Study on Maximum Power Point Tracking Algorithm of Automobile Exhaust Thermoelectric Generator

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Abstract. Considering the soft output performance of automobile exhaust thermoelectric generator (AETEG), an AETEG using Buck based DC/DC converter were established, based on the duty ratio disturbance observation method, an improved maximum power point tracking algorithm(MPPT) named adaptive hill climbing algorithm was present, including its principle and flow diagram. The simulation result based on UDDS driving cycle proves that the practical power of AETEG can follow its theoretic maximum output power, the algorithm has advantages on the dynamic and steady performance of AETEG in the MPPT.

Introduction

The utilization efficiency of fossil fuel energy in internal combustion engine of traditional automobiles is below 30%, while nearly 40% of the rest one is wasted from exhaust directly [1], recovering the exhaust heat energy with thermoelectric technology and employ the generated power in the vehicle system is the research focus all over the world. However, the output character of automobile exhaust thermoelectric generator (AETEG) is soft, i.e. its output voltage decreases as its output current increases, while its power increases to its maximum value and drops latter. In the practical application, how to track the maximum power of AETEG to enhance its output performance and reduce its costs is significant.

In this paper, an AETEG of thermoelectric modules in series is constructed, a modified adaptive hill climbing algorithm is put forward, and the system performance is evaluated by both simulation and experiment.

Design of AETEG

The Schematic of AETEG. As shown in Fig.1, there are one heat exchanger, two cooling units, and two groups of thermoelectric modules. For the thermoelectric modules of each layer, all the hot sides are connected with the heat exchanger, while their cold sides are connected with cooling unit 1 and 2, respectively. The operating parameters such as the overall voltage and current of the AETEG are detected by the main controller and monitored by a PC-based software interface. It includes 64 single thermoelectric modules fixed in 2 layers, as shown in Fig.2, there are 32 independent single thermoelectric modules above a heat exchanger of a layer [2], where they are arranged with 4 rows and 8 columns from the exhaust inlet to exhaust outlet direction. As to thermoelectric modules group 1, the number of single thermoelectric module is from 1 to 32, while the number of single thermoelectric module in thermoelectric modules group 2 is from 33 to 64.

Furthermore, there are a series of dummy plates at both sides of the heat exchanger’s interior cavity, which is called herring-bone structure [3]. The effective heat conduction length is 542 mm, the effective width is 280 mm, the exterior height is 18 mm, the interior thickness is 2 mm, and the dimensions of all the parts of the heat exchanger are also given in Fig. 2.
DC/DC Converter. All the thermoelectric modules stated above in both Fig.2 are connected in series, considering the soft character of AETEG, a Buck-based direct DC/DC converter is applied in Fig.1.

The Maximum Power Point Tracking Algorithm

The Principle of Adaptive Hill Climbing Algorithm. There are lots of advanced MPPT algorithms in the application of solar energy, wind energy and fuel cell [4]. Different MPPT algorithms, different disadvantages. In this paper, an adaptive hill climbing algorithm is adopted, it adjusts the output power of AETEG to its maximum value by controlling the duty ratio of switching tubes used in DC/DC converter. The relationship between the power of AETEG and the duty ratio of DC/DC converter is presented in Fig.4. To get the maximum power point, \( \frac{dP}{dD} \) is equal to 0. When \( \frac{dP}{dD}>0 \), AETEG works on the right side of its maximum power point, on the contrary, once \( \frac{dP}{dD}<0 \), it works on the left side of its maximum power point. Thus, the variability of duty ratio can be decided by comparing the current power with the previous one.
**The Flow Diagram of Adaptive Hill Climbing Algorithm.** The adaptive hill climbing algorithm is based on duty ratio disturbance method, how to choose the step size to adjust the duty ratio of DC/DC is the key problem. The smaller step size is, the longer time it takes to track the maximum power point of AETEG, which will degrade its dynamic performance. On the contrary, the fluctuation of output power will be larger, the average power will be much smaller than its maximum power, which will increase the steady state error of AETEG system.

The flow diagram of adaptive hill climbing algorithm is shown in Fig.5, where $|\Delta P/a(k-1)|$ is the variable quality of control loop, $e$ is the error of MPPT. In our work, the variable quantity of duty ratio $a(k)$ is adopted to solve the problem above, the relationship between it and the variable quantity of power $\Delta P$ and its previous value $a(k-1)$ is as follows\[5\]:

$$a(k) = M \frac{|\Delta P|}{a(k-1)}$$

(1)

Where $M$ is a nonnegative number, $slope$ is the symbol of direction var. When $|\Delta P/a(k-1)|>e$, $\Delta P$ is caused by the variation of temperature difference of AETEG, the direction var of both $a(k)$ and $\Delta P$ is the same, $a(k)$ is adjusted on-line so that AETEG is adapt to the temperature variation. When $|\Delta P/a(k-1)|<e$, it means small temperature variation, and AETEG is in steady state, $slope$ is decided according to $\Delta P$, and $a(k)$ is adjusted accordingly. Both $e$ and $M$ are important parameters which decide whether the maximum power of AETEG can be tracked freely.

![Fig.5 Flow diagram of adaptive hill climbing algorithm](image)

**Simulations and Analysis**

**The Driving Cycle.** There are lots of different driving cycles in the performance simulation of vehicles such as UDDS, ECE-EUDC, HWFET and so on. To confirm the adaptive hill climbing algorithm above, UDDS driving cycle is used in this paper. At this moment, the according rotate speed of engine used in the vehicle is shown in Fig.6.

![Fig.6 Rotate speed of engine based on UDDS driving cycle](image)
Simulation of AETEG MPPT. Firstly, the models of DC/DC converter and AETEG described above are set up, based on the UDDS driving cycle above, according to the rotate speed of engine shown in Fig.6, the MPPT simulated result of AETEG is presented in Fig.7. It can easily be seen that the maximum power of AETEG simulated based on adaptive hill climbing algorithm follows its maximum power simulated well, their variation trends are almost the same, thus, the adaptive hill climbing algorithm adopted can enhance the dynamic performance of AETEG in its MPPT, it is feasible and practical.

![Simulated result of MPPT algorithm](image)

Conclusions

Up till now, the efficiency of single thermoelectric module is still low, the maximum power of AETEG designed all over the world is nearly below 1000W. Different driving cycles, different temperature differences and different maximum power of AETEG, in the application of AETEG, its output power should be the maximum as much as possible. Even though there are many advanced algorithms in the MPPT of solar energy, wind energy and other new energies, the adjustment of their step size is difficult. In this paper, based on the method to duty ratio disturbance observation, the improved MPPT of adaptive hill climbing algorithm is put forward, it can enhance the dynamic and steady performance of AETEG in MPPT.

In our experiments, based on the adaptive hill climbing algorithm above, the practical output power of AETEG approaches its maximum power in theory in different driving cycles. For the length limitation of paper, the experimental results are not provided.

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