_0 \ldots R_{n-1}$ connecting in series, each resistor (Rk) parallel with a switch (SWk). The resistance Rk is expressed in (1). Combinations of the switches $(\mathrm{SW}_{n-1} \ldots \mathrm{SW}_0)$ change the resistance value on the *I–V*-curve tracer. Equation (2) expresses the number of resistance created by n resistors. R_0 expresses the resolution or the smallest resistance. Equation (3) expresses the maximum resistance achievable on the *I–V* curve. Table 2 lists the switching combinations. Column $\mathrm{SW}_{\mathrm{OC}}$ lists the conditions of switch $\mathrm{SW}_{\mathrm{OC}}$, whereas column $\mathrm{SW}_{n-1} \ldots \mathrm{SW}_0$ lists the bit sequence for the conditions of switches $\mathrm{SW}_{n-1} \ldots \mathrm{SW}_0$

$$Rk = 2^k R_0 \tag{1}$$