2nd INTERNATIONAL CONFERENCE on
ENERGY RESEARCH
11-13 April 2019, Marmaris / Turkey

# Konut Tipi Şebeke Bağlantılı Fotovoltaik Sistemde Adaptif Nöro Bulanık Arayüz Sistemi Tabanlı Enerji Yönetimi Uygulaması

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## Özet

Talep tarafı yönetiminin enerji piyasalarında aktif kullanımı ile ülke genelindeki elektrik şebekesi üzerindeki yükü azaltmak ve şebekenin kesintilerinden kaçınmak mümkündür.İsteğe bağlı hassasiyet analizi, elektrik güç sistemlerinin doğru çalışmasını sağlar.Ancak, yalnızca talep tarafındaki düzenlemeler bir çözüm için yeterli değildir; arz tarafının çevre ile daha sürdürülebilir ve daha uyumlu bir enerji arz-talep dengesi oluşturmak için geliştirilmesi gerekmektedir. Bunun nedeni gelecekteki güneş ve rüzgar enerjisi teknolojilerinin ve diğer yenilenebilir enerji türlerinin fosil yakıt bazlı üretim ile birlikte yer almasıdır. Böylece, akıllı şebekeden yararlanılarak güç dağıtımı geliştirilebilir. Bu çalışmada, Adabtif Nöro-Bulanık Çıkarım Sistemine (ANFIS) dayanan yeni bir enerji yönetimi yöntemi önerilmiştir. Önerilen model için öncelikle talebi etkileyen faktörler belirlenir ve verilen modelin veri tabanı oluşturulur. Sistem, prototip bir şebekeye bağlı fotovoltaik sistemde uygulandı ve üretilen güç gün boyunca ölçüldü ve tasarruf edildi. Yöntemde müşteri talep gücü ve elektrik fiyatları da kullanılmış ve sunulan yöntemin geçerliliği test edilmiştir. Bir kış günü verileriyle birlikte bir yaz günü verileri alınmış ve sistemde belirli bir zamanda yüklerle tüketilmesine izin verilebilecek referans güç yüzdesi elde edilmiştir. Elde edilen sonuçlar, doğruluk ve verimin, bu araştırma alanında kullanılan geleneksel yöntemlerle karşılaştırıldığında arttığını göstermektedir.

**Anahtar kelimeler:** Adabtif Nöro-Bulanık Çıkarım Sistemi, Talep tarafı yönetimi, Enerji yönetimi, Akıllı şebeke

# Adaptive Neuro-Fuzzy Interface System-based Energy Management Application for a Residential Photovoltaic On-Grid System

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## Abstract

With the active use of demand-side management in energy markets, it is possible to reduce the load on the electricity network around the country and avoid the interruptions of the mains. On-demand sensitivity analysis ensures that electrical power systems operate properly. However, the regulations only on the demand side are not sufficient for a solution; the supply side needs to be developed to create a more sustainable and more harmonious energy supply-demand balance with the environment. This is because the future solar and wind energy technologies and other renewable energy types take its place along with fossil fuel-based production. Thus, delivery of power can be improved by taking advantage of the smart grid. In this study, a new energy management method is proposed based on Adaptive Neuro-Fuzzy Inference System (ANFIS). For the proposed model, firstly the factors affecting the demand are determined and the database of the given model is established. The system has been implemented on a prototype grid-connected photovoltaic system and generated power was measured and saved throughout the day. Costumer demand power and electricity prices are also employed in the method and validity of the introduced method was tested. A summer day data, along with a winter day data, were taken and the percentage of reference power that can be allowed to consume by loads at a given time in the system was obtained. The obtained results show that the accuracy and the efficiency are improved compared to conventional methods that have been used in this research field.

**Keywords:** Adaptive Neuro-Fuzzy Inference System, Demand side management, Energy management, Smart grid

## Introduction

The increase in energy prices, global warming, and climate change, increase in population and living standards, increase in energy demand in line with developments in industry and technology, the dependence on rapidly depleting fossil fuels which will continue in the near future, foreign dependency and security of supply, and developments in new energy technologies are leading countries to new quests. These concerns suggest the need for using renewable energy sources at a higher rate for electricity generation. With the spread of distributed production from renewable energy sources, a reduction in the use of fossil fuels and a transformation of the electric system to reduce costs and pollution is expected.

With the evolution of concepts of microgrid and smartgrid, the traditional power system is advancing to a new era. Smart grid offers the possibility of control, communications, and monitoring in the power system. Integration using a suitable converter defines the connection of heterogeneous types of energy sources with AC or DC supply. As the power output of distributed renewable energy sources is dependent on climatic conditions, energy management systems become crucial. For the effective operation of the smart grid, it is also necessary to disperse generation and storage communication between the various control nodes. With this system, the consumer can have the opportunity to play a role in the optimization of the electrical system. However, in order to have the opportunity to purchase electricity, consumers must have more dynamic pricing automation. As a result, users can manage their consumption habits according to the price signals of the smart grid (Giordano and Fulli, 2012).

Several classical or statistical techniques have been carried out in literature but this interesting field still needs further research to improve the accuracy in a satisfactory manner. A literature search of studies on the Adaptive Neuro-Fuzzy Inference System (ANFIS) based algorithms and demand-side energy management variants show that a range of methods on this topic has been proposed in recent years. ANFIS has been widely used in many fields of engineering. Ekici and Aksoy have proposed an algorithm to forecast building energy consumption in a cold region adopting an ANFIS model (Ekici and Aksoy, 2011). The objective of their study was to study the feasibility and applicability of ANFIS in load forecasting for the energy of a building. The authors observed that ANFIS is an effective tool with an energy prediction of 96.5 and 83.8% for heating and cooling, respectively, in the pre-design stage of energy efficient buildings for choosing the best combinations. In a study by Bogaraj and Kanakaraj proposed an energy management method for a hybrid renewable energy system supplying AC loads using ANFIS (Bogaraj and Kanakaraj, 2016). The developed algorithm is designed to increase the power transfer capability between the source side and load side. From the analysis made by using different environmental and load test conditions, the method confirmed that control method is effective in prediction of energy required for the next instant and manages the energy flow among hybrid power sources and energy storage devices.

Sarduy *et al.* proposed linear and non-linear methods for prediction of peak load at the University of São Paulo. The obtained results confirm that the predicted and real peak load for all developed models agree well (Sarduy et. al., 2016). However, the accuracy was better for nonlinear models, especially for Adaptive Neural Networks Inference Systems. Pérez-Romero *et al.* presented a local energy management system to optimize energy consumption of a home by absorbing or delivering energy to energy storage system according to the residential consumption (Perez-Romero et. al., 2013). It utilizes different types of communication to help them to adopt efficient energy behavior in a prototype system. Ozturk *et al.* proposed a personalized home energy management system for residential demand response (Öztürk et. al., 2013). The Master Energy Controller implements a branch and bound scheduling algorithm for managing appliance runtime schedules. For a personalized home energy management system, the described Master Energy Controller in the paper provides a user-friendly, inexpensive, and easy to install/maintain architecture for both customer and utility provider.

Most of these studies use assumed consumption values and some of them use simulated power generation values in their studies. In order to improve the viability of the proposed algorithm, this study uses the actual values of generation and consumption. In this paper, an energy management algorithm has been realized by reducing the peak load by obtaining an output according to three inputs using ANFIS, according to a certain calculation of the actual consumption data of a house belonging to the PECAN STREET data which is focused on advancing university research and accelerating innovation in water and the electricity energy generation obtained from an on-grid PV system and electricity prices obtained from electricity market (Anonymous, 2016). The paper is organized as follows. Following the introduction section, Section 2 describes the material and method used in this work. Here, PV modules, on-grid inverter, and energy analyser are briefly explained. This section also addresses the ANFIS-based energy management application. Application of the proposed method and results are given in Section 3 and the final conclusions are addressed in Section 4.

## Material and Method

### A. Photovoltaic modules

Solar energy systems provide many benefits to the environment in today's world. Energy from solar photovoltaic is used to convert solar energy into electrical energy by means of the unit referred to as a solar cell. The DC power is converted to AC power to be used in residential and commercial buildings (Giordano and Fulli, 2012). Peak power of each PV module used in this study is 250Wp. Five modules were connected in series to obtain bus voltage for the DC input of the inverter and 1250Wp power was obtained (Bakır and Kulaksız, 2016).

### B. Grid-connected Inverter

Grid-connected photovoltaic systems can meet some or all of the electricity demand in the housing. In the system, the excess energy can be sold to the grid. Inverter, converting the DC voltage into AC voltage is a device that can operate fully compatible with the network (Giordano and Fulli, 2012). The advantages of the grid-connected system are as follows; ease of installation, high efficiency, reliability, flexible/modular scalable structure. The model of the grid-connected inverter used in this study is Fronius Galvo 1.5. Schematic diagram of the grid-connected PV system architecture employed in this study is shown in Fig. 1. The on-grid PV power system was considered in evaluating the proposed algorithm (Bakır and Kulaksız, 2016).

### C. Energy analyzer

In the system, energy analyzer is used to measure the electrical parameters of the plant. The device used is ENTES Power and Energy Meter. The device can measure three-phase active, reactive and apparent power values in the power system (Bakır and Kulaksız, 2016).

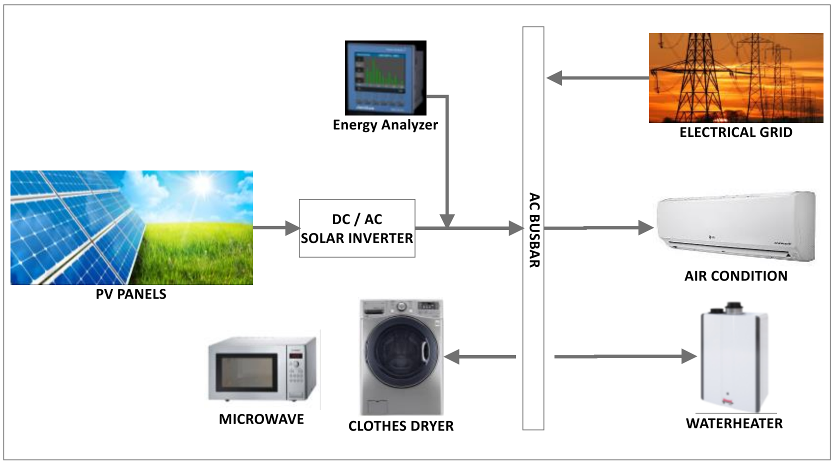



Fig. 1. Grid-connected PV System diagram

**D. Adaptive Neuro-Fuzzy Inference System**

One of the most important research topics of the smart grid is energy management applications. In particular, energy management techniques such as load-side management and the demand-side response is common (Shao et. al., 2011). Users and electricity companies deploy some of the benefits provided by this energy management applications. The energy management method presented in this study is based on ANFIS. On the basis of the ANFIS method, Fuzzy inference systems have Takagi-Sugeno-Kang fuzzy inference system.

Jang developed the ANFIS method and system is used in the modeling of nonlinear functions, in estimating nonlinear components in the control system and in estimating chaotic time series (Jang, 1993). ANFIS model is shown in Fig. 2.

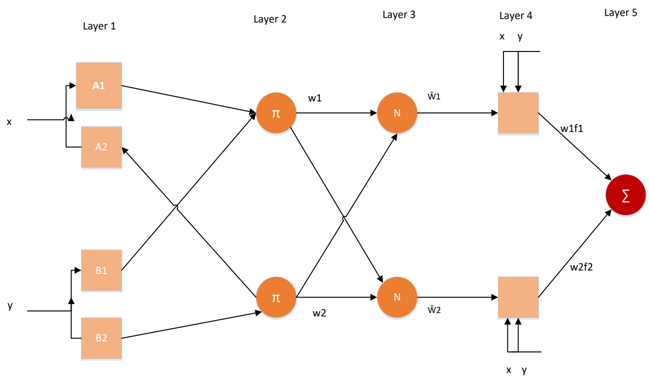



Fig. 2 . ANFIS model for two input-one output

In this model, the values of A1 and B1 are used in the first layer to express verbal variables. The values of A1 and B1 are derived from the layer by taking a membership grade through a membership function. On the 2nd layer, the inputs are multiplied and removed from a node. In the third layer, the ignition power values are normalized to the total ignition power values. After the fourth layer, the Takagi-Sugeno-Kang model is operated (Şen, 2017).

The definition of each layer are given below (Ekici and Aksoy, 2011).

Layer 1: A membership function $\mu(x)$ is chosen to be a member of determined verbal variables. A and B are the linguistic labels, $\mu_{Ai}(x)$ and $\mu_{Bi}(x)$ are the membership function outputs obtained from these nodes.

$$P_i = \mu_{Ai}(x), P_{i+1} = \mu_{Bi}(x) , \qquad (1)$$

Layer 2: The firing strength of each rule is calculated by this formula.

$$w_i = P_i = \mu_{Ai}(x) * \mu_{Bi}(x) , \qquad (2)$$

Layer 3: The $i^{th}$ node calculates the ratio of the $i^{th}$ rule's firing strength to all rules firing strength.

$$w'_i = \frac{wi}{w1+w2} , \qquad (3)$$

Layer 4: Where $f_1$ and $f_2$ are the fuzzy if-then rules as follows the outputs written as given in this formula.

$$P_i = w'_i * f_i \quad , \qquad (4)$$

Layer 5: This node computes the overall output of ANFIS as the summation of all incoming signals from the $4^{th}$ layer.

$$P_i = \sum_0^n w'i * f_i = \sum i w_i f_i / \sum i w_i , \qquad (5)$$

## Research Findings and Discussion

In this study, for the operation of electrical appliances at home, the ANFIS method was used to determine total reference power in percent to be consumed by appliances for the next instant depending on the consumer demand for any given time. This is done to reduce present load demand by enabling each consumer to employ their own strategy by delaying flexible loads (Bakır and Kulaksız, 2016). The input variables introduced for the ANFIS control, shown in Fig. 3, are explained below:

PV power generation: The system has been implemented on a 1.25 kWp grid-connected photovoltaic system and generated power was measured and saved throughout the day.

Costumer demand power: Daily consumption data for specific loads from PECAN STREET dataport have been taken to evaluate the algorithm using real data.

Electricity price: Retail Electricity Tariffs Table in Turkey in 2017 have been used. Three-time residential electricity tariff was considered here (Anonymous, 2017). Figures 4 and 5 show the daily consumption data for certain flexible loads from the PECAN STREET dataport.

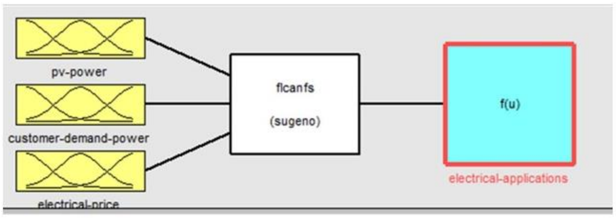
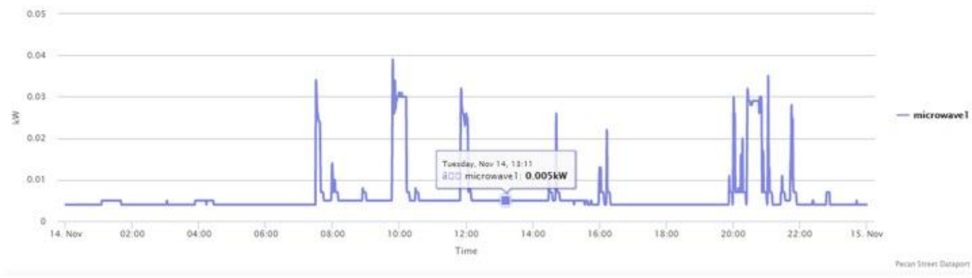



Fig. 3. Three input-one output ANFIS structure of the system design

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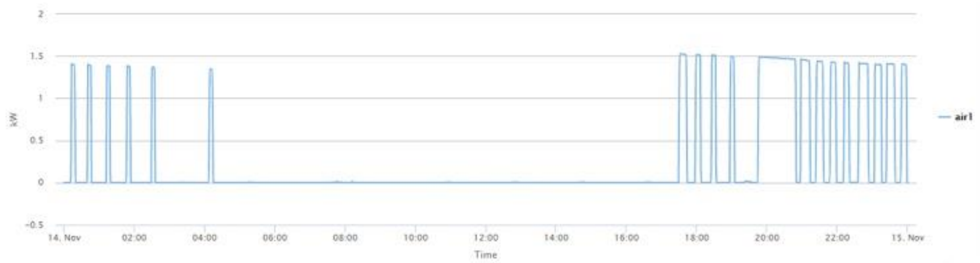


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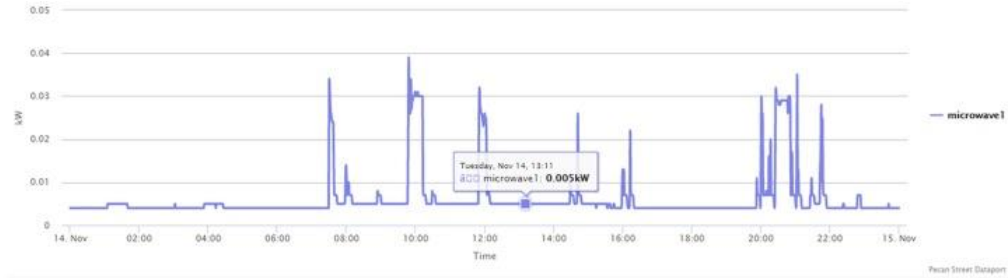


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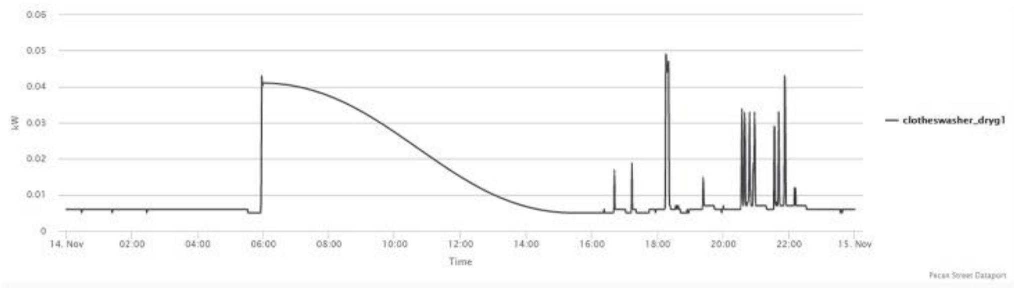
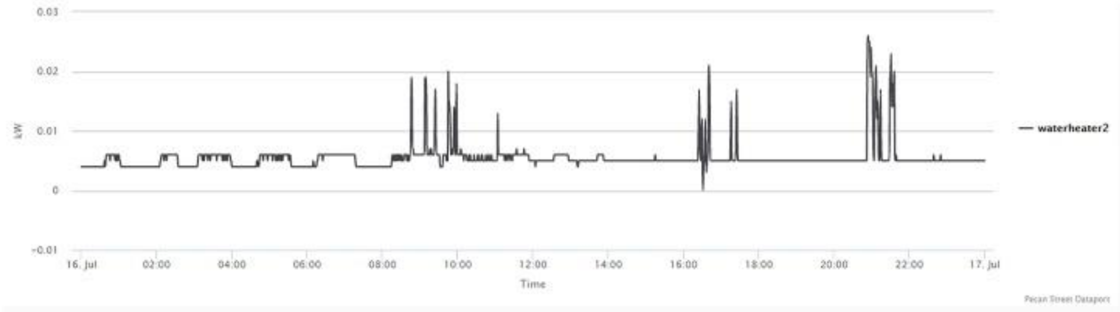



(d)

Fig. 4. The consumption values on 14.11.2017 (a) daily consumption dataport for waterheater, (b) for airconditoner, (c) for microwave, (d) for clotheswasher_drying

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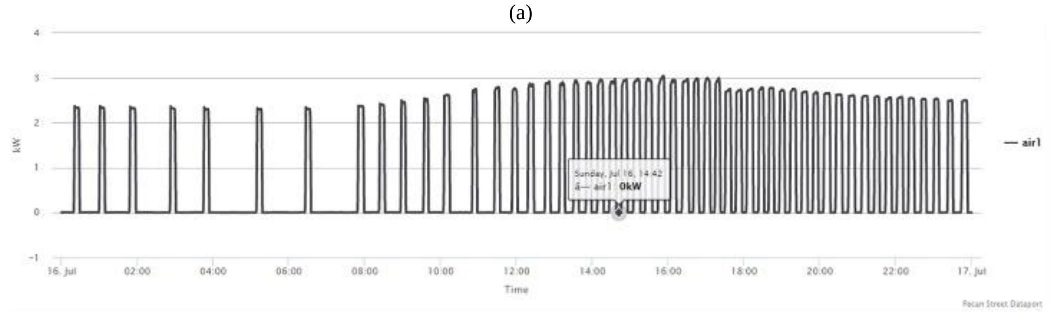


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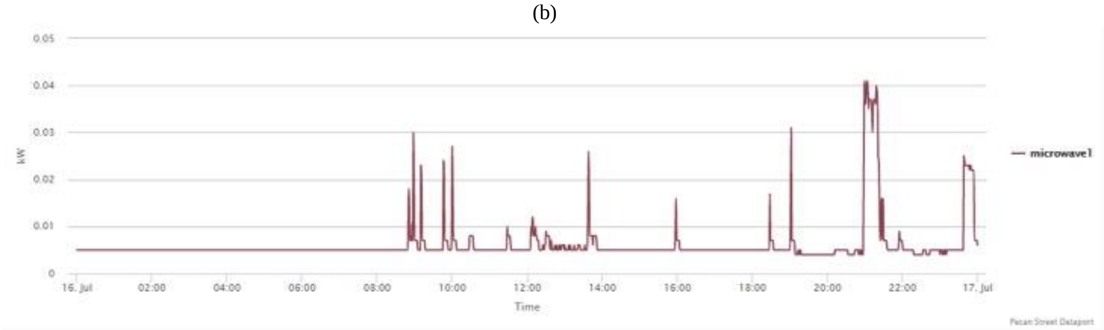



(c)


(d)

Fig. 5- The consumption values on 16.07.2017 (a) daily consumption dataport for waterheater, (b) for airconditoner, (c) for microwave, (d) for clotheswasher_drying

The fuzzy rules are the sets of "If" and "then" statements. The three input parameters are fuzzified as per the membership function of the respective variable. These, in addition to the membership function curves, are utilized to obtain a solution (Hatagar and Halase, 2015). This value is important to assign priorities to each load in a home and delay times can be determined for each of them (Bakır and Kulaksız, 2016).

ANFIS output produces a result that can be measured. This is called the defuzzification. This unit interprets the degree of membership of the real valuable input. The centroid method was used for defuzzification to get a scalar output value (Hatagar and Halase, 2015). The method was tested on a sunny day. The profiles of PV power, customer demand power of the current time, and electrical price, which are the inputs of ANFIS and percent power of electrical appliances, which is the output of ANFIS, respectively, are shown in Figs. 6-7 for a day in winter and in summer, respectively. For the day in winter (Fig. 6), the percentage of electricity power output is lower because the energy generated from the PV system is less. Consequently, the output percentage for electrical applications is %75, all loads cannot be switched on, and one or two loads will be switched on at the subsequent phase depending on the new results. For the day in summer (Fig. 7), the percentage of electric power is higher because the energy generated from the PV system is larger and the algorithm encourages the consumption. Consequently, the output percentage for electrical applications is %100 and all of the loads can be switched on.

Based on the results, the output responds accordingly depending on the input values. For example, from the results, it can be reflected that in the early morning the percentage power was at the maximum level. This can be justified as the PV power production is high at that time. In the late afternoon, the result of reference power gets the smallest value as electricity price is high, PV power is low and customer demand power is high. Thus, by identifying the reference power, flexible loads are either connected as demanded by the consumer or they were disconnected. It can be concluded that the method can be employed to reduce peak loads, use the PV generation more efficiently and reduce the cost of electric invoice of the consumer.

## Results and Suggestions

In this paper, a new energy management system was proposed and it was confirmed that by the inclusion and exclusion of flexible loads demanded by the consumer, it can possible to achieve a reduction in cost and the peak load for the consumer can be decreased. The electrical power generated by PV modules, customer demand power, and electrical price were used as input variables in ANFIS and the results proved that the method can be employed to spread the peak load throughout the day as high customer demand inhibits the output in ANFIS. Electricity price was another factor inhibiting ANFIS-output when the price is high. ANFIS also encouraged operating the electrical appliances when PV generation is high. A summer and winter day data were taken and the percentage of output power in the system was compared as a reference value. For summer day in the system, it was seen that there is a higher percentage of electric power and the delay in the operation of loads is less because the power generated from the PV system is larger. For a winter day, the percentage of electric power output is lower and the delay to the more economic price time occurs more because the power generated from the PV system is smaller.

The adoption of ANFIS method in this study was that it required less time to prepare the model than conventional methods. Because this method does not require the definition of the relation between the data, a function should be established. They learn by themselves through the relevant training dataset between the data. As a result, within the scope of this study, a solution to the demand estimation problem was searched with ANFIS methods.

As a future study, priorities will be assigned to each load in a home and the results of this study will be used to determine delay times for each of them. The results of our system will be tested in a test bed having based communication network and more experiments will be carried out.

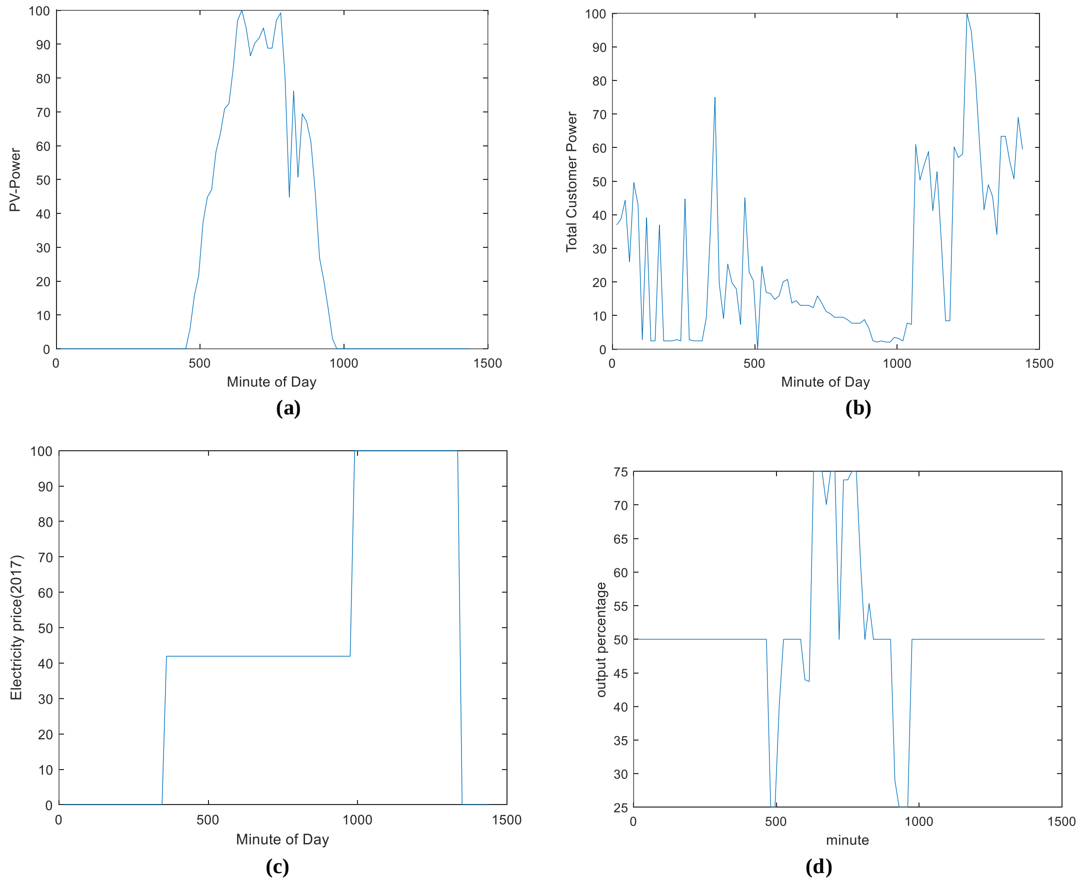
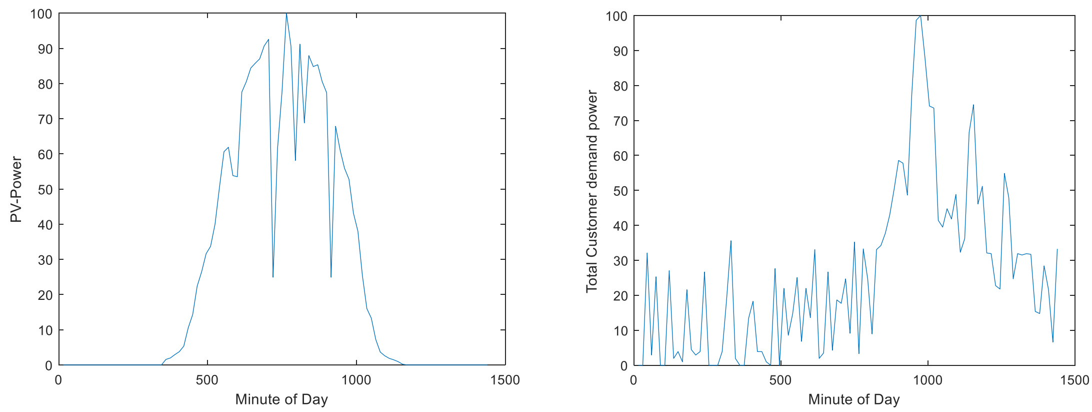
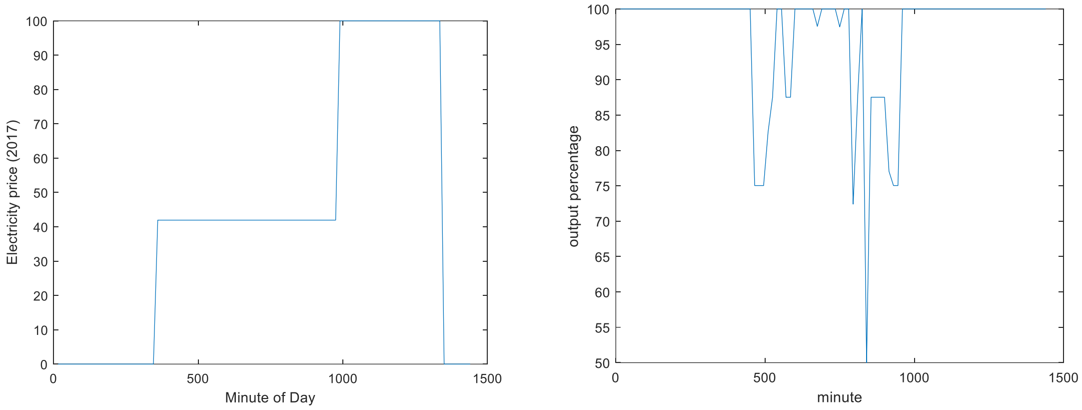



Fig. 6. For 14.11.2017 (a) Profile of power produced by the PV panel (b) Profile of total customer demand power for water heater, for airconditioner, for microwave, for clotheswasher_drying (c) Electricity price 2017 in Turkey (d) Profile of percent power of electrical appliances during per 15 sec for water heater, for airconditioner, for microwave, for clotheswasher_drying




(a) (b)




(c) (d)

Fig. 7. For 16.07.2107 (a) Profile of power produced by the PV panel (b) Profile of total customer demand power for water heater, for airconditioner, for microwave, for clotheswasher_drying (c) Electricity price 2017 in Turkey (d) Profile of percent power of electrical appliances during per 15 sec for water heater, for airconditioner, for microwave, for clotheswasher_drying

**Acknowledgment:** Authors would like to thank Pecan Street Project Inc. (http://www.pecanstreet.org) for allowing us to access electrical usage database.

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