ARTICLE IN PRESS
Journal of the Association of Arab Universities for Basic and Applied Sciences (2016) xxx, xxx–xxx

University of Bahrain
Journal of the Association of Arab Universities for Basic and Applied Sciences
www.elsevier.com/locate/jaaubas
www.sciencedirect.com

Shapeable maximum-power point-tracking algorithm to improve the stability of the output behavior of a thermoelectric-solar hybrid energy-harvesting system

A. M. Yusop *, R. Mohamed, A. Ayob, A. Mohamed

Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

Received 8 May 2015; revised 28 December 2015; accepted 7 January 2016

KEYWORDS

Perturb and observe;
Thermoelectric-solar;
Hybrid energy system;
Input shaping;
Inverse dynamic

Abstract This study presents the development of a novel maximum-power point-tracking (MPPT) method based on an input shaping scheme controller. The proposed method that changes the initial input response into a shapeable MPPT algorithm is designed based on an exponential input function. This type of input function is selected because of its capability to stabilize the system at the end of the simulation time and remain at the same condition at the final response time. A comparison of the system with the proposed method and the system with traditional perturb and observe (PnO) method is also provided. Results show that the system with the proposed method produces higher output power than the system with PnO method; the difference is approximately 15.45%. Results reveal that the exponential function input shaper allows the overall output system to exhibit satisfactory behavior and can efficiently track the maximum output power.

1. Introduction

Natural energy-harvesting devices harness environmental energy into useable energy. This approach has made energy harvesting as an important research area and a solution to the environmental pollution caused by the hazardous waste of non-renewable energy sources. However, this type of energy harvester is unpredictable and can exhibit erratic behavior in a data-driven system. Many studies have combined energy from different sources, such as solar-thermal (Chávez-Urbiola et al., 2012; Lesage et al., 2013; Liao et al., 2014; Xiaodong et al., 2010; Zhang and Chau, 2011), solar-wind (Tianpei and Wei, 2014; Xiangjun et al., 2013), and solar-thermal-vibration (Bandyopadhyay and Chandrakasan, 2012). This combination is implemented based on the belief that doing so would increase the overall system efficiency. Many previous studies selected solar energy as the main energy source because this source produces high power. In Zhang and Chau (2011), they acclaimed that their newly developed power conditioning system was able to increase the overall hybrid system output power. The combination between the proposed method and

* Corresponding author. Tel.: +60 192248523.
E-mail address: azdiana@utem.edu.my (A. M. Yusop).
Peer review under responsibility of University of Bahrain.

http://dx.doi.org/10.1016/j.jaubas.2016.01.002
1815-3852

Please cite this article in press as: M. Yusop, A. et al., Shapeable maximum-power point-tracking algorithm to improve the stability of the output behavior of a thermoelectric-solar hybrid energy-harvesting system. Journal of the Association of Arab Universities for Basic and Applied Sciences (2016), http://dx.doi.org/10.1016/j.jaubas.2016.01.002

the Ćuk–Ćuk converter has proved that both thermoelectric and solar branches can attain the maximum power conversion individually. Furthermore other related works regarding the hybridization between thermoelectric and solar in Dallan et al. (2015), Wu et al. (2015) has also given extra credit to the development of the hybrid system in the energy harvesting field. However, solar energy only functions when sunlight is available. In addition, heat dissipation and the development cost of solar energy limit the efficiency improvement of this energy source (Jha, 2009; Odeh and Behnia, 2009). These circumstances impede the performance of solar energy unless combined with other renewable sources that can take over the task of solar energy when sunlight is unavailable.

In this research, a thermoelectric module (TEM) was employed to boost the performance of solar energy because this device is known to convert the heat dissipation of waste heat energy into electrical energy. This condition occurs when thermal differences exist between the two junctions of the TEM, namely, hot and cold junctions (Nguyen and Pochiraju, 2013). However, a TEM cannot function individually because it produces low power. By combining a TEM with solar energy to develop a hybrid energy-harvesting system, the disadvantages of each system can be overcome because these two sources complement each other.

Given that solar energy and TEM are non-linear devices, a DC–DC converter is utilized to extract the maximum power from each system individually. Three main maximum-power point-tracking (MPPT) algorithms, namely, perturb and observe (PnO) (Balato and Vitelli, 2014; de Brito et al., 2013; Kortabarria et al., 2014; Mamarelis et al., 2014; Murtaza et al., 2014), incremental conductance (Kumar et al., 2014; Tey and Mekhilef, 2014), and impedance matching (Yamada et al., 2014), have been adopted in previous studies without focusing on the sources. The PnO algorithm is commonly used in both solar energy and TEM because of its simplicity and ease of design development. Many enhancements on the PnO algorithm have been made in recent research. Kortabarria et al. (2014) developed a new PnO method that employs the adaptive intelligent algorithm. However, this newly developed PnO was applied to wind turbines. By concentrating on applying the application solely to solar energy, Mamarelis et al. (2014) also focused on PnO algorithm improvement by introducing a two-step algorithm. They confirmed that their proposed method requires simple mathematical calculations. Hybridization of the MPPT method has also been attracting a significant amount of attention recently. In Murtaza et al. (2014), the authors worked with PnO and fractional open-circuit voltage. A hybrid MPPT can make the system focus solely on the maximum power point (MPP) without exhibiting power loss oscillation. Validation is performed under the condition of steady weather. For instance, in Balato and Vitelli (2014), distributed maximum-power point-tracking was developed with rapid tracking and robustness for systems that contain errors.

All the above mentioned PnO methods have been improved either to make the methods work in high speed tracking or increase the sensitivity of the perturbation technique. No previous study has discussed the stability of the overall system behavior. The previous PnO method also involved a complex numerical analyses which need extra time and effort on scrutinize the performance of the improved PnO method. Although the PnO method is known for its easiness in terms of implementation, the oscillations problem caused by this method tends to decrease its accuracy (Sahnoun et al., 2013). If this oscillation can be counter back, the output response of this method can become stable. Sahnoun et al. (2013) in their paper has proposed a neural technique algorithm to control the PnO method but this method is very complex. In order to improve the previous PnO method by ensuring its stability, a new method must not compromise in any oscillation problem. This method also must be easy to implement so that no complex calculation in maximum power point is issued later on that needs extra effort in this matter.

Thus, a new control method was developed in the present study by combining the PnO method and an input shaper to ensure the overall stability and simplicity of a hybrid energy-harvesting system. The proposed method was designed with improved identification to increase the efficiency of the existing hybrid thermoelectric module and solar array (TEM–SA) and reduce the energy consumption of the system. The input shaper employed in this study is a feed forward control method commonly applied to flexible systems (Sahinkaya, 2001, 2004) to reduce system vibration. Devasia (2012) employed this method to control the settling time of a positioning system. The input shaper is based on inversion dynamic analysis, which was proposed by Piazzi and Visioli (2000). This approach is implemented by setting a polynomial function as the acquired output function. The method suggested by Piazzi and Visioli is impressive and beneficial in terms of stability. However, the polynomial function at the end point of the validation time exhibits unpredictable behavior and thus limits the application of the method. To overcome this problem, the polynomial function must be switched into a different form. Several methods, such as the Lyapunov function (Wang et al., 2014; Xiang and Xiang, 2014; Zhang et al., 2014; Zhao et al., 2014), dwell time approach (Briat, 2014; Xiang et al., 2014; Zhang et al., 2014), and sojourn method (Tian et al., 2014a,b), have been discussed recently. With regard to the switching requirement, Iravani and Sahinkaya (2010) reported that switching would affect the first and second derivatives of the function and result in the unstable output behavior of the overall system. Hence, in the present work, the stability of the overall system was not based on the switching method. Based on the work of Piazzi and Visioli, several notable solutions that employ an exponential function have been proposed by several other researchers (Iravani and Sahinkaya, 2010; Rymansaib et al., 2013; Sahinkaya, 2001, 2004). This type of function overcomes the drawbacks of the polynomial function. Thus, this type of function was applied in the MPPT circuit in the current study. The proposed method was proven to require minimal mathematical calculation, which eases the MPPT development of the overall system. The proposed method is also capable of efficiently tracking MPP with high efficiency.

2. Modeling of TEM–SA

In a TEM–SA hybrid energy-harvesting system, the systems that correspond to TEM and SA were designed as individual systems. Both systems were then merged to produce a hybrid system. This hybrid model was designed according to the electrical specifications provided by the manufacturers to imitate

Please cite this article in press as: M. Yusop, A. et al., Shapeable maximum-power point-tracking algorithm to improve the stability of the output behavior of a thermoelectric-solar hybrid energy-harvesting system. Journal of the Association of Arab Universities for Basic and Applied Sciences (2016), http://dx.doi.org/10.1016/j.jaubas.2016.01.002