International Journal of Energy Applications and Technologies
Available online at http://dergipark.gov.tr/ijeat/issue/31601
Research Article
Vol. 4 Issue 4 pp. 152-163 Year 2017

SOLAR PV SYSTEM COST ANALYSIS FOR A SMART HOME

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Abstract

Solar energy is the technology that finds the greatest development and application area among the renewable energy technologies. There has been a significant increase in the use of solar energy in recent years due to the decrease in the prices of solar photovoltaic(PV) panels. Various financial incentives, including tax and production incentives are given to ensure widespread use in many countries. Solar PV systems can be used either alone or depending on the electrical grid. In this study, information about the components that should be used in the solar PV systems in smart homes are given and economic analyses are made.

Key words: *Cost analysis, solar PV system, smart home*

Paper submitted: August 3, 2017
Paper accepted: December 27, 2017

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International Journal of Energy Applications and Technologies, Year 2017, Vol. 4, No. 4, pp. 152-163

1. Introduction

Population growth and industrialization increase the electrical energy demands. On the other hand, fossil fuel reserves, which provide much of the world's energy needs, are rapidly declining. The use of fossil fuels causes harmful effects such as global climate change and ecological balance deterioration. For this reason, many countries have turned their energy production investments into renewable energy sources, such as solar, wind, water, geothermal and biomass energy. Also, the efforts are being made to use existing energy resources more efficiently [1, 2].

It is predicted that the world's electricity needs will increase by 1.4% per annum between 2007 and 2035, and by 49% in total. European Union (EU) countries, which have an important share in world energy market, are the first in energy import and second in energy consumption. In Turkey, it is estimated that annual electricity demand will increase by 4.5-6.7%. Turkey is the country with the fastest increase in energy demand among Organization for Economic Co-operation and Development (OECD) countries [3, 4].

EU countries provide various financial incentives, including tax and production incentives to ensure widespread use of renewable energy sources. The EU aims to increase the share of renewable energy in the energy sector to 20% in 2020 and to 50% in 2040. The increase of energy efficiency and reduction of greenhouse gas emissions are also among Turkey's 2023 targets. In Turkey, the "Law on the Use of Renewable Energy Sources for Electricity Generation Purposes" provides a base price guarantee and a certain period purchase guarantee for energy produced from renewable energy sources. In addition, renewable energy power plants with a certain capacity can operate without any production license [5, 6].

2. Solar PV Systems

Solar energy has been used in different forms for centuries. Solar energy has many advantages and disadvantages compared to other energy types [2, 7]. Advantages can be listed as follows;

- ✓ Solar energy is an abundant and inexhaustible source of energy.
- ✓ Solar energy is a clean energy source and the environment is free of pollutant wastes.
- ✓ It is possible to use solar energy wherever energy is needed.
- ✓ There is no external dependence. It is far from the economic crises that may occur.
- ✓ The technology used is not complicated and therefore operating expenses are very low.

In addition to the advantages mentioned above, solar energy also has many disadvantages compared to other energy types. These disadvantages can be listed as follows;

- ✓ Large surfaces are needed because the radiation to the unit surface is low.
- ✓ Storage is required as storage is not continuous. Storage possibilities are limited.
- ✓ In the winter months when there is a lot of energy demand, solar radiation is low.
- ✓ In order for the system to be able to receive the sun's rays continuously, the environment of the system should be clear and not shadowed.
- ✓ Many systems utilizing solar energy have high initial investment costs.

Figure 1 shows the potential to benefit from solar energy in European countries. Turkey’s solar potential is more than all European countries, except Spain. But Turkey is under the European average in terms of solar energy applications. As shown in figure 2 and figure 3, Turkey's average annual total sunshine duration is 2640 hours (total of 7.2 hours per day) and the average total solar radiation is 1.311 kWh/m²-year (total daily 3.6 kWh/m²) [8, 9, 10].

The solar cells are connected serially in solar PV panel. An object, a tree duck or a bird-dropping event that prevents sunlight from sticking to the cell is called shading. If the power of a cell is reduced by the reason of shading, the power of the other cells will also decrease. In other words, there is no difference between shadowing a half of a cell in a panel and half of the whole panel. Pollution also causes shading and loss of 3%. In order to catch maximum solar radiation, solar panels must be placed at the latitude of the place where they are located. Solar PV systems can be applied in two different ways in terms of

International Journal of Energy Applications and Technologies, Year 2017, Vol. 4, No. 4, pp. 152-163

output voltage: on-grid and off-grid. The position of the solar PV panel can also be designed as fixed and mobile systems. Studies in the field of solar PV systems include; modeling and design of the system, constant hold on the tension to obtain maximum power from solar batteries, optimum solar PV panel angle and control of the used devices [12, 13, 14].

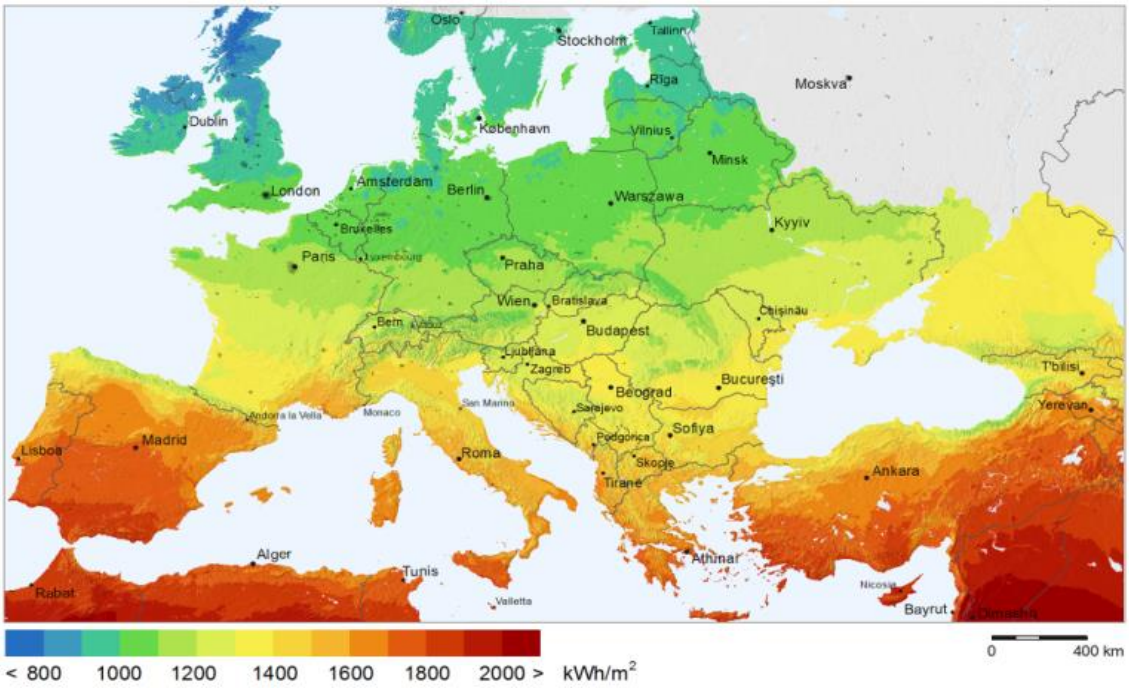

Fig. 1. Solar energy potential of European countries [11].

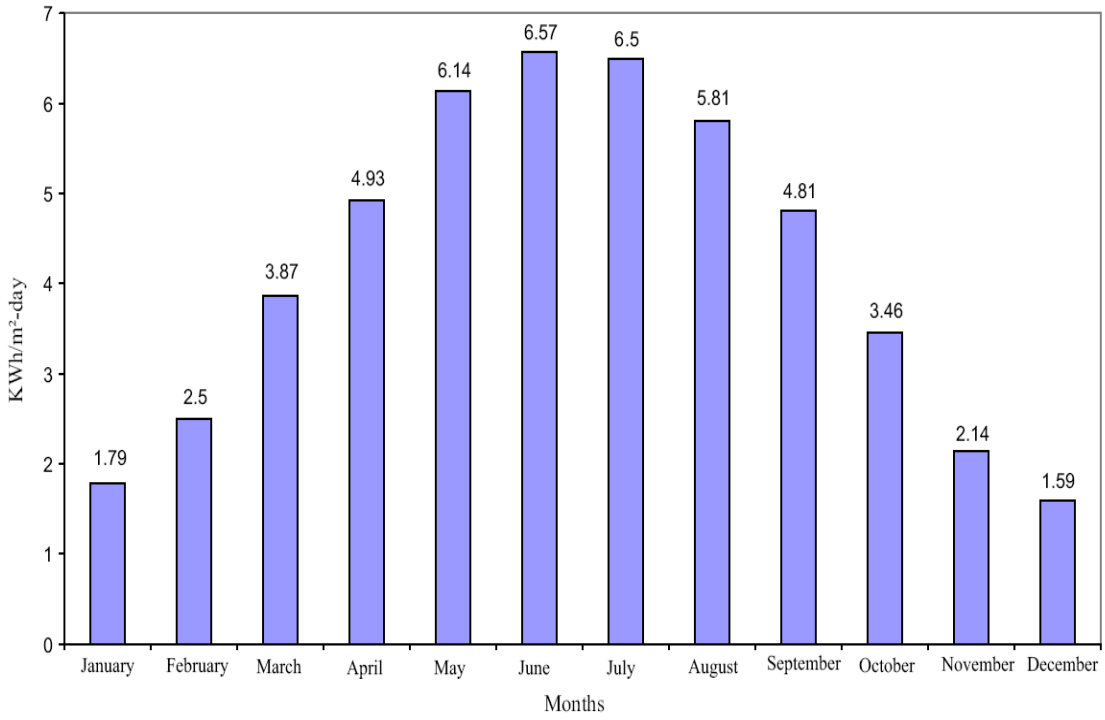

Fig. 2. Turkey's global radiation values [15].

2.1. Off-grid Solar PV System

They are the systems designed without any mains power connection. They usually provide electricity for lighting, railway, pedestrian crossing, water pumps, house lighting, yachts, small houses exposed to

sunlight and the like. Such systems include solar panels, batteries, charge regulators and inverters. Batteries come into play when the solar panels do not generate energy or the generated energy is inadequate [13].

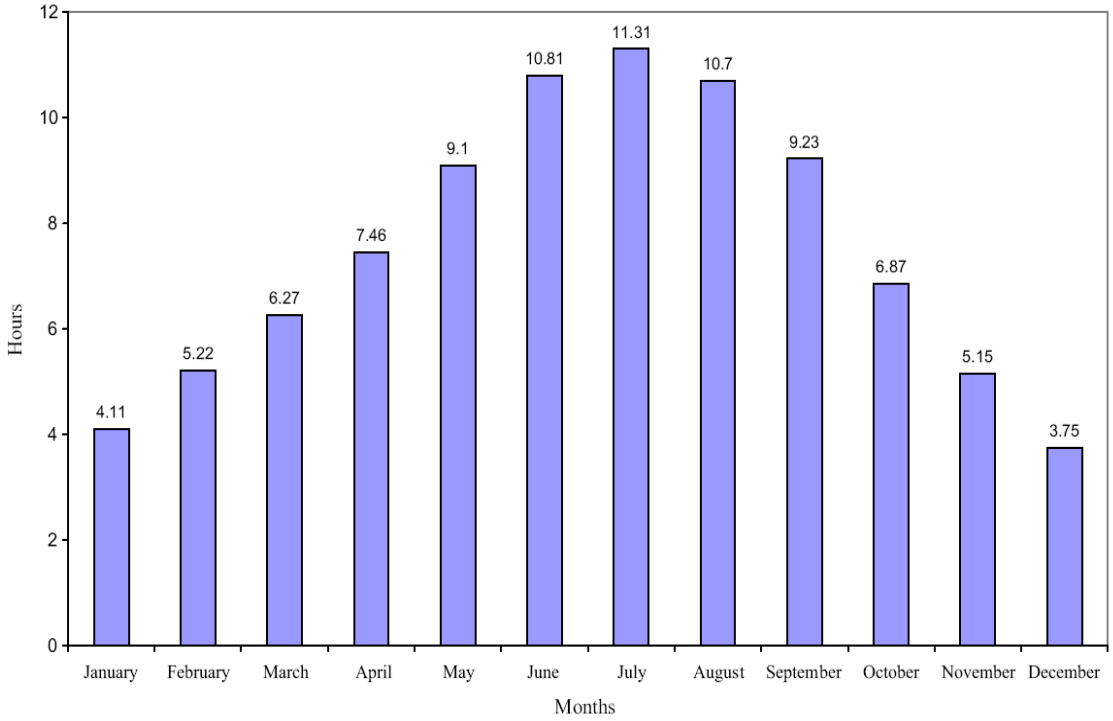

Fig. 3. Turkey's duration of sunshine [15].

Fig. 4. Off-grid residential solar PV system [16].

2.2. On-grid Solar PV System

In these systems the energy requirement is provided directly from the solar panels while the solar radiation is at a sufficient level. The energy required is provided by the grid at times when solar radiation

International Journal of Energy Applications and Technologies, Year 2017, Vol. 4, No. 4, pp. 152-163

diminishes or disappears. The excess energy produced in these systems can also be sold to the electricity grid. There is no need to store energy in the system. This system is compatible with the grid [13].

Fig. 5. On-grid residential solar PV system [17].

3. Off-grid and On-grid Solar PV System Components

3.1. On-grid Solar PV System

Solar cells are semiconductor materials that directly convert the sunlight that comes to their surface into electrical energy. When sunlight falls on them, electrical voltage is generated at the ends of solar cells. In order to increase the power output, a large number of solar cells are mounted on a surface in series. This structure is called solar cell module or solar panel. Depending on the power demand, the modules can be connected to each other in series or parallel, from several watts up to megawatts [18].

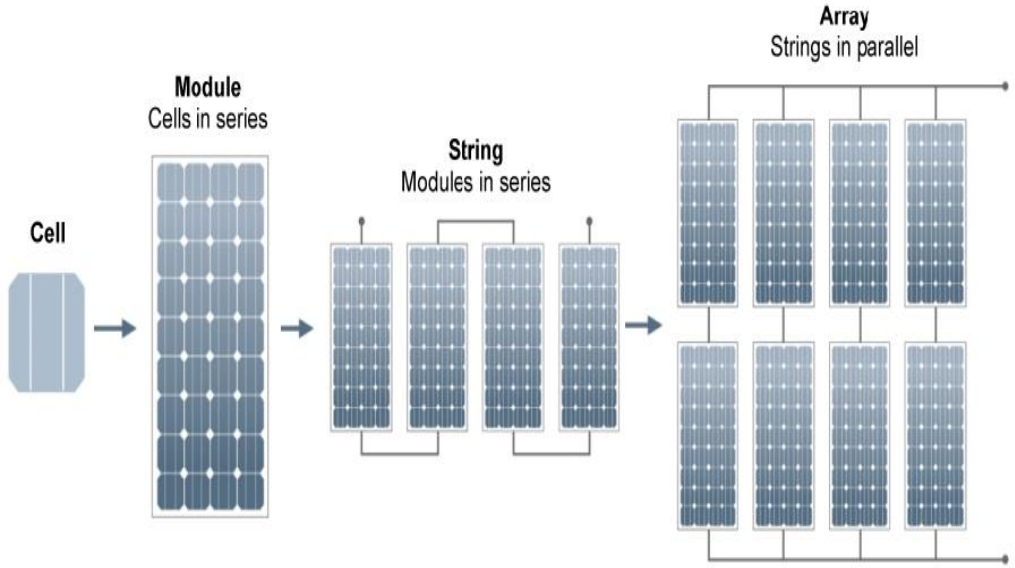

Fig. 6. From solar cell to solar array [19].

International Journal of Energy Applications and Technologies, Year 2017, Vol. 4, No. 4, pp. 152-163

Solar panels can be produced by using many different materials. Today the used semiconducting materials are; crystalline silicon, amorphous silicon, gallium arsenide, cadmium telluride and copper indium dieseline. The most common solar panels on the market is silicon. Solar panels are available in mono crystalline, polycrystalline and thin film technologies. They are durable, reliable and long lasting. Their efficiency is between 10-20 %. They do not cause electrical problems during work. As shown in Figure 7, a PV module's current versus voltage curve varies with the irradiance of sunlight The greatest threats to the solar panels are the lightning strike and weather conditions. The biggest disadvantage of solar panel system is the initial investment cost is high and the panels operate with low efficiency. One of the best aspects of these systems is that they do not have negative environmental impacts, such as other renewable energy sources (wind, biomass, hydraulics, geothermal) [20, 21, 22].

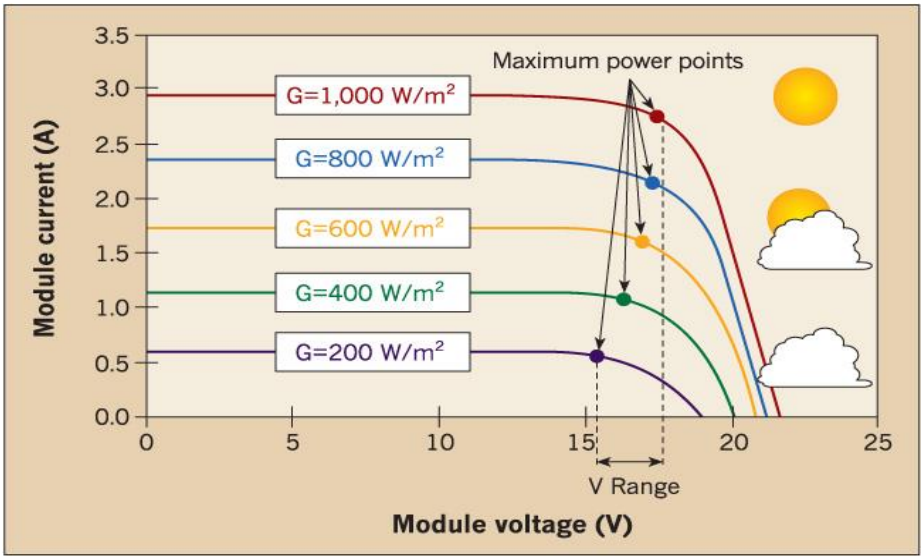

Fig. 7. A PV module's current versus voltage curve varies with the irradiance of sunlight [23].

3.2. Batteries

Batteries are the equipment used to store the electricity produced and then to use the electricity. Batteries used in solar PV systems are usually gel-type batteries. Gel-type batteries require no maintenance. The basic characteristics required in the batteries to be used in solar PV systems are [24];

- ✓ Resistant to high temperatures.
- ✓ The amount of self-discharge is the lowest.
- ✓ Easy to charge with low internal resistance.
- ✓ Durable polymer separator ensures high efficiency.

To be able to use effectively in applications where the energy input is not regular.

Fig. 8. Solar batteries [25].

3.3. Cables, Connectors and Combine Box

Unfortunately, in solar PV systems the choice of cable, connector and combination box is not considered very well. It is one of the main factors to pay attention to in the calculation of DC (direct current) systems, and the cost of damage is high if it is not observed. Selection of the products required in the solar PV system is not easy, but it is much higher than the connection products which are generally neglected and should not be neglected. At the cost of a system, the value of the cable, connector and combination box is limited to about 5%. When the wrong choice is made, it can be exposed to a fire hazard, causing material damage and more importantly it can harm human life [7].

International Journal of Energy Applications and Technologies, Year 2017, Vol. 4, No. 4, pp. 152-163

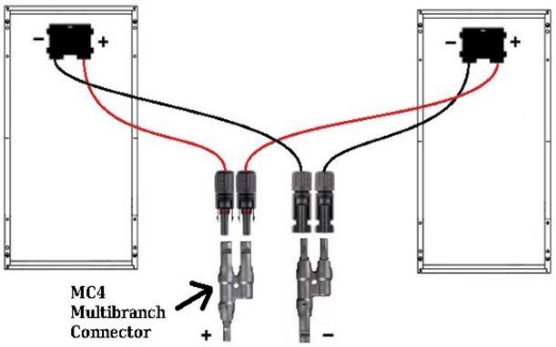

Fig. 9. Cable with connectors [26].

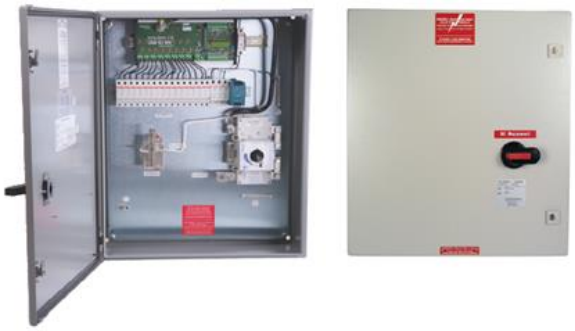

Fig. 10. Combine box [27].

3.4. Charge Control and Inverter

During the daytime when the solar radiation is insufficient or at night, the panel voltage falls below under the battery voltage. The main task of the charge control device is to prevent the current flowing from the battery to the panel array in the reverse direction. This device prevents the battery from being damaged by overfilling or draining. There are two types of charge controllers [24].

- ✓ Pulse Width Modulation (PWM) Charge Controller
- ✓ Maximum Power Point Tracker (MPPT) Charge Controller

Solar panels produce direct current(DC), whereas electrical appliances we use at home operate in alternating current(AC). Inverters are power electronic devices that used to convert direct current into alternating current. Solar panels are often designed to produce DC voltage between 12-24 volts. If a 220 V alternating voltage is required, this can be achieved with an inverter. With the use of the inverter, a significant power loss of up to 5-12% occurs. However, it allows for the use of alternating current appliances. On-grid and off-grid inverters which used in solar systems, differ from used in other applications inverters. This is because the voltage at the maximum power point tracking required for the operation of the system should be kept constant. Also, the off-grid inverters must be used with the charge control device [21, 22].

a) Off-grid inverter including charge controller **b)** Residential type on-grid inverter

Fig. 11. Off-grid and on-grid inverters [28, 29].

3.5. Construction

The solar PV panels should be installed in a good manner in the carrier construction. Panels and construction must be compatible. If nonconforming materials are used, galvanic corrosion may occur on the contact surfaces of the materials. The construction must be resistant to weather conditions (rain, low temperature and sunshine etc.) The construction must be made of stainless steel or abrasion resistant (galvanized or special painted) metal. Solar panels should allow for the thermal expansion of the construction. All parts of the construction must be grounded [30].

International Journal of Energy Applications and Technologies, Year 2017, Vol. 4, No. 4, pp. 152-163

Fig. 12. Constructions for solar PV panels [31].

3.6. Grounding

Fig. 13. Grounding for a solar PV system [32].

The grounding system can be defined as establishing a conductive connection between the touch points of the panels, devices and machines and the earth electrode. This ground electrode (grounding spar and grounding plate, etc.) is buried in the ground and an electrical connection is made with the ground. A good grounding protects people and electronic devices against leakage current. If all the elements of the carrier parts are separated from each other by insulating materials, these parts must be connected to each other by a conductor and then grounded. Otherwise, ungrounded components may reach voltage levels that may be dangerous. Grounding cables may be bare cable or may have a different color than power cables [30].

3.7. Bidirectional Meters

As shown in figure 14, the bidirectional meters are used in on-grid system. When the consumption is more than production, electricity is purchased from the grid. If the daily production is more than the consumption, the excess generated electricity can be sold to the grid. The bidirectional meter records the amount of electricity you bought from the grid, as well as to the amount that is sold to the grid.

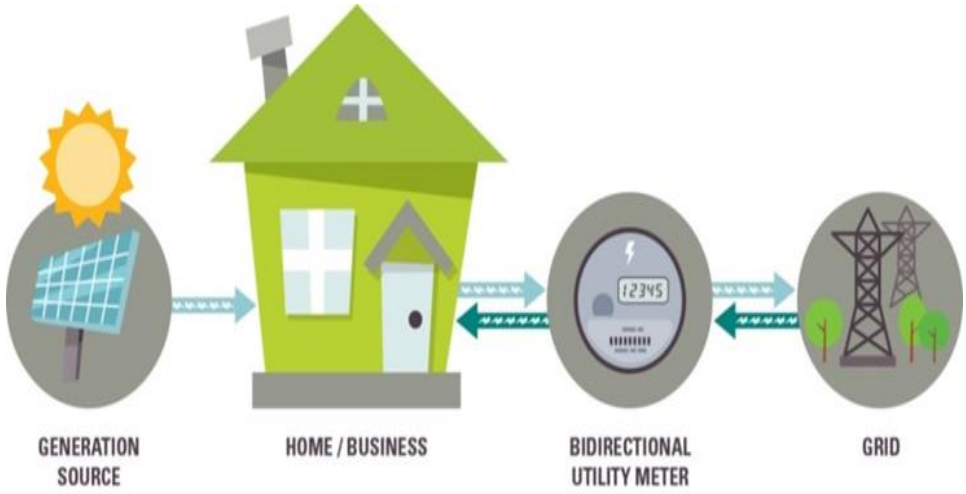

Fig. 14. The use of bidirectional meter [33].

International Journal of Energy Applications and Technologies, Year 2017, Vol. 4, No. 4, pp. 152-163

4. Smart Home Cost Analysis

Smart home text was first used in the United States in the early 1980s. The first application in Turkey was made in 1984. The first system is designed for monitoring only. In first application, a smart home for non-disabled people is considered. Later, it was designed and used for various purposes [34].

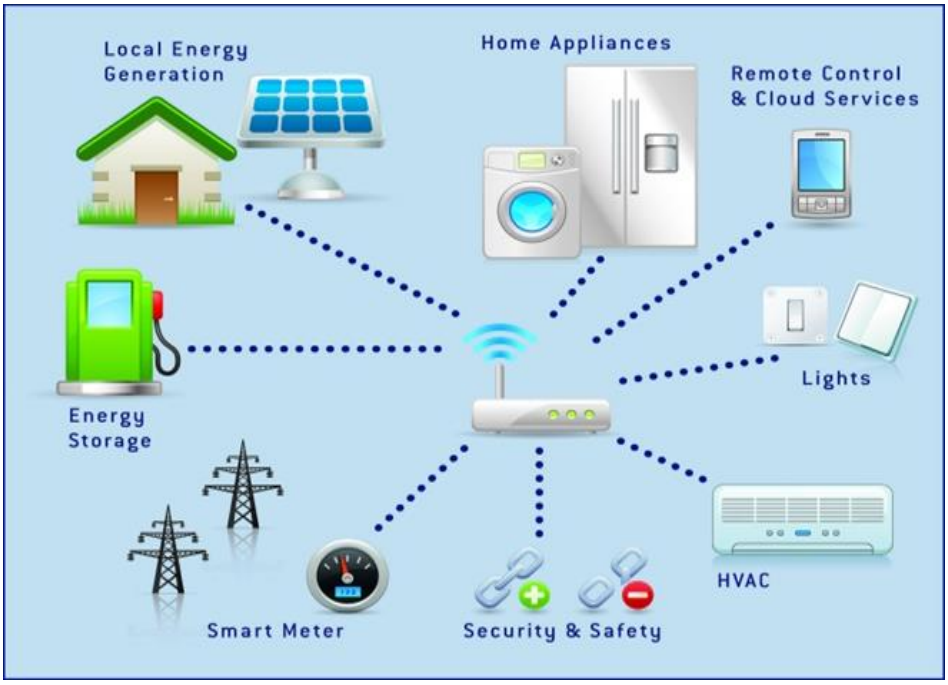

Fig. 15. A smart home automation system [35].

Smart home automation systems do not only provide comfort but also provide safety and energy savings. Electronic devices and systems, such as lighting, temperature, security, television, sound system, irrigation system, curtain control and garden/garage door control etc. are the smart home control system. These systems provide people with great convenience, especially for the disabled and the elderly people. Methods commonly used in smart home automation systems and usually designed with micro-controllers are telephone, internet, PLC, computer and X-10 technology [36, 37].

Table 1. Energy consumption for a normal and efficient home devices.

Monthly Energy Consumption		
Devices	**Normal (kWh)**	**Efficient (kWh)**
Dishwasher	21.8	13.6
Refrigerator	34.11	17.85
Washing machine	14.25	11.25
Oven	58	48
Television	9.33	4.75
Lighting	33.6	9.6
Vacuum cleaner	36	18
Iron	9.6	9.6
Paddle box	4.05	4.05
Computer	5.4	5.4
Blender	0.825	0.825
Kettle	2.2	2.2
Hair dryer	4.8	4.8
Total energy	233.965	149.925

Factors that increase normal home energy costs and cause unnecessary energy consumption include unnecessarily open lights, heating and cooling systems that operated at high levels etc. Devices with high energy efficient are used in smart home automation. These devices provide great energy savings. As seen in the Table 1, the monthly electricity consumption of a normal home placed in standard devices is 233.965 kWh. Monthly electricity consumption is calculated as 149.925 kWh in smart homes where energy efficient devices are used. It has been estimated that this reduces the monthly electricity cost by 36% [38].

International Journal of Energy Applications and Technologies, Year 2017, Vol. 4, No. 4, pp. 152-163

Table 2. Amount of the cost for a 2.5 kw off-grid system.

Components		Off-Grid System		
Name	**Feature**	**Num.**	**Price (TL)**	**Total (TL)**
Solar panel	250W Mono crystalline	12	550	6600
Battery	200 Ah-12 V	6	850	5100
Inverter with charge control	24/48 Volt-4000 Watt	1	2250	2250
Construction	Aluminium/Galvanized	1	650	650
Combine Box	Cable collection	1	220	220
Grounding	Underground plate	1	170	170
Solar cable	4-6 mm	50 m	2,2	125
Connector	Male-Female	8	4,5	40
Total (Excluding VAT)				**15155**

Table 3. Amount of the cost for a 2.5 kw on-grid system.

Components		Off-Grid System		
Name	**Feature**	**Num.**	**Price (TL)**	**Total (TL)**
Solar panel	250W Mono crystalline	12	550	6600
On-Grid inverter	3000W-2xMPPT	1	2000	2000
Bidirectional meter	Home type	1	1050	1050
Construction	Aluminium/Galvanized	1	650	650
Combine box	Cable collection	1	220	220
Grounding	Underground plate	1	170	170
Solar cable	4-6 mm	50 m	2,2	125
Connector	Male-Female	8	4,5	40
Total (Excluding VAT)				**10855**

Some parameters that affect the production of energy by the panels are overheating, dusting, transmission losses and inverter internal consumption. They cause about 12% loss in the amount of energy produced by the panels. Table 2 and Table 3 show amount of the cost for a 2.5 kW off-grid and on-grid system. The figure 16 shows the off-grid and on-grid solar PV systems annual earnings.

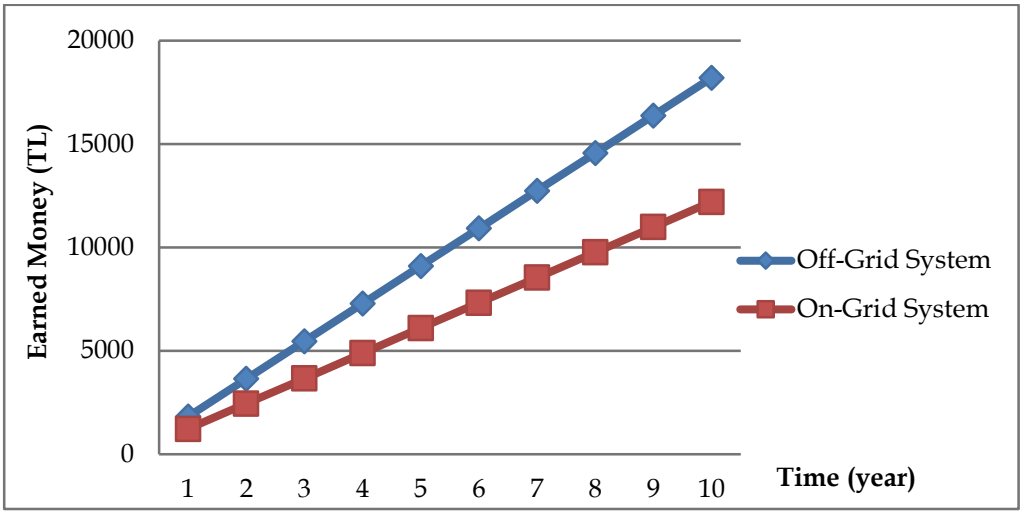

Fig. 16. Solar PV systems annual earnings chart.

5. Conclusions

In this study, the components that should be included in the on-grid and off-grid energy systems are presented and the initial setup cost for a smart home is created. Turkey's one-year general average of solar radiation data is used. The unit price of electricity from the grid is 0.13 $ / kWh based on the exchange rate of Turkish Lira to the US dollar in July 2017. The cost of installation was calculated by making a sample design. To meet all the electricity needs of a smart house with the solar PV system in

the current conditions, initial investment cost of between 11000 and 16000 TL is required. The repayment of this initial investment is between 8-10 years. The use of the solar panels lasts at least 20-25 years. After the initial investment expense, the electric energy will be used for free for years.

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