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Design of Stand-Alone PV System on a Farm House in Bilecik City, Turkey

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Abstract: In this study, the design of the components in the system was carried out in order to meet the energy of a stand-alone farm house in Bilecik city only by a photovoltaic (PV) system. Firstly, the loads to be used in the farm house have been determined and it has been calculated that the average energy consumption of the house is 5.58 kWh per day. It was determined that it would be appropriate to use OPzS batteries in the system in order not to have power outage even if there is no solar radiation for 4 days. Under these conditions, it was estimated that 28 batteries 2 OPzS 100 model and 12 V values would be needed in the system. Since the farm house is thought to be used during the whole year, PV panels are estimated to be located at the tilt angle of 40° on the roof, which is the latitude of the city. It has been calculated that 12 PV panels with Per Light 100 Wp PLM-100P/12 model should be used for the system. It has been proposed to use a central inverter system for the design and it is calculated that the inverter should be at least 6 kW power.

Keywords: Stand-alone PV system; battery; inverter; charge controller

Türkiye'de Bilecik İlinde Yer Alan Bir Çiftlik Evinin Şebekeden Bağımsız FV Sistem Tasarımı

Özet: Bu çalışmada, Bilecik ilinde şebekeden uzak bir çiftlik evinin enerjisinin tamamen fotovoltaik (FV) sistem ile karşılanması amacıyla sistemde bulunan bileşenlerin tasarımı gerçekleştirilmiştir. Öncelikle çiftlik evinde kullanılacak yükler belirlenmiş olup evin ortalama günlük 5.58 kWh enerji tükettiği hesaplanmıştır. Bu enerjinin karşılanıp 4 gün art arda güneş ışınımı olmasa dahi enerjinin kesintiye uğramaması amacıyla sistemde OPzS akülerinin kullanılmasının uygun olacağı belirlenmiştir. Bu koşullar altında sistemde 28 adet 12 V değerinde 2 OPzS 100 model akülere ihtiyaç duyulacağı hesaplanmıştır. Çiftlik evinin yıl boyunca kullanılması düşünüldüğünden FV panelleri çatıya ilin de enlem açısı olan 40^0 lik eğim açısında yerleştirilmesi öngörülmüştür. Sistem için Perlight marka 100 Wp PLM-100P/12 model FV panellinden 12 adet kullanılması gerektiği hesaplanmıştır. Tasarım için merkezi evirici sistem kullanılması önerilmiş olup eviricinin en az 6 kW gücünde olmasının uygun olacağı hesaplanmıştır.

Anahtar kelimeler: Şebekeden bağımsız FV sistem; akü; evirici; şarj kontrolörü

1. Introduction

There has been great increase in electrical energy demand due to the developments in technology and the industrialization. Much of the electrical energy is supplied by fossil fuels. However, the gases arising from the burning of the fossil fuels pollute the environment and cause global warming. Moreover, the alternative energy sources are considered as the most convenient solution when taking into account that the fossil fuels will run out in the near future. Among the alternative energy sources, PV systems are clean, easy to use and simple in construction. Especially, these systems have gained great importance with the recent investments on PV systems [1-4].

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PV systems are used commonly in many fields such as irrigation systems, farm houses, stand-alone buildings, space vehicles and military applications. PV systems are generally preferred in stand-alone buildings and farm houses to meet the electrical energy demand since they are easy in construction and simple in usage [5,6]. PV systems include PV panels, batteries, charge controller and inverter components [7]. Solar energy is directly converted to direct current (dc) with the semiconductor materials used in the PV panels [8]. Since the devices used at homes run with alternative current (ac), the conversion of the dc to ac is provided by inverters. DC obtained from PV panels is stored in batteries when the devices at homes do not demand energy. Therefore, the energy required for the devices when the solar radiation is not enough and during night is provided by the batteries. Battery charge controller device must be used to prevent the overcharging and over discharging [9-11].

In this study, a daily energy demand required for a stand-alone farmhouse in Bilecik city is calculated and the PV panel, battery and inverter calculations are provided for the PV system to be used. The optimum tilt angles for the PV panels to be placed depending on the seasonal and annual energy usage of the farmhouse are examined. The batteries, the most important part of the PV systems, are also examined and the most suitable ones for the system are determined. Moreover, a central inverter system is recommended for the system by identifying its advantages and disadvantages.

2. Design of Stand-Alone PV System

There is no electrical connection in stand-alone PV systems. Such systems are often used to meet the electricity needs of stand-alone buildings and farmhouses located at remote areas. The schematic of the stand-alone PV system is shown in Figure 1 [12-14].

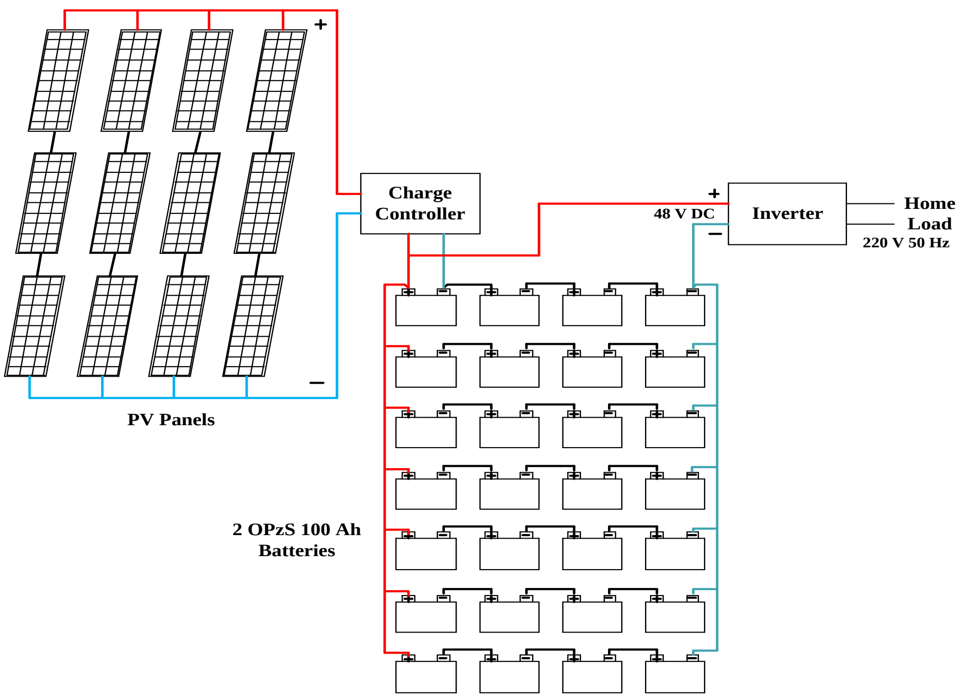

Figure 1. The schematic of the stand-alone PV system

The energy of the system is provided by PV panels. The energy obtained from the PV panels is stored in the batteries. DC energy stored in the batteries in converted to ac energy by the inverter. Meanwhile, when solar radiation is not available (night time) or when it is inadequate, the energy of the system is provided directly from the batteries. The components used to balance the system components and are between the production and consumption of the energy are called as balance of system (BOS) components. BOS components are charge controller, batteries, inverters, cables, fuses etc. [15-17]. It is important to determine where the system will be installed before the system is designed. Solar radiation differs from region to region on a daily, monthly and seasonally. For this reason, when such systems are designed, meteorological information such as average annual sunshine duration, number of cloudy days, temperature values should be known. Turkey is located between 36^0-42^0 North latitudes and Turkey's yearly average total sunshine duration is 2640 h and the yearly average solar radiation is 1311 kWh/m². Therefore, Turkey is well situated in terms of solar energy potential. The design of the system was carried out for Bilecik province, which is on 40 ^{0} latitude in the west of Turkey. The daily average sunshine duration in Bilecik city is 6.6 h and yearly average total sunshine duration is 2424 h. The daily average solar radiation is 3.87 kWh/m² and the yearly average total solar radiation is 1412 kWh/m². When the values of sunshine and solar radiation are examined, it is seen that solar potential of Bilecik province in Turkey is appropriate [18].

3. Determination of Components

3.1. Determination of Loads

The first step in designing the system is to calculate the average amount of daily energy that the farm house will consume. Table 1 shows the household devices and the energy amount that they will consume. The calculations have been carried out with the assumption that the devices to be used at home are energy-saving.

Table 1. Energy consumption of household devices

Household Devices	**Number**	**A1 Rated Power (W)**	**A2 Adjustment Factor**	**A3 Adjusted Power (W)**	**A4 Daily Usage (h/day)**	**A5 Energy Cons. (Wh/day)**
Light bulbs (15 W)	8	120	0.90	134	6	800
Refrigerator	1	100	0.90	112	8	896
Television	1	100	0.90	112	6	672
Computer	1	120	0.90	134	2	268
Washing machine	1	700	0.90	778	0.6	467
Dishwasher	1	1200	0.90	1333	0.4	533
Other devices	-	1750	0.90	1944	1	1944
Total	-	4090	-	4547	-	5580

The A1 column in the Table 1 shows the rated power values of the household devices. The sum of these values gives the total maximum ac power value of household devices (4090 W). The value in A2 column is adjustment factor and is related to the inverter efficiency (0.90). A3 value is calculated by dividing the A1 value to A2 value and the sum of this value gives the total maximum dc power value (4547 W). The daily operating hours of household appliances are shown in A4 column. Daily operating hours have been calculated considering that devices such as washing machines and dishwashers are operated once or twice a week. The values in A5 column are calculated by multiplying the A3 values by A4 values. This value is 5.58 kWh and is the average energy amount of the house.

3.2. Determination of Battery Sizing and Selection of Battery Type

In stand-alone systems, there must be batteries in order to be used during night time and when the solar radiation level is not adequate. Deep cycle batteries are required in PV systems. Such batteries are generally lead acid batteries. Among the lead acid batteries, OPzS batteries are preferred, which has a long life span of 15-20 years, require less maintenance, can be discharged slowly and can be discharged up to 80% of its capacity. These batteries are among the most appropriate batteries for the stand-alone PV applications [19,20].

Battery autonomy should be taken into account when calculating the battery number in the system. Days of autonomy are the number of the cloudy days coming from each other sequentially in a month and where no energy is not generated from PV panels [21]. This value differs from region to region. For example, the autonomy value of the Mediterranean Region is lower than the Black Sea Region. This value should be chosen using the meteorological information and taking the worst weather conditions into account. The values of the battery calculation are given in Table 2.

Table 2. Calculation of battery values

B1 Battery Bus Voltage (V)	**B2 Daily Capacity (Ah)**	**B3 Days of Autonomy**	**B4 Depth of Discharge (%)**	**B5 Battery Efficiency (%)**
48	116	4	80	91
B6 Required Battery Capacity (Ah)	**B7 Capacity of Selected Battery (Ah)**	**B8 Voltage of Selected Battery (V)**	**B9 Number of Batteries in Parallel**	**B10 Number of Batteries in Series**
638	100	12	7	4

According to the total ac power value in column A1 of Table 1, the battery voltage in column B1 of Table 2 is determined as 48 V [14]. The total daily capacity value (B2) is calculated by dividing the daily energy amount calculated in column A5 by B1 value. The number of autonomy days for Bilecik province was selected as 4 days (B3 value). OPzS batteries can discharge up to 80% of its capacity. For this reason, B4 value was chosen as 0.8. The B5 value shows 91% [22] which is the maximum charging efficiency of the OPzS battery. B6 value is calculated by Equation 1.

$$[(B2\times B3)/(B4\times B5)] \qquad (1)$$

The existing standard voltages of OPzS batteries are 2, 6 and 12 V. For the B7 and B8 values, 2 OPzS 100 models with 100 Ah 12 V were selected. The number of batteries to be connected in parallel in the system (B9) was found by dividing the value in column B6 by B7. The number of series-connected batteries (B10) in the system is found by dividing B1 value to B8 value. According to the calculations in Table 2, a total of 28 (B9xB10) batteries, 7 parallel and 4 serial, should be used in the system. Since the batteries are chemical products, ambient temperature affects the efficiency and lifetime of the batteries. Therefore, they are kept away from the operating areas and kept at the appropriate room temperatures. In this study, the temperature correction factor is not taken into account considering that the batteries are kept at room temperature of 25 °C.

3.3. Determination of PV Panel Sizing and Selection of PV Panel Type

Because of the movement of the sun during the day, the sun rays do not reach the PV panel directly. Maximum power can be transferred from PV panels by tracking the solar using one and two axis solar tracking systems. However, these systems are very complex and costly. Therefore, they are not much preferred. Instead of these systems, systems which are mounted on the roofs with a fixed optimum tilt angle are preferred. The important thing is to determine when the stand-alone system can be used. The system can only be used in winter, summer or spring, or annually. In a system that will only be used seasonally, PV panels should be placed with an appropriate tilt angle. For the design of the farm house in Bilecik province, the autumn season optimum tilt angle is 20^0, the winter season optimum tilt angle is 40^0, the spring and summer seasons optimum tilt angle is 10^0. The annual optimum tilt angle is 40^0, which is the latitude of the province [8]. The values for the PV panel calculation are shown in Table 3.

Table 3. Calculation of PV panel values

C1 Annual Optimum Tilt Angle	**C2 Efficiency of BOS**	**C3 Required PV Panel Output (Wh)**	**C4 Voltage of Selected PV Panel (V)**	**C5 Power of Selected PV Panel (W)**	**C6 Average Sunshine (h)**	**C7 Energy Output Per PV Panel Per Day (Wh)**
40^0	0.87	6414	15.93	90	6.6h	594
C8 Derating Factor	**C9 Panel Energy Output (Wh)**	**C10 Total Number of PV Panels**	**C11 Number of Series Connected PV Panel**	**C12 Number of Parallel Connected PV Panel**	**C13 Nominal Rated PV Panel Output (W)**	**C14 Nominal Rated Array Output (W)**
0.90	535	12	3	4	100	1200

Considering the yearly use of the farmhouse, it is appropriate to place the PV panels to the roof horizontally with angle of 40° (C1). 5.58 kWh energy calculated in A5 column is the daily total energy of the house. The efficiency of BOS components is indicated in column C2 as 87%. The amount of energy (C3 value) that should be obtained from the PV panels daily is found by dividing A5 by C2. A Perlight 100 Wp PLM-100P/12 model polycrystalline PV panel is selected for the system. The PV panel data are shown in Table 4.

Table 4. Electrical data of PV panel

Electrical Data of PV Panel	**Values**
Maximum Power (W)	100
Maximum Power Point Voltage (V)	17.7
Maximum Power Point Current (A)	5.65
Open Circuit Voltage (V)	22
Short Circuit Current (A)	6.21

PV panels cannot always operate at maximum power point (MPP). The values in Table 4 are the values obtained from the PV panel under standard test condition (STC) (25 ^{0}C temperature, 1000 W/m^2 solar radiation and 1.5 air mass). When the STC changes, the values obtained from the PV panels also change. Therefore, C4 and C5 values were obtained, assuming that there will be 10% loss, by multiplying the maximum voltage and power values of the panel by 0.9. Since the system is considered to be in operation throughout the year, the average sunshine duration of Bilecik is 6.6 h, which is the C6 value. The amount of energy (C7) produced by a PV panel daily is found by multiplying C5 and C6 values. Derating factor is factors such as dusting, shading and aging of PV panel. This factor (C8) is multiplied by the value of C7 and C9 value is calculated, which is actually the amount of energy that a PV panel will generate. In order to find the total PV number in the system, the value of C3 is divided by C9 value and it was calculated that 12 PV panel would be used in the system. The system's battery bus voltage is calculated as 48 V (B1 value). Since the voltage to be produced by the PV panel is 15.93 V (C4), the PV number that should be connected in series in the system is calculated by B1/C4. The number of PVs that should be connected in parallel is found as 4 by C10/C11 operation.

3.4. Determination of Charge Controller and Inverter Sizing

Charge controller prevents the batteries from being over charge and over discharge by regulating the current and the voltage obtained from PV panels. Moreover, it provides the maximum power transfer from PV panels. One of the factors that should be taken into account in the determination of the appropriate charge controller for the system is that charger controller must be durable to the maximum current and compatible with the bus voltage. Since the battery bus voltage is 48 V, charge controller must also be 48 V. Rated current calculation of the charge controller is given in Equation 2:

$$I_{controller} = C12 \times I_{SC} \times k \tag{2}$$

Where; in the designed system, PV number connected in parallel is (C12), short circuit of the determined PV panel is (I_{sc}=6.21A) and the current calculated by multiplying the 1.25 coefficient for the security (k) is found as 31.05 A. Values of 40 or 60 A can be selected according to this current value. In this case, a charge controller with a value of 48V 40-60 A should be used for the system.

Since the devices used in houses are operated by ac, the conversion of dc provided by the batteries to ac (220 V 50 Hz) is carried out by inverter. Many inverter systems can be used in stand-alone systems. The central inverter system shown in Figure 1 is used in this system. The greatest advantage of this system is that there is a significant reduction in cost using a single inverter. It is important to note that the choice of high power inverter for the system will be more flexible as the load will increase in the future. The main disadvantage of such systems is that any fault in the inverter will affect the whole system. When calculating the power of the inverter, the total power must be calculated considering that all devices in the house can operate at the same time. Meanwhile, devices with inductive loads such as washing machines, dishwashers and refrigerators should also be considered for over currents during initial operation. Therefore, while calculating the inverter the value obtained by multiplying the 1.25 coefficient should be taken into account. The calculation of the input power of the inverter is given in Equation 3.

$$P_{inverter} = A3_{total} \times 1.25 \tag{3}$$

The minimum power of the inverter needed for the system should be 6 kW. In the system the power of the inverter should be 6 kW, the input voltage should be 48 V dc and the output voltage should be 220 V 50 Hz with ac pure sine wave characteristic.

4. Conclusion

In this study, the calculation of the required components needed to meet the energy demand of a stand-alone farm house using by only PV system was carried out. Some factors such as optimum tilt angle, daily average sunshine duration, days of autonomy, efficiency of BOS components, derating were taken into account in the design of the system. The detailed information about the selection of the components used in the system is given. The application of this system which has become widespread is becoming more popular. Therefore, this study is carried out with the view that it will be useful in terms of solar energy applications which will be made in the region in the future.

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