ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2011. No. 10(116)
ELEKTRONIKA IR ELEKTROTECHNIKA

AUTOMATION, ROBOTICS
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AUTOMATIZAVIMAS, ROBOTECHNIKA

Determination of Output Parameters of a Thermoelectric Module using Artificial Neural Networks

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http://dx.doi.org/10.5755/j01.eee.116.10.884

Introduction

The concept of the thermoelectric (TE) defines the direct transformation between thermal energy and electrical energy. This transformation is performed by the TE semiconductors most efficiently [1, 2]. TE modules are obtained by connecting tens of P and N type of TE semiconductors as electrically serial and thermally parallel [3, 4]. TE modules are working as a heat pump by pumping the heat in one surface to the other surface. Thus, while the one surface is cooling, the other surface is heating. If the heat energy that occurred in one surface is sinked by using a fun or another device, the temperature of the cooling surface can be reduced further [1]. TE modules have many advantages which are silent operation, being durable, small size and practical applicability. Nowadays, there are many application areas which are especially heating and cooling or production of electrical energy as a thermoelectric generator. Example application areas are medicine, space working and hybrid cars etc. [5, 6].

In order to test the TE modules, many methods have been developed [7–11]. These methods based on to determine parameters as Seebeck factor, electrical resistance and thermal conductance. However, these methods cannot be used by consumers since these parameters are not given by the manufacturers. Furthermore, in the marketplace, there is no indication on the surface of many TE module about their manufacturers. The output parameters of TE module have been calculated by measuring the amount of current that passes through the module, the value of voltage that consisted in the module terminals, the value of the EMK and the value of heated surface temperature of any TE module using the newly devised measurement method by Ciylan and his friends. A system which has microcontroller control system has been implemented to measure and calculate of these values [1, 12-14]. The dynamic output parameters of any TE module which is in a working condition can be obtained by using this implemented system. A disadvantage of this system is that many experiments has to be done to determine the dynamic output parameters in the desired value of any temperature or under a thermal load of the TE module. This process takes quite a long time where new method brings improvement.

In this study, the dynamic output parameters of TE module have been tried to be estimated by using the Artificial Neural Network (ANN). The data from the TE test system which is implemented by Ciylan and his friends have been used for testing process and training of the ANN. In order to create the ANN, the program which was created by Çetiner and his friends and MATLAB-ANN tool software are used [15–17]. It is enough to obtain the dynamic output parameters of TE module experimentally in a few different states for training the ANN. Thus, the behavior under any condition and the dynamic output parameters of the TE module can be easily estimated by ANN model.

Electro-thermal model

Modeling of a TE module with an electro-thermal model will be useful for explaining the characteristics of TE pellets. A TE module as an electrothermal component can be modeled as shown in Fig. 1 [18].

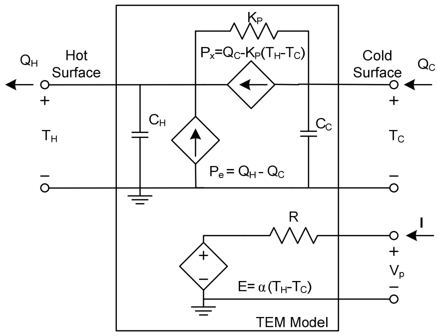

Fig. 1. The electrothermal model of the TE module

In the model Q_C, is the quantity of the thermal load that absorbed from the cooling surface of the module (1). Q_H is the quantity of thermal energy occurred in the heated surface (2):

$$Q_C = \alpha I T_C - 0{,}5 I^2 R - K(T_H - T_C), \quad (1)$$

$$Q_H = \alpha I T_H + 0{,}5 I^2 R - K(T_H - T_C), \quad (2)$$

here, α refers to the Seebeck factor, I refers to the quantity of current that passed through module, T_C and T_H refer to the value of cooling and heating temperature in Kelvin, R refers to the value of electrical resistance and K refers to thermal conductance. When the current applied to any TE module, in the module ends there will be a voltage drop as seen in Fig. 2. The voltage arises instantly to the value of $V_r = IR$ and then to the value of $V_i = V_r + V_O$ asymptotically. At the current cut off, the voltage drops down instantly to $V_O = \alpha \Delta T = E$ and goes down to zero [19].

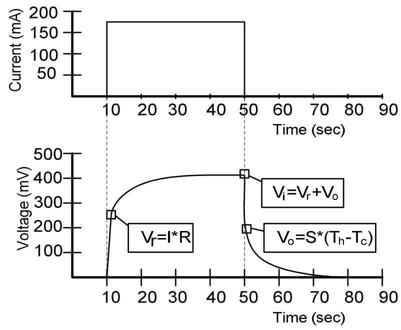

Fig. 2. The current applied to a TE module and the voltage formed in the module ends

Some of the dynamic output parameters measured and calculated by the TE test system under the thermal load in the different values applied to the cooling surface of a TE modules are given by Table 1 [13].

Table 1. The data obtained by the experimental study with the help of the test system

No	Q_C (W)	E (V)	T_H (°C)	T_C (°C)
1	3,88	3,20	29,73	-33,20
2	5,82	3,00	31,18	-28,24
3	6,78	2,90	31,50	-25,74
4	8,70	2,70	31,94	-21,26
5	10,64	2,50	32,32	-17,26
6	11,58	2,40	33,00	-14,09
7	12,54	2,30	33,20	-12,53
8	15,42	2,00	34,00	-5,87
9	16,34	1,90	35,20	-2,42
10	17,31	1,80	35,80	-0,29
11	19,23	1,60	35,80	3,72
12	21,13	1,40	36,00	7,91
13	22,09	1,30	35,80	9,73
14	23,95	1,10	35,90	13,84
15	25,87	0,90	36,20	18,13
16	26,83	0,80	36,80	20,71
17	28,68	0,60	37,00	24,92
18	30,60	0,40	37,10	29,05
19	32,51	0,20	37,30	33,27
20	33,43	0,10	37,50	35,48
21	34,38	0,00	37,70	37,70

Artificial neural network (ANN) and training of the ANN

The ANN, is preferred in the solution of complex problems since its learning capability, easy applicability to different problems, capability to make generalizations and lack of requirement to describe relationship between input-output. The ANN has the ability to establish the relationship between input-output that identified depending on the parameters of a system. Thus, the ANNs can produce appropriate outputs to the inputs of a defined system which has unknown output values and thus provide convenience in solving the complex problems [20].

In the experimental studies that have been done by the developed TE test device, the dynamic output parameters of a working TE module are determined. Nevertheless, determining the quantity of thermal energy that produced for each value of T_C which required to do more experiments, has taken quite time. The time can be shortened by taking advantage of the ANN's ability to prediction. Taking advantage of the data which obtained from the result of the experimental studies by the TE test device, by the help of the ANN, it is possible to estimate the intermediate values. For this purpose, MATLAB ANN (ver. 2009a) and a simulator program software were used.

Creation of the ANN using MATLAB ANN software

The data obtained from the experimental studies has been processed and duplicated by the ANN which has a multi-layer structure where the error is back-propagated. The neural network has three inputs and one output. Where the inputs are the value of EMK (E), temperature of heating surface (T_H), temperature of cooling surface (T_C) and the output gives the values (Q_C) quantity of thermal load occurring on the cold surface. In the training of the ANN 7 of 21 data from the data that obtained by the experimental studies are used. The ANN has a 3-10-5-1 layer structure, hidden layers have tansig function and output layer has purelin function. Thus, if the data has non-linear character, it may be easy to process. Comparing the values between the data that obtained after the training of the ANN and the experimental data is given in Fig. 3.

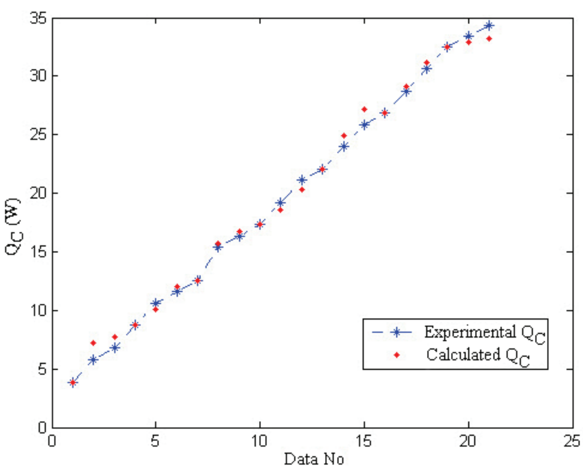

Fig. 3. Comparison of the experimental data with the results obtained using ANN model

The experimental results and the results of the ANN have shown small differences from time to time and a bit large differences from time to time. This situation proves the ANN which works in a correct way.

Creation of the ANN using the simulator program

In recent years, using ANN simulator program has been very widespread. Special and general purposes many Computer programs have been developed oriented to the use of the ANN by scientists and engineers. In this study, it has been taken advantage of the ANN application program which is developed by Cetiner and his friends, in addition to MATLAB ANN program [16, 17].

The output monitor of the training data input to the simulator program is shown in Fig. 4.

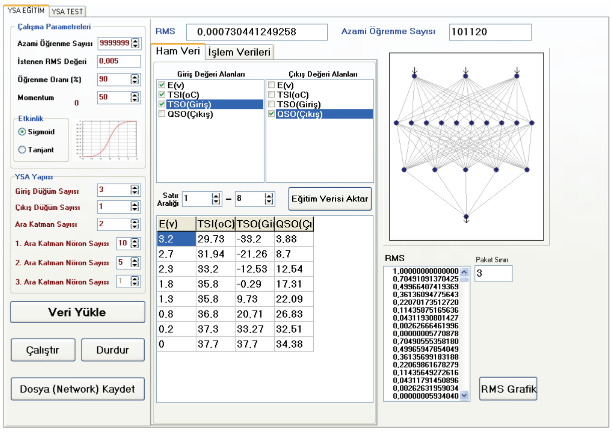

Fig. 4. The main menu of training of the simulator program

Via this menu, 7 data selected from experimentally obtained 21 data to use for ANN training. Selection process has been made up on the experimental data by using a random selection method and recorded in a new file. Via this menu again, it is determined that which parameters will be input and which parameters will be output, how many input and output of the ANN will have, how many intermediate layers it will have and how many neuron the intermediate layers will have.

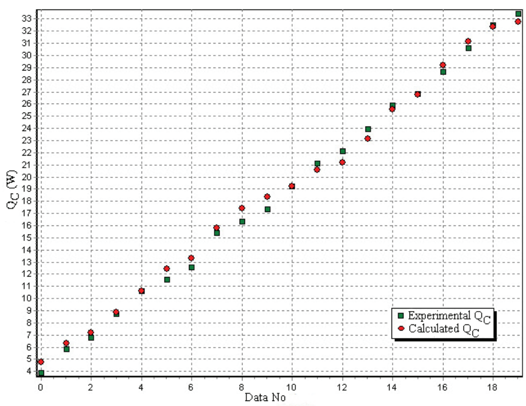

Fig. 5. Comparison of the experimental data with the results obtained using ANN Simulator program

After finishing the training of the network simulator which created by the simulator program, it is passed to the testing menu. With the help of this menu, the testing process of the trained network can be done and the results are revealed graphically. The 21 data points that experimentally obtained have been used in the testing process. The values of Q_C that obtained by result of the experimental studies and Q_C that produced by the ANN are seen in Fig. 5.

As seen clearly in this graphics, the results of the experimental and the results that produced by the network have revealed very close to each other. The values that not overlapped each other show that the memorization was not occurred and the training was successful.

Results comparison

In this study, a network created by the Matlab ANN and ANN training simulator programs which use data obtained from the experimental studies. These networks have been trained by using 7 data which obtained experimentally and then useful results have been taken. Both networks were implemented in the format of 3-10-5-1. The data that obtained from the network created by same data and structure of the network were compared graphically in Fig. 6. As a result, it was shown that the both networks carried out a good result and could generate results close to the experimental results. The dynamic output parameters of the TE modules are possible to obtain by using one of the MATLAB ANN or the ANN training simulator programs.

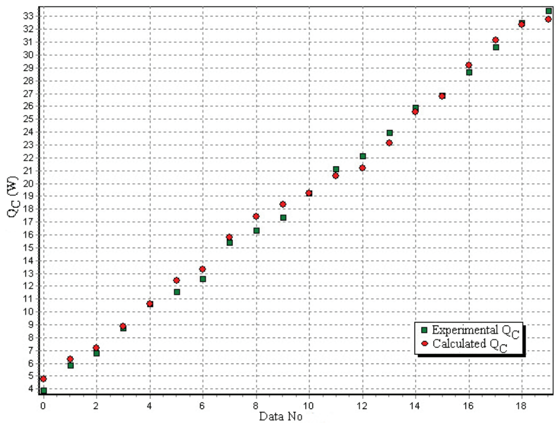

Fig. 6. Comparison of the experimental data with the results obtained using ANN Simulator program and MATLAB ANN tools

Conclusion

Thanks to the developed test systems, dynamic output parameters of any TE modules can be determined experimentally. Nevertheless, in order to determine the reaction of the module in any thermal condition, it is necessary to perform many experiments. This process will be taken very long time, the modeling of the ANN model with the help of The MATLAB-ANN and simulator program has been become easier. In this study, instant dynamic output parameters of thermoelectric module have been estimated by using the ANN model which trained with the data that obtained from the experimental studies.

The instant dynamic output parameters of thermoelectric module which is working within a system, the structure of the ANN that trained with LM can be used as a good controller and given a good result in very high speed and performance was determined. This situation was shown the validity of the selected methods as well. The values obtained from the ANN and obtained from the experimental studies were very close to each other, putting forward by the graphics. The results obtained from the ANN by placing microcontroller program which controls the TE module can be provided to take precautions against possible situations. So that, the protection of module and the adaptation of system to new conditions, can be provided.

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Received 2011 03 04
Accepted after revision 2011 04 07

B. Ciylan. Determination of Output Parameters of a Thermoelectric Module using Artificial Neural Networks // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 10(116). – P. 63–66.

Determination of instant dynamic output parameters of thermoelectric module which is worked in any system is very important. Despite of the new methods this process takes a lot of times. In this study, two artificial neural network (ANN) models are designed for the estimation of dynamic output parameters at any desired moment of the thermoelectric modules. MATLAB-ANN tools and an ANN simulator program are used for creating the models. Experimental dynamic output parameters data which obtained from eight different thermal load conditions were used for training the ANN Models. On the designed ANN models which were created to estimate instant dynamic output parameters of the thermoelectric module, the Levenberg-Marquardt (LM) learning algorithm has been used. The results obtained with these ANN models, compared with the experimental data and it was shown in graphs. Ill. 6, bibl. 20, tabl. 1 (in English; abstracts in English and Lithuanian).

B. Ciylan. Termoelektrinio modulio išėjimo parametrų nustatymas taikant dirbtinius neuroninius tinklus // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 10(116). – P. 63–66.

Svarbu gebėti nustatyti momentinius nuolat kintančius bet kokioje sistemoje veikiančio termoelektrinio modulio išėjimo parametrus. Naujų metodų taikymas neužtikrina laiko sąnaudų mažėjimo. Parametrams nustatyti pasiūlyti du nauji metodai, taikant dirbtinius neuroninius tinklus. Modeliai sudaryti taikant programų paketą MATLAB-ANN ir ANN imitatorių. Modeliuose pritaikytas Levenbergo ir Marquardto algoritmas. Gauti rezultatai buvo palyginti su ekspermentiniais rezultatais. Il. 6, bibl. 20, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).