

Microcontroller Based Thermoelectric Generator Application

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ABSTRACT

In this study, a microcontroller controlled thermoelectric generator which transforms geothermal energy, one of the renewable energy sources, to directly electrical energy was designed, and then the system was tested and its performance analysis was examined. In the system, energy transformation is provided via the Seebeck effect in the thermoelectric modules. Since changeable DC voltage depending on temperature difference is obtained by the thermoelectric modules, the accumulator, regulator circuit and DC/AC convertor are used in order to obtain the values 5V DC, 12V DC and 220V AC in the electrical energy. System control signals are arranged by using the PIC16F877 microcontroller in the system. The system is quite useful to meet electrical energy needs easily, cleanly and cheaply from the geothermal sources.

Keywords : Thermoelectric Generator, Microcontroller, Control

1. INTRODUCTION

The need of electrical energy of the countries around the world is increasing everyday. The sources of traditional energy which consist of fossil fuels such as petroleum and coal being limited the increasing tendency of these energy sources to be consumed and the problem of world pollution has increased the importance of renewable energy sources.

Studies in the world of electrical energy production from thermoelectric modules have increased rapidly [1]. In this study, a microcontroller controlled geothermal thermoelectric generator (MCGTG), which transforms geothermal energy, one of the renewable energy sources, directly to electrical energy was designed, and then the system was tested and its performance analysis was examined [2].

2. MATERIAL AND METHOD

2.1. Thermoelectric Generator

The foundation of the thermoelectric generator (TEG) is based on the Seebeck effect which was discovered by Thomas Seebeck in 1821. Thermoelectric energy production which is one of the many processes of changing heat flow directly into electrical energy, promises a long life working without maintenance due to its reliability, silence, simplicity and the non-existence of moving parts. Thermoelectric modules are formed by P and N type semiconductors which are connected in series electrically and in parallel thermally among two ceramic layers. A TEG is made by heating one face of thermoelectric module, and cooling the other face in the thermoelectric circuit which is made by connecting a load to the end points of the thermoelectric module. A TEG is shown in Figure 1 [3-7].

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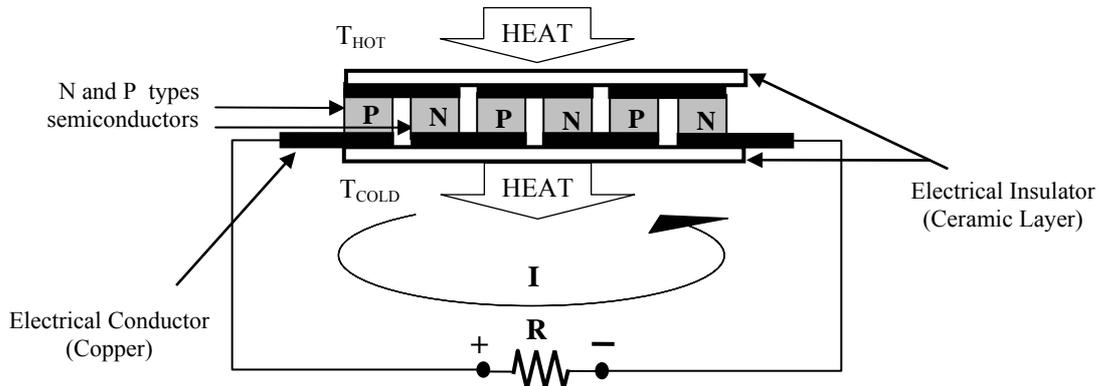


Figure 1. Thermoelectric module in generator mode

The TEG part of the designed system consists of 3 parts; a heating block, a cooling block and a thermoelectric module arrangement. In the TEG, heat which is produced by the heating block is applied to the thermoelectric module face, and this heat gets sucked by the cooling block from the other side. This ensures the transfer of TEG heat. Aluminium blocks were used for the heating and cooling of the thermoelectric module surfaces. In the system, a thermoelectric module arrangement was made by connecting 12 numbers of thermoelectric modules (Melcor CP1.4-127-06L) in series electrically and in parallel thermally [8]. Thus increasing the output has brought the power of the accumulator charger to its sufficient level.

2.2. General Construction and Operation of System

On the front panel of the MCGTG, there are 5V DC, 12V DC and 220V AC generator outputs, a Liquid Crystal Module (LCM) for the system operating information and warning messages, the adjusting buttons for the upper temperature limit (UTL) value and the on/off switch for the accumulator and TEG unit (Figure 2). On the back panel of the MCGTG, there are the input-output of geothermal water and the input-

output of cool water. The specifications of the system are given in Table 1.

Together with giving geothermal and cool water to the MCGTG system, there occurs a the difference in temperature between the thermoelectric module faces occurs which produces DC voltage. This DC voltage provides, with the help of the charging unit, the accumulator to be charged. The 5V DC, 12V DC and 220V AC outputs occur due to the accumulator, DC/AC converter and the regulator circuit in the system. The thermoelectric generator and accumulator starts working with the K_{SYSTEM} switch which is in the accumulator charging circuit. Necessary control signals with the data obtained according to the temperature and voltage measures, are made by the microcontroller. In the system, V_{HOT} and V_{COLD} voltage values and the V_A and V_C analog voltage values which are taken out of the voltage dividing circuit for V_{ACCU} and V_{CHARGE} voltages are applied to the analog inputs of the microcontroller. Necessary controls are made according to the data and information about hot-cold measure values, whether the temperature difference of ΔT is enough or not, the UTL, the accumulator voltage, the accumulator charging voltage, accumulator charging current and the operation details are given by the LCM. The block diagram of the MCGTG is shown in Figure 3.



Figure 2. Microcontroller controlled geothermal thermoelectric generator

Table 1. General characteristic specifications of the System

Dimension	48 cm x 44.5 cm x 92 cm
Weight	25 Kg
Maximum geothermal water temperature value	130 °C
Generator Power (for $\Delta T = 40^{\circ}\text{C}$)	Maximum 6.15W
Duration of generator charging (for $\Delta T = 40^{\circ}\text{C}$)	Minimum 24 Hours
Output Voltage (DC and AC)	5V DC, 12V DC, 220V AC

By means of the temperature sensors in the temperature measurement circuit, heating and cooling block temperatures are measured, and V_{HOT} and V_{COLD} analog voltages are applied to the microcontroller. In the temperature measurement circuit a linear approach was followed and LM35 temperature sensors, which supply 10mV voltage for each 1°C temperature increase, were used. As 5V is the of reference voltage of the PIC16F877 microcontroller and the A/D converter is 10 bits, the sensitivity is calculated approximately 5mV from $5/2^{10}$. This ensures that for each 5mV increase of the microcontrollers' analog input it is possible to do a measurement with a 0.5°C sensitivity. The accumulator charging (V_{CHARGE}) and accumulator (V_{ACCU}) analog voltages get divided with the voltage dividing circuit and reach a level of V_A and V_C voltage, which is a solubility over 5V for the microcontroller.

Since the thermoelectric modules used in the design endure up to 130°C, the UTL has been determined and a protection has been taken against the extreme temperature [8, 9]. The value of the UTL is continuously shown in the LCM and the arrangement of this value is made with a circuit that shows an increase or decrease of 1°C on each press of the B_1 and B_2 buttons. The increasing and decreasing signals are given to the RC5 and RC6 ports of microcontroller. A microcontroller controlled solenoid valve that automatically cuts off the geothermally water input when the heating block temperature has reached the UTL and opens it when the temperature is 5°C below the UTL was used. The RD4 port of the microcontroller is used to open and close the solenoid valve.

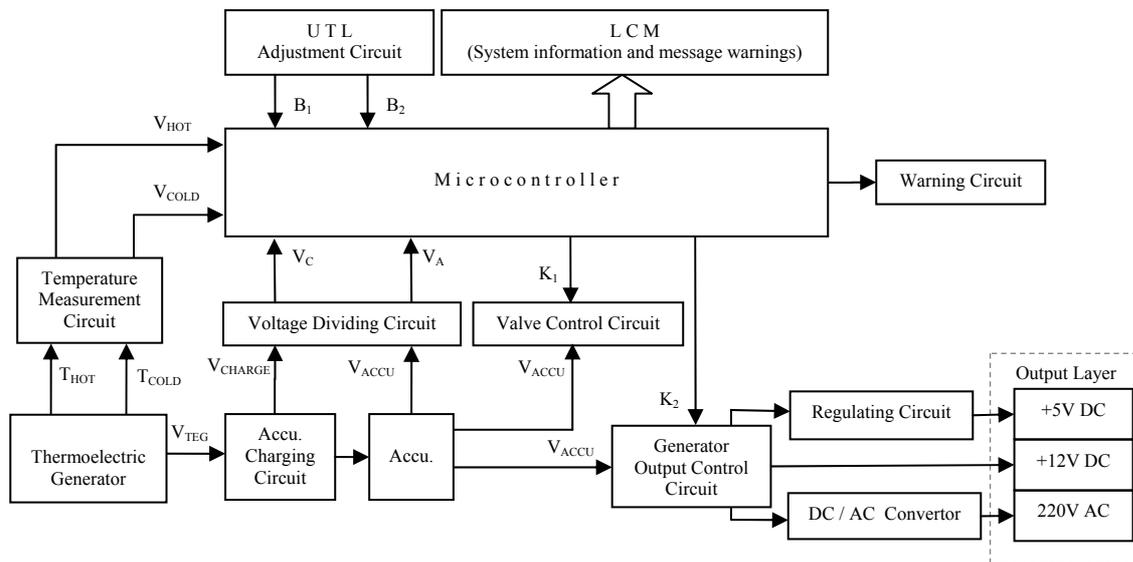


Figure 3. Block diagram of microcontroller based thermoelectric generator

In the system, when the heating block temperature reaches the UTL, the geothermal water input is cut off automatically; similarly, when the accumulator voltage comes below 10V, the generator outputs are closed and a voiced warning is given. An alarm control circuit that gives a voiced warning with a frequency of 4 Hz from the RD1 port was used.

A Xiamen GDM2004D series 4x20 characters LCM was used for the screening of the microcontroller based results and condition messages belonging to the system operating environment. The screen of LCM is shown in Figure 4.

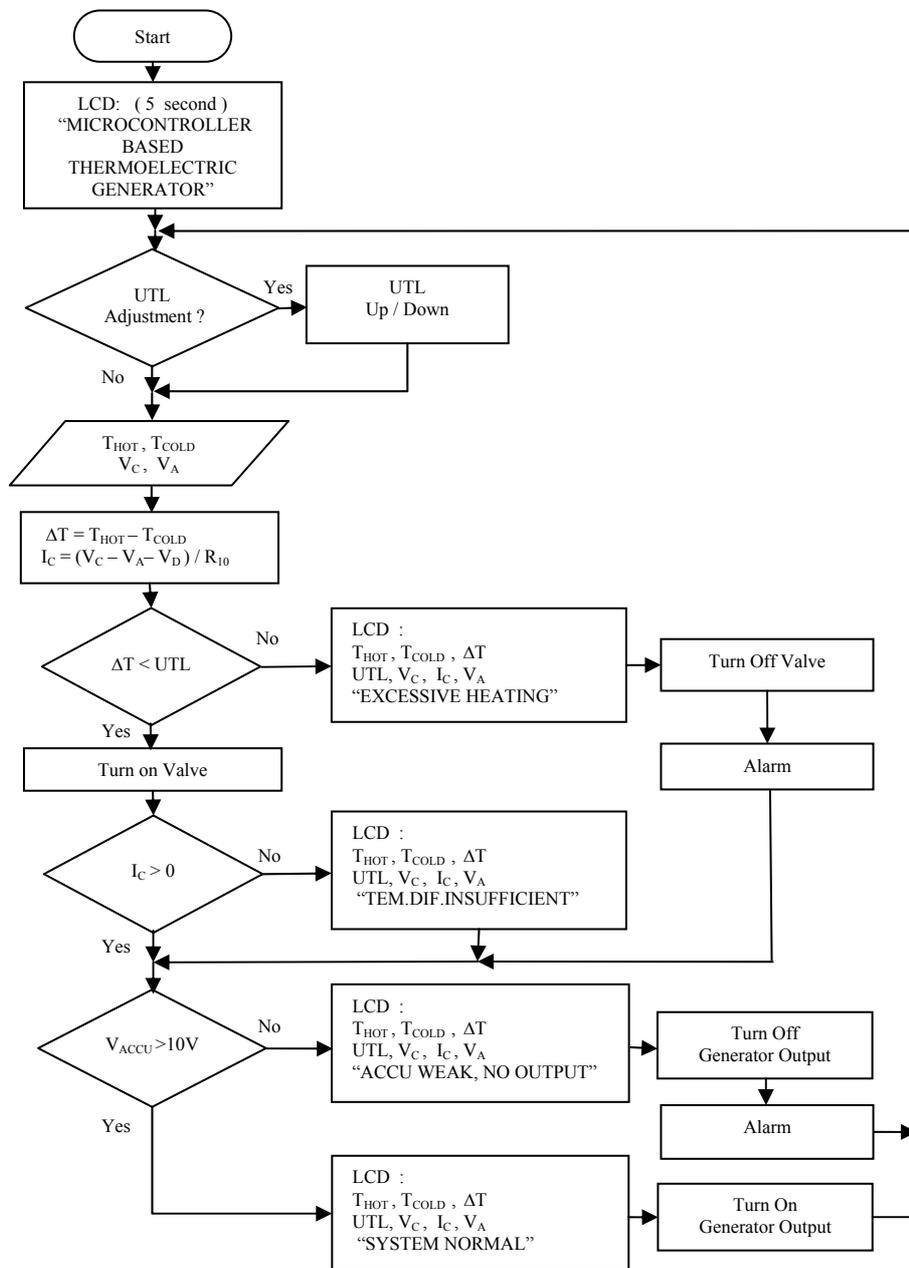


Figure 5. Flow diagram of microcontroller program

The system's output power was calculated according to the measured current and voltage values which were provided by the R loads of 10Ω, 30Ω and 50Ω getting connected onto the end points of thermoelectric module arrangement. The system load-power relation was

obtained according to current, voltage and power values based on load resistance at fixed temperature differences, this load-power relation is shown in Figure 6.

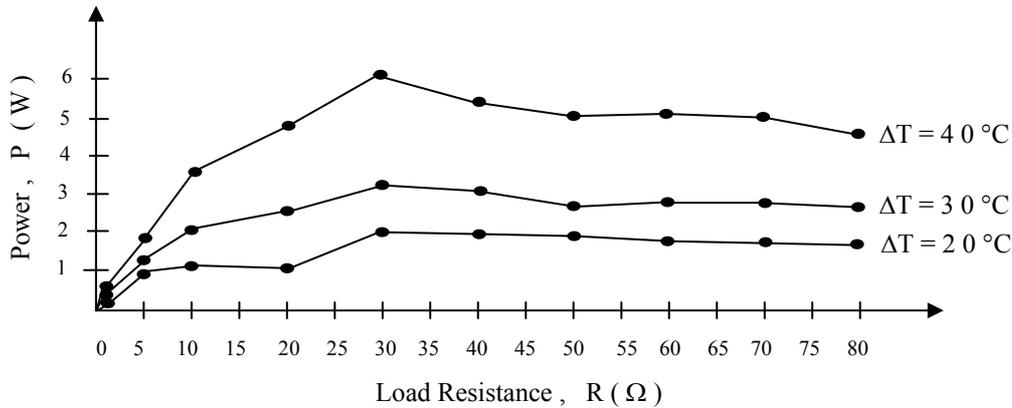


Figure 6. The Systems Load – Power relation

3.2. TEG Efficiency

The input power is the total heat energy which enters the system since electrical energy is produced due to the temperature difference in the thermoelectric module. The output power was calculated with the voltage and current values obtained from the thermoelectric generator as a result of the temperature difference. In this case, the system's input-output power and efficiency easily obtained by using the TEG efficiency calculations (see appendix) [2,8,9].

The CP1.4-127-06L model thermoelectric module that was used in the TEG, is formed of a 127 couple (N) micromodule. The geometry factor of the thermoelectric module is 0.118 cm. According to the $T_{HOT}=70^{\circ}\text{C}$ (343.2°K), $T_{COLD}=27^{\circ}\text{C}$ (300.2°K) measurement that were obtained from the system, the $\alpha=0.000207\text{V}/^{\circ}\text{K}$, $\rho=0.00116\Omega\cdot\text{cm}$, $\kappa=0.0153\text{W}/\text{cm}\cdot^{\circ}\text{K}$ values were found from the material parameters of the thermoelectric module. Regarding to these values, the average Seebeck coefficient (α_M) was calculated as 0.0526V/°K, the module's average resistance (R_M) as 2.4969Ω and the module's thermal conductivity (K_M) as 0.4586W/°K. In the TEG, 12 thermoelectric modules were connected in series electrically and in parallel thermally. In this case, the number of series thermoelectric module is (NS) = 12, the parallel lines is (NP) = 1 and the number of total thermoelectric modules is (NT) = 12. The maximum power is supplied when the R_L load resistance equals the generator internal resistance. Because of this, load resistance was found approximately 30Ω from $12\cdot R_M$. The current (I) taken from R_L was calculated as 0.4526A, the output voltage of the TEG (V_o) as approximately 13.5792V, the generator output power (P_o) as 6.1459W, TEG's total heat input (Q_h) as approximately 253.5672W and TEG's efficiency (η) as approximately %2.5.

4. RESULT AND SUGGESTIONS

In this study, a microcontroller controlled thermoelectric generator which transforms geothermal energy, one of the renewable energy sources, directly to electrical energy was designed, and then the system was tested and its performance analysis was examined. System control signals are arranged by using the PIC16F877 microcontroller in the system. For the heating of the TEG geothermal water can be used, whereas for the cooling normal cold water obtained from a well, stream or elsewhere can be used. 12 CP1.4-127-06L model thermoelectric modules were used for the TEG. As the maximum working temperature of the modules is +130 °C, the temperature of the heated surface of the module has been designed in an adjustable way. A heating block designed for the system was used when thermal temperatures were applied to the thermoelectric module. Instead of using geothermal water for heating the block water that has been heated by solar energy or direct solar energy has been used for the production of electrical energy. With a few changes in the system a thermoelectric generator that works with solar energy can be made. Also, it is possible to produce a thermoelectric generator by using any other heat source.

Experimental measurements were made by using hot water obtained from a water heater, instead of using geothermal water. The voltage produced by the TEG at 43°C temperature difference while the TEG was unloaded, was measured as 28.12V. Power was found from the current and voltage values that were measured as a result of temperature difference practices by connecting different loads between 1Ω and 80Ω to the TEG. While connecting a 30Ω load resistance to the TEG, maximum power was obtained (1.96W at 20°C, 3.28W at 40°C and 6.15W at 40°C). The power of TEG was obtained using theoretical and experimental methods and were very similar to each other. The efficiency of the TEG was also calculated as approximately %2.5. The efficiency doesn't change for series and parallel thermoelectric module connections, but it may change in respect of the internal resistances

of the thermoelectric modules. Because of using high internal resistanced thermoelectric modules for cooling purposes, the efficiency obtained has been low. The output power can be increased by enlarging the cooling and heating surfaces, increasing the number of thermoelectric modules, using low internal resistanced thermoelectric power modules and connecting in parallel many units [11].

By taking the system's experimental results and produced electrical energy into consideration, it is possible to produce electrical energy in geothermal regions where the temperature is higher than 70°C. The system is important in respect to meeting the electrical energy needs for these regions who have thermal resources.

Due to the fact that geothermal energy is a renewable energy source, that thermoelectric modules produce proper power for low and middle temperatured thermal regions and that many low and middle temperatured geothermal regions exist, the usage rate of this system is very high. The importance of the system is evident in respect to meeting electrical energy needs cheaply, cleanly and easily.

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APPENDIX

TEG Efficiency Calculation

The average Seebeck coefficient of thermoelectric module (α_M) in the generator;

$$\alpha_M = 2 \cdot \alpha \cdot N$$

The average resistance of thermoelectric module (R_M) in the generator;

$$R_M = \frac{2 \cdot \rho \cdot N}{G}$$

The thermal conductivity (K_M) of thermoelectric module;

$$K_M = 2 \cdot \kappa \cdot N \cdot G$$

The current(I) taken from the load resistance (R_L) in the generator;

$$I = \frac{NS \cdot \alpha_M \cdot \Delta T}{\frac{NS \cdot R_M}{NP} + R_L}$$

TEG's output voltage (V_o);

$$V_o = R_L \frac{NS \cdot \alpha_M \cdot \Delta T}{\frac{NS \cdot R_M}{NP} + R_L}$$

TEG's output power (P_o);

$$P_o = V_o \cdot I$$

TEG's total heat inlet (Q_h) as watt;

$$Q_h = NT \cdot \left(\frac{\alpha_M \cdot T_h \cdot I}{NP} - 0,5 \cdot (I/NP)^2 \cdot R_M + K_M \cdot \Delta T \right)$$

TEG's efficiency (η);

$$\eta = \frac{P_o}{Q_h} \cdot 100\%$$