MAXIMUM POWER POINT TRACKING BASED ON PERTURB AND OBSERVATION ALGORITHM COMBINED WITH AQUILIA OPTIMIZER ALGORITHM FOR THERMOELECTRIC GENERATORS

Mehmet Ali Üstüner[1], Hayati Mamur[1], Sezai Taşkın[1]

[1] *Manisa Celal Bayar University, Department of Electrical and Electronics Engineering, Manisa, TURKIYE*

Abstract

Since the efficiency of thermoelectric generators (TEG) used to convert waste heat into electrical energy is low, converters with maximum power point tracking (MPPT) algorithms are used in such systems. In this study, a hybrid AO-P&O MPPT algorithm is developed with conventional Perturb & Observe (P&O) and Aquila Optimizer (AO) algorithms to maximize the power of a TEG. For the studies, a TEG model is designed in the MATLAB/Simulink environment and the performance of the hybrid AO–P&O algorithm is tested. The power of the designed TEG model is 57 W, and the internal resistance value is 7.3 Ω when the cold surface temperature is 30°C and the hot surface temperature is 200°C. When using only P&O, the power obtained is 54.53 W, while using the hybrid AO–P&O, 54.87 W is obtained. As a result of the study, it is seen that the hybrid AO–P&O algorithm increases the TEG MPPT value by 0.596%.

Keywords: Aquila optimizer, hybrid MPPT, thermoelectric generator, maximum power point tracking

INTRODUCTION

The possibility of renewable and sustainable energy sources being the main energy policy in the future will necessitate the efficient implementation of these source [1]. Therefore, waste heat recovery systems show promise in reducing energy waste [2]. One of the technologies used for this purpose is thermoelectric generators (TEGs). TEGs are semiconductor devices that work with the Seebeck effect and convert the temperature difference between their surfaces into electrical energy [3]. Since low efficiency is the biggest disadvantage of TEG systems, TEGs must be operated at near full capacity [4]. Full capacity operation of TEGs is related to taking maximum power from TEGs [5]. Therefore, maximum power point tracking (MPPT) methods embedded in DC-DC converter applications are used to capture the maximum power point (MPP) of a TEG system [6].

The P&O algorithm is the simplest, cost-effective and most widely used MPPT algorithm among MPPT methods. However, the oscillation problem around the MPP and its rapid effect from the suddenly changing environmental conditions led the researchers to develop this algorithm [7]. Among the developed algorithms, metaheuristic algorithms used together with P&O draw attention. These algorithms, designed as hybrids with P&O, include algorithms such as ant-colony optimization (ACO) [8], Fireworks algorithm (FA) [9], learning automata (LA) [10], and genetic algorithm (GA) [11].

In this study, the AO algorithm together with the P&O algorithm is used as a hybrid MPPT method. The step size is used as a constant in the P&O algorithm. In the hybrid AO-P&O method, the step size adjustment of the P&O algorithm is optimized by the AO.

THERMOELECTRIC GENERATORS

The electrical equivalent circuit of the TEG consists of a temperature dependent voltage source and an internal resistor R_{int} as seen in **Figure 1**. The load is connected to supply power from R_L, TEG. When this load value and the internal resistance of the TEG are equal ($R_{int} = R_L$), the power transmitted from the TEG reaches the maximum power point (MPP)

[12]. As the load value changes, the power value transmitted from the TEG decreases.

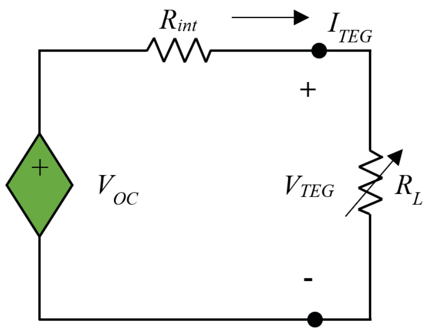

Fig. 1. *Electrical equivalent circuit of TEG*

When the power value delivered from the TEG is at the MPP point, the open circuit voltage and short circuit current are at their half values as described below:

$$V_{MPP} = V_{OC}/2 \text{ and } I_{MPP} = I_{SC}/2 \quad (1)$$

where, V_{MPP} and I_{MPP} are voltage (V) and current (A) at maximum power point, respectively. I_{SC} is the short-circuit current (A). With these values, MPP can be determined. The current value passing through the TEG is given below:

$$I_{TEG} = V_{OC}/(R_{int} + R_L) \quad (2)$$

where, I_{TEG}, R_{int}, and $R_L$are TEG current (A), TEG internal resistance (Ω), and load resistance (Ω), respectively. The power delivered from the TEG depending on the load resistance and internal resistance is as follows:

$$P = \frac{V_{OC}^2}{(R_{int} + R_L)^2} \cdot R_L \quad (3)$$

where, P is the power (W) generated from the TEG. As can be seen from Equation 3, the power produced from the TEG depends on the internal resistance of the TEG, R_{int} and the load resistance connected to the TEG, R_L. The MPPT methods are used with a converter to deliver maximum power from the TEG by equalizing the load resistance to the internal resistance of the TEG. This synchronization is done with the duty cycle sent to the switching element of the converter by the MPPT algorithm.

METHOD

In this study, a hybrid MPPT method is developed using a metaheuristic algorithm, AO, in order to obtain maximum power from TEGs. In the northern hemisphere, the Aquila is one of the most popular raptors [13]. The Aquila optimizer (AO) arrives at the conclusion by modeling the hunting methods of Aquila [14]. The AO algorithm flowchart is shown in **Figure 2**. The hunting methods of the golden eagle can be expressed in four steps: high soar with a vertical stoop, contour flight with short glide attack, a low flight with a slow descent attack, and walking and grab prey.

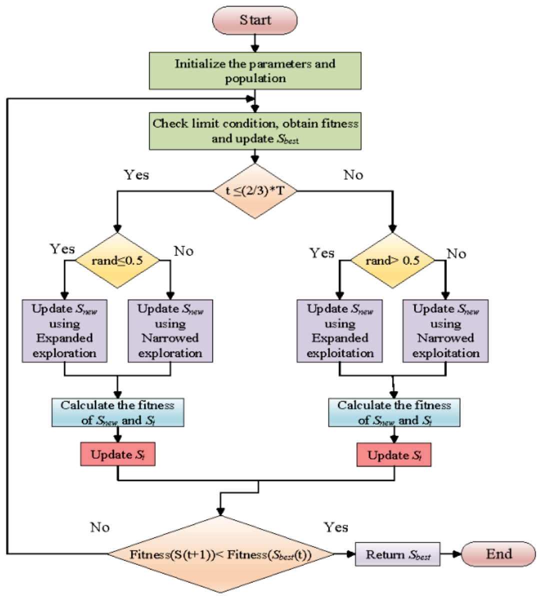

Fig. 2. *Flowchart of aquila optimizer*

Table 1 shows the properties of the TEG system designed for simulation studies in this study. Since the efficiency of TEG systems used for waste heat recovery is low, it is very important to use an MPPT control algorithm. MPPT is a control method used to achieve maximum power in power generation systems.

Table 1. *Properties of TEG system*

Characteristics	TEG system
Output Power at MPP (P_{MPP})	57 W
Output Voltage at MPP (V_{MPP})	20.5 V
Output Current at MPP (I_{MPP})	2.8 A
Open circuit voltage (V_{OC})	41 V
Short circuit current (I_{SC})	5.61 A
Internal Resistance	7.3 Ω
Hot-side temperature	200°C
Cold-side temperature	30°C

MPPT algorithms adjust the duty cycle of the converter switching element in a TEG system consisting of TEG, converter, and load. In this work, a hybrid MPPT algorithm named AO-P&O is developed to monitor the maximum power, and a boost converter designed to match the impedance is used. Firstly, the traditional P&O MPPT algorithm is used in the study. The step size of the P&O algorithm is used as 0.001. Then, the metaheuristic algorithm AO is adapted for MPPT. Finally, the AO algorithm and the P&O algorithm are developed as a hybrid. In the developed AO-P&O algorithm, AO is used to optimize the step size of the P&O. Thus, instead of fixed step size, the step size is continuously calculated according to the changing conditions in the dynamic system. Ultimately it helps to improve MPPT performance. The performance of the developed hybrid algorithm is compared with the traditional P&O algorithm and the AO algorithm.

RESULTS

In this study, three different simulations are made for the hot surface temperature of 120°C, 200°C, and 160°C by keeping the cold surface temperature of TEG constant at 30°C. When the hot surface temperature rises and falls, the response and performance of the algorithms are observed. **Table 2** shows the maximum power values obtained with AO, P&O, and hybrid AO-P&O algorithms. Also in **Figure 3**, there is a graphical comparison of the powers obtained by the algorithms.

***Table 2** Powers obtained by MPPT algorithms from TEG for different temperature difference values*

Algorithm	T_C=30°C, T_H=120°C	T_C=30°C, T_H=200°C	T_C=30°C, T_H=160°C
AO	16.65 W	51.64 W	32.96 W
P&O	18.08 W	54.53 W	35.16 W
AO-P&O	**18.16 W**	**54.87 W**	**35.36 W**

The powers obtained by AO, P&O, and hybrid AO-P&O algorithms from TEG are 16.65 W, 18.08 W, and 18.16 W, respectively, at $T_C = 30°C, T_H = 120°C$ conditions. They give results as 51.64 W, 54.53 W, 54.87 W under $T_C = 30°C, T_H = 200°C$ conditions, and 32.96 W, 35.16 W, 35.36 W under $T_C = 30°C, T_H = 160°C$ conditions. As can be seen, AO gives the worst results and is quite inadequate as a stand-alone MPPT algorithm. When the MPPT efficiencies are calculated using the data in Table 1, the MPPT efficiency of the AO, P&O, and hybrid AO-P&O algorithms is 90.597%, 95.667%, and 96.263%, respectively.

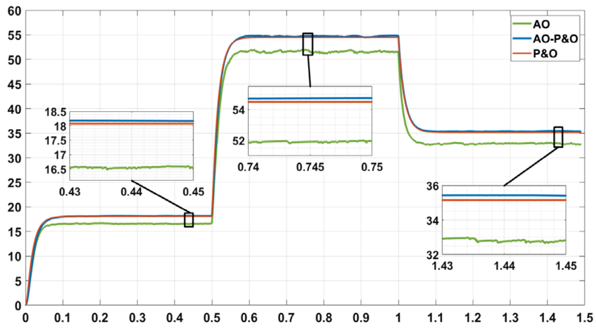

***Fig. 3** Comparison of AO, P&O and hybrid AO-P&O MPPT algorithms*

CONCLUSION

Energy efficiency is one of the most important issues of recent times. Therefore, MPPT algorithms used to obtain maximum power from TEGs used in waste heat recycling are also being developed day by day. Metaheuristic algorithms, which have increased in number in recent years, have recently been used as MPPT methods. In this study, the results of the AO algorithm, which is a metaheuristic algorithm, when used as an MPPT method are investigated. Like other metaheuristic algorithms, AO, which is based on multiple iteration methods, cannot produce successful results when adapted as a stand-alone MPPT method. However, when used as a hybrid method together with the conventional P&O algorithm, which is well known as the MPPT method, it appears to provide 0.596% better MPPT efficiency than the conventional P&O. It is a possible field of study that the more powerful metaheuristic algorithms in the literature are used as hybrid methods, and they have the capacity to increase the performance of MPPT methods.

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