IMPROVED PERTURB AND OBSERVE MAXIMUM POWER POINT TRACKING METHOD WITH THERMOELECTRIC GENERATOR MODEL

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Abstract

One of the green technologies that can be used to increase energy efficiency by recovering a part of waste heat as electrical energy is thermoelectric generators (TEG) by using the Seebeck phenomenon. Conventional and modern maximum power point tracking (MPPT) methods used to deliver maximum power from energy sources frequently appear in the literature. The biggest disadvantage of TEGs is their low efficiency. Therefore, MPPT methods are expected to deliver the highest power from the TEG in the shortest time and this is important to obtain the best result. The most common MPPT method in the literature is the Perturb and Observe (P&O) MPPT method. In this study, an improved version of the P&O MPPT method is used. With this method, it is aimed to obtain the maximum power from the TEG in a shorter time. The simulation results show that with the improved method, more power is delivered from the TEG in a shorter time. In addition, steady-state oscillations are also reduced.

Keywords: Thermoelectric Generators, Maximum Power Point Tracking, Perturb and Observe, TEG model.

INTRODUCTION

Low efficiency is a disadvantage of TEG systems and it is necessary to improve the performance of the TEG and extract the maximum power to operate close to its full capacity. For this reason, power conditioning methods are used to extract maximum power from TEG systems [1]. Power conditioning methods include impedance matching and DC-DC converter implementations. The impedance matching contains a balancing the total internal resistance, R_{TEG} and load resistance, R_L. Appropriate impedance matching is important to transfer the maximum power to the load. In order to transfer the maximum power to the load, the optimum electrical load must be same as the internal resistance of the TEG ($R_{TEG} = R_L$) [2].

As shown in Figure 1, the electrical equivalent circuit of the TEG consists of a temperature dependent voltage source and an internal resistor, R_{int}. The load, R_L, is connected to deliver power from the TEG. When the load value and the internal resistance of the TEG are equal ($R_{int} = R_L$), the delivered power from the TEG reaches the maximum power point (MPP) [2]. As the load value changes, the delivered power value from the TEG decreases.

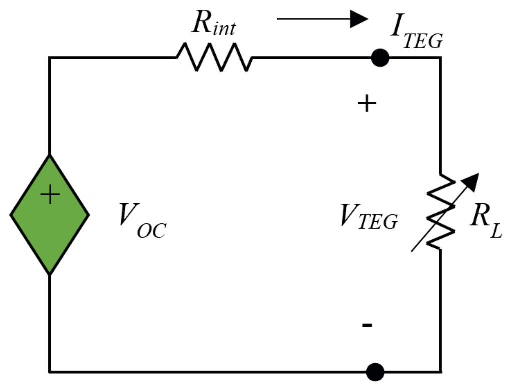

Fig. 1. *Electrical equivalent circuit of TEG*

When the power value delivered from the TEG is at the MPP, the open circuit voltage and short circuit current are at their half values as explained 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) delivered from the TEG. As can be understood from Equation 3, the power delivered from the TEG depends on the internal resistance of the TEG, R_{int}, and the load resistance connected to the TEG, R_L. Maximum power point tracking (MPPT) methods are used with a converter to deliver maximum power from the TEG by equating the load resistance to the internal resistance of the TEG.

When the load is connected directly to the terminals of the TEGs, if the connected load and the internal resistance of the TEG are not equal, the efficiency of the TEG drops further. This is referred to as impedance imbalance [1], [3]. To avoid this situation, converters capable of both MPPT and power regulation are used with TEGs [4]. MPPT is a well-known control method that can enable the TEG waste heat recovery power system to operate at maximum power capacity under various loads and temperature differences.

PERTURB AND OBSERVE ALGORITHM

Perturb and Observe (P&O) algorithm, whose flow chart is given in Figure 2, is the most popular among MPPT methods. When power is taken from TEGs, not only the change in load, but also the change in temperature results in a change in the MPP value. In this case MPPT is required. The P&O MPPT algorithm performs impedance matching by adjusting the duty cycle of the switching element in the converter used in the system. Firstly, current and voltage values are measured. Secondly, the power value is calculated and the change in power and voltage is found. Then, the change in power is questioned and the duty cycle is adjusted according to the power change until the MPP value.

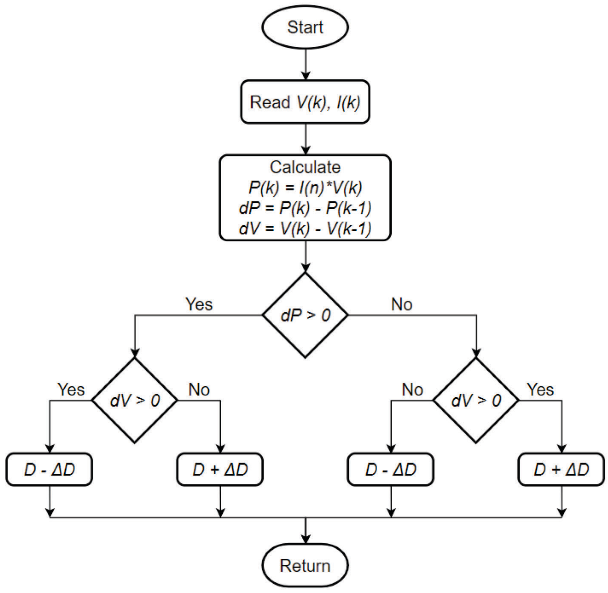

Fig. 2. *Perturb & Observe algorithm* [9]

Although P&O is a simple and reliable algorithm, it has two main drawbacks. First, tracking causes oscillations in output power as it approaches the MPP. Second, the P&O algorithm cannot handle the change in environmental conditions and deviates from the MPP [5]. In order to overcome these drawbacks, modifications and improved versions of the P&O algorithm have been studied. Dalala *et al.* proposed a new P&O MPPT algorithm based on the application of open-circuit voltage detection and short-circuit current estimation methods for TEGs in [6]. Nakayama *et al.* proposed a simple MPPT algorithm that consumes less energy. In this method, the open circuit voltage of the TEG is monitored without measuring it and there is no need to measure and compare the voltage frequently in [7]. Bond *et al.* proposed a duty cycle-based MPPT method with current sensorless power estimation. This method includes a P&O-based reference voltage generator and overcomes this disadvantage as it does not require disconnecting the source and load for current or open-circuit voltage measurement [8]. MPPT algorithms, which were first used in photovoltaic (PV) systems, are also adapted to TEG systems due to the similar characteristics of TEGs with PV systems.

In this study, an adaptive P&O algorithm previously proposed for PV systems is adapted to a new simple TEG model. Using a TEG model formed in Simulink, the performances of the Improved P&O algorithm and the conventional P&O algorithm are compared.

IMPROVED P&O ALGORITHM

P&O MPPT algorithm is the most widely used MPPT algorithm due to its simple structure and easy applicability. It gives reliable results and converges to the maximum point fast. However, the two biggest drawbacks of the P&O algorithm are that it uses a fixed duty cycle, causing oscillations in the MPP, and inability to make accurate decisions in rapidly changing environmental conditions. Because the P&O algorithm cannot detect whether the power fluctuation is caused by environmental conditions. Singh *et al.* [10] have overcome these drawbacks by developing the conventional P&O MPPT algorithm for PV systems. In this improved method, changes in current are included in the process along with changes in voltage, thereby accelerating the decision-making process. In addition, the oscillation problem at the MPP is reduced by the non-constant duty cycle. Figure 3 shows the flow chart of the improved P&O algorithm.

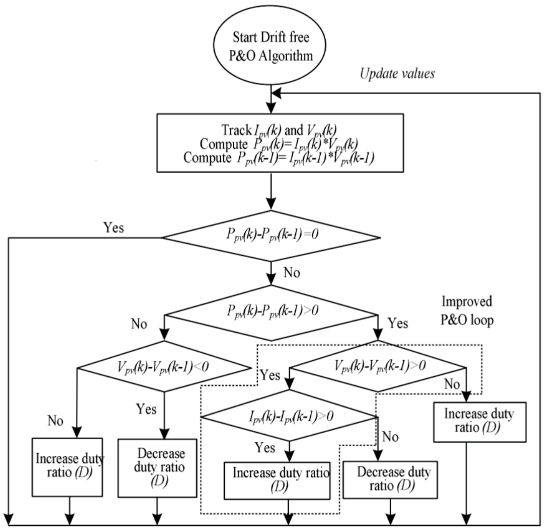

***Fig. 3.** Improved Perturb and Observe algorithm* [10]

METHODS

In this study, the improved P&O MPPT algorithm given in reference [10] and described in the previous section is applied to a TEG system consisting of 40 TEG modules. Two groups consisting of 20 serially connected TEG modules are connected in parallel to form a TEG system in the simulation environment. By connecting a constant load to this system, the hot surface temperature is changed and the simulation is performed according to the temperature change. The duty cycle used in the simulations is kept constant for the conventional P&O algorithm. For the improved P&O algorithm, different duty cycles are used according to the size of the power change. According to the simulation results, the improved P&O algorithm reaches the MPP point faster and generates more power than the conventional P&O algorithm. With constant load connected to the system, the hot surface temperature is first set to 160°C, then 200°C at 0.35 s and 180°C at 0.7 s.

RESULTS

The simulation results are shown in Figure 4. Under variable surface temperature, the improved P&O algorithm reaches the MPP with 1% error in 0.15 seconds and the conventional P&O algorithm in 0.21 seconds. Maximum power delivered from the TEG system with Improved P&O is 261.5 W, 448.8 W and 348.8W at 160°C, 200°C and 180°C, respectively. The maximum power achieved with conventional P&O is 236 W, 403.8 W and 315.2 W at 160°C, 200°C and 180°C, respectively. With the improved P&O algorithm under variable surface temperature, 10% more power is received 40% faster than the P&O algorithm. In addition, it is observed that the oscillations in the MPP are reduced with the improved P&O algorithm.

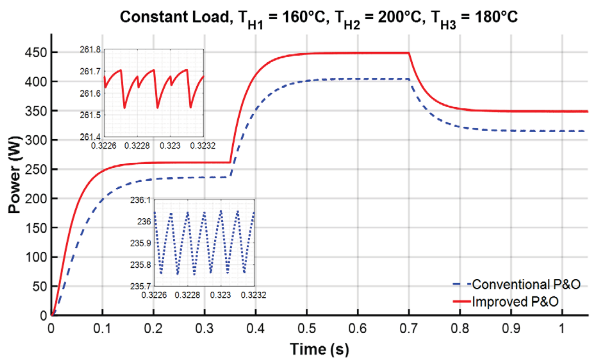

***Fig. 4.** The obtained power with conventional and improve P&O MPPT algorithms*

CONCLUSION

The maximum power obtained from TEGs depends on the temperature difference between the surfaces of the TEG. This is achieved by means of MPPT algorithms. The most widely used MPPT algorithm in the literature is the P&O MPPT algorithm, however, it needed to be improved due to its inability to respond quickly to changing environmental conditions and the lack of oscillation in MPP. In this study, a simulation study is carried out with varying surface temperatures using the improved P&O algorithm and compared with the conventional P&O algorithm. The simulation results show that the improved P&O algorithm obtained higher power from TEG than the conventional P&O algorithm and reduced the oscillations in MPP.

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