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Research Article

Optimal Cost Planning of a Photovoltaic-Battery-Diesel Generator Hybrid Power System in Kahramanmaras Conditions

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Abstract: Mountain houses prevail in Mediterranean region. Electricity costs are considerably high for these houses when they are located remotely from electric network. The development of photovoltaic (PV) solar cells has become a new prospect for electricity in mountain houses. In addition to mountain houses, PV system can also supply electricity for places located remotely from electric networks such as transmitting stations, highway sales points, nomadic communities and fields. In case of insufficient radiation, energy is supplied by a diesel generator. This study mainly focuses on planning, modelling and cost analysis of a hybrid system which will optimally supply electricity for a mountain house without an electricity network.
Keywords: Photovoltaic, Solar Energy, Hybrid, Off grid

INTRODUCTION

Industrialization and rapid population growth in the world increases the need for energy. Gradual decline in the existing energy sources and their harmful effects on the environment forced mankind to seek for new energy sources. Use of solar energy, which is clean, infinite and environment-friendly, increases day by day [1]. Energy can be obtained via a reversible counter as long as electric network exists. In case of energy surplus, energy is transferred to the electric network while the network meets the need in case of an energy shortage. However, energy can be obtained through a hybrid system with various energy sources if it is remotely located from the electric network. In general, PV system operates with batter groups hybrid. Diesel generators also operate hybrid in order to strengthen the system [2-4]. In addition, more often than not, wind energy is used along with PV solar energy system hybrid.

Although people prefer to live in cities, the number of people living in rural areas is also remarkable [5]. People living in those areas also use electricity for their basic needs. Therefore, PV systems are used in order to supply electricity for rural areas. Although it is considered that PV systems cost higher, systems which do not depend on electric network prove to be more economical than the network [6]. Even though electricity networks are quite prevalent, they still do not suffice for mountain houses, farms, transmitting stations, building sites, highway sales points, nomadic communities and farmers. Nearly 20% of all people around world live in a remote area from electricity network, particularly in underdeveloped countries [7]. Installation of electricity networks can be costly if it is not a densely populated area. Electricity is quite important in terms of social equality and rural development [8]. Diesel generators, which are very expensive systems, are used in areas located remotely from the network. As a result, the development of alternative energy sources such as biogas, PV systems, wind and micro-hydroelectricity has become a new prospect for rural areas. PV systems are particularly significant energy sources which do not depend on the network. These systems are sustainable in the long run. Another advantage is that they can be installed, depending on specific needs, in a very short time [9, 10].

PV systems are less costly compared to an electricity network. Furthermore, their operation costs are also very low [11]. The installation of an electricity network in rural areas is not an economical solution and, sometimes, it may even cost 6340 USD per km [12].

Electric facilities in rural areas have been affected by various political, social and environmental factors. Thus, the enlargement of electric network is important in terms of rural settlement. However, major problems in the electric network lead to high losses and costs [13, 14].

PV power systems which operate independently from electric network were installed and analyzed in rural areas of Cambodia [15], Latin America [16], Iran [17], Nepal [18], China [22] and Kyrgyzstan [23] as well as Maltese islands [19], Djibouti Republic [20], Botswana Republic [21], Ethiopia [24], Bangladesh [25], South Africa [26], Peru [27], Nigeria [28] and Brazil [29].

In this study, a photovoltaic-diesel-generator hybrid power system was designed to supply electricity for a mountain house located remotely from electricity network in Kahramanmaras Province of Turkey and its cost analysis was performed.

ENERGY NEED

A photovoltaic-battery-diesel generator hybrid power system was designed to supply electricity for a mountain house of 105 m^2 located remotely from electricity network on Ahir Mountain in the southern part of Kahramanmaras (Latitude 37,64°N, Longitude 36,95°E and Altitude 1696 m.). Daily energy need in this house was calculated as 5562 kWh. It was assumed that 6 pieces of LED lamps consumed energy for 6 hours, TV and a computer for 4 hours, refrigerator for 24 hours, small house appliances for 3 hours, dishwasher for 1.5 hours on a daily basis while washing machine run for 4.5 hours weekly. The system is more successful because mountain houses are used more during summer when radiation and insulation reach higher levels. Weekly energy need is 44534 Wh and monthly energy need is 178136 WH. The list of energy needed by a mountain house is given in Table 1.

Table 1: Energy need for a mountain house

	Power	Piece(s)	Duration (daily)	Energy (daily)	Energy (weekly)	Energy (monthly)
LED armature	7 W	6	6 h/day	252 Wh	1764 Wh	7056 Wh
TV	120 W	1	4 h/day	480 Wh	3380 Wh	13440 Wh
Computer	120 W	1	4 h/day	480 Wh	3380 Wh	13440 Wh
Refrigerator	25 W	1	24 h/day	600 Wh	4200 Wh	18000 Wh
House Appliances	250 W	1	3 h/day	750 Wh	5250 Wh	21000 Wh
Washing Machine	1250 W	1	4,5 h/week	1200 Wh	11200 Wh	44800 Wh
Dishwasher	1250 W	1	1,5 h/day	1200 Wh	11200 Wh	44800 Wh
Other	200 W	1	3 h/day	600 Wh	4200 Wh	16800 Wh
Total				5562 Wh	44534 Wh	178136 Wh

In Figure 1, it is demonstrated how energy consumption is scheduled and battery groups are listed accordingly. Because they consume higher energy, washing machine and dishwasher is scheduled to operate at noon when solar energy reaches its peak.

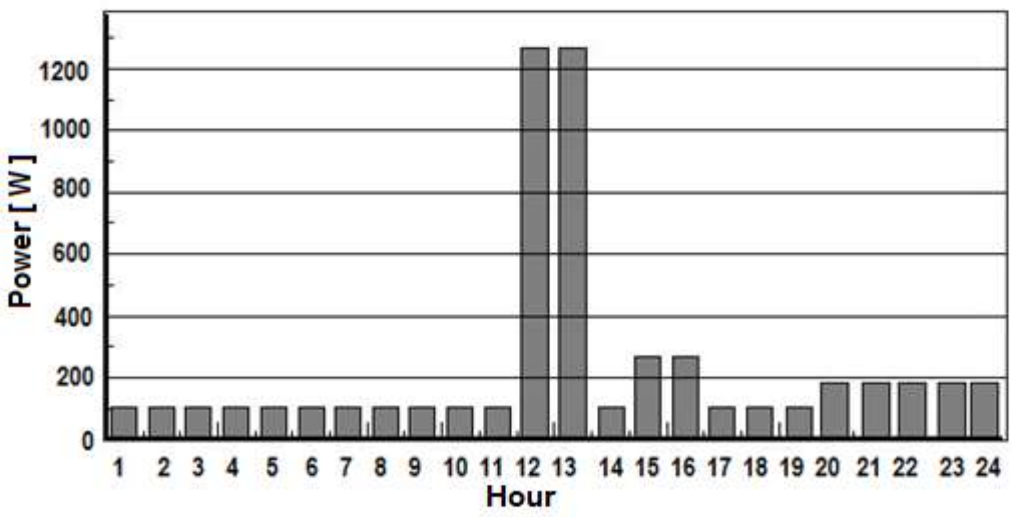

Fig. 1: Daily distribution of energy consumption

HYBRID POWER SYSTEM

Hybrid power system consists of PV, battery group and diesel generator. Suntech 250 W polycrystalline panel was used as PV panel. For systemic efficiency, 2 pieces of panels must be connected in series. Therefore, panels must be designed as 2, 4, 6, 8 etc. For battery group, Concorde 12 V 99 Ah battery was used. 4 pieces of panels must be connected in series for system efficiency. Therefore, panels must be arranged as 4, 8, 12, 16 etc. Additionally, Generic 1.5 kW inverter with MPPT and Datsu 1.5 kVA single-phase diesel generator is used. The scheme of hybrid power system is shown in Figure 2.

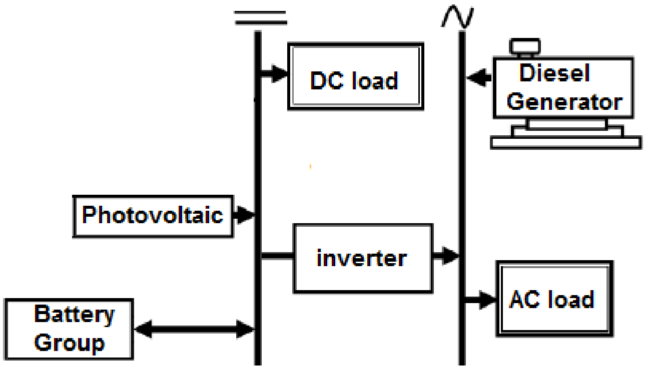

Fig. 2: Hybrid power system scheme

Photovoltaic Panels

6 pieces of Suntech 250 kW polycrystal panels were used in PV power system. Its nominal voltage is 30.7 V and nominal current is 8.15 A. Its efficiency is 17.13%. Panel properties are given in Table 2.

Table 2: Panel Properties

Brand Name	Suntech
Model	STPE 250 P
Technology	Si-poly
Max Power (Pmax)	250 W
Nominal Voltage (Vmp)	30.70 V
Nominal Current (Imp)	8.15 A
Open Circuit Voltage	37.40 V
Short Circuit Voltage (Isc)	8.63 A
Efficiency	%17.13
Length	1640 mm
Width	992 mm
Weight	19.40 kg

Photovoltaic Cell Model

PV panel is modelled based on one-diode equivalent circuit. Series resistance is calculated as 0.28 Ω and parallel resistance as 380 Ω. 60 cells in the panel are connected in series. In this power system, 6 pieces of Suntech 250 W polycrystalline panel were used. Its nominal voltage is 30.7 V and nominal current is 8.15 A. Its efficiency is 17.13%. In Figure 3, one-diode model developed for modelling of PV panel is shown.

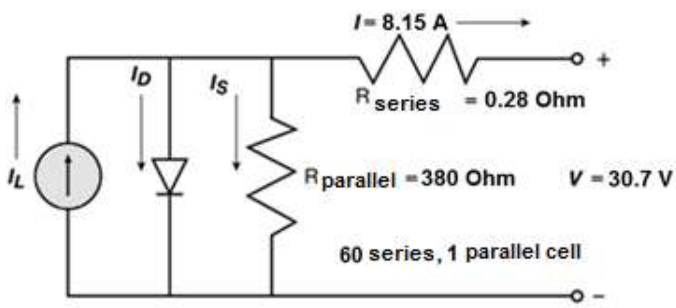

Fig. 3: Single diode model

If Kirchhoff's law is applied to these currents, $I_{cell} = I_L - I_D - I_s$ is the result. Current-voltage and power-voltage characteristics of the panel, which were obtained thanks to the model, are given in Figure 4.

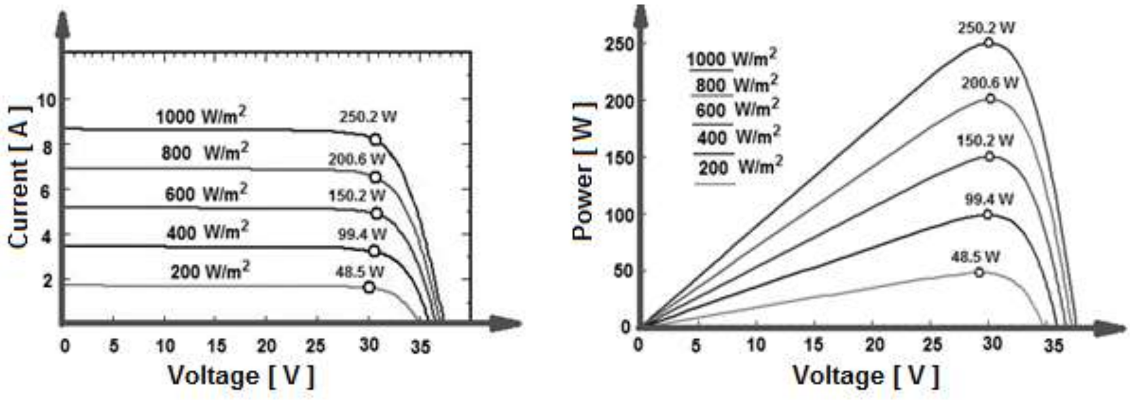

Fig. 4: Characteristics of PV panel

Batteries

Battery properties are given in Table 3. Maintenance free and leak-proof lead-acid batteries are small and light. They are quite economical due their high performance. Their leak-proof and maintenance-free structures do not require adding water and. Because they were designed in accordance with a constant charge-discharge process, they are highly suitable as an instance source of energy. They can last 5 to 10 years. In addition to being one of the basic components of uninterruptible power supplies, they can also be used in applications such as telecommunications, security system, wind energy systems, solar energy systems, defence industry and inverters. Batteries will be needed more as renewable energy sources become more widespread. A battery can be charged within 6.2, 12.5 hours and 57.7 hours at currents of 20 A, 10 A and 2 A, respectively.

Table 3: Battery Properties

Brand	Concorde
Model	PVX-1080T
Technology	Lead-acid
Nominal Capacity	99 Ah
Nominal Voltage	12 V
Internal Resistance	61.86 mΩ
Width	172 mm
Length	328 mm
Height	228 mm
Weight	31.8 kg

Inverter

A Generic 1.5 kW inverter with MPPT is used in PV system. Direct current generated in PV panels is converted to alternative current via an inverter. It is a single-phase that operates independently from the electric network and its efficiency is 96%. Its input is between 44-72 Volts and output is 220 Volts 50 Hz. Its maximum MPPT voltage is 40 Volts.

SYSTEM OPERATION

PV-battery-diesel hybrid power system will be used in Kahramanmaraş conditions. Minimum planning of energy cost without any loss of quality is aimed. PV solar panels are the main source of energy. In case of insufficient solar energy, battery group will supply electricity. If lack of solar energy continues for a long time, diesel generator, the fuel cost of which is high, will supply energy. The number of batteries and PV panels must be planned optimally in order to reach minimum amount of energy. Battery group will be increased by 4 for system efficiency while PV panels will be increased by 2. 1 piece of diesel generator is used based on the climatic conditions.

The effect of the number of panels on the cost (Mp) depends on the number of panels (P) and energy supplied by PV panel (E1).

$$M_p = \frac{130xP}{E_1} \qquad (1)$$

The effect of the number of batteries on the cost (Ma) depends on the number of batteries (a) and energy supplied by batteries (E2).

$$M_a = \frac{150xa}{E_2} \qquad (2)$$

The effect of the diesel generator (Mj) depends on the amount of fuel (S) and energy supplied by diesel generator (E3).

$$M_j = \frac{(250+1{,}62xS)}{E_3} \qquad (3)$$

If ET is total energy,

$$E_T = M_p + M_a + M_j \qquad (4)$$

MT=total unit cost of energy;

$$M_T = \frac{M_p.E_1+M_a.E_2+M_j.E_3}{E_T} \qquad (5)$$

Thanks to the present hybrid model, it is possible to calculate changes in the total unit cost of energy based on the climatic values in Kahramanmaras, depending on the numbers of panels and batteries. Results are given in Table 4 and Figure 5.

Table 4: Changes in unit cost of energy depending on the numbers of panels and batteries

Number of Batteries	Number of Panels: 2	4	6	8	10	12	14	16	18	20
4	0,88	0,53	0,37	0,58	0,58	0,54	0,55	0,57	0,59	0,59
8	0,77	0,39	0,26	0,24	0,27	0,31	0,35	0,38	0,38	0,38
12	0,78	0,4	0,26	0,23	0,23	0,23	0,24	0,24	0,26	0,26
16	0,82	0,41	0,27	0,24	0,23	0,24	0,25	0,25	0,27	0,27
20	0,82	0,42	0,29	0,24	0,24	0,26	0,26	0,26	0,27	0,28

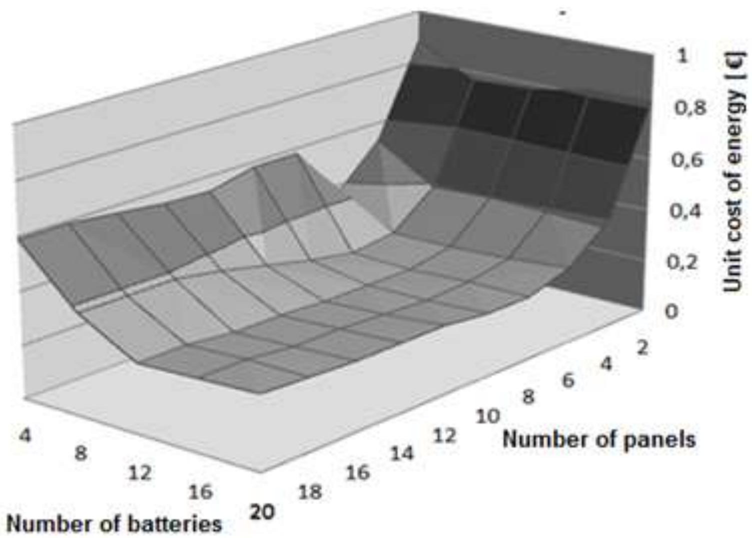

Fig. 5: Changes in unit cost of energy depending on the numbers of panels and batteries

Unit cost of energy is calculated minimally for (8 panels- 12 batteries), (10 panels- 12 batteries), (12 panels-12 batteries) and (10 panels-16 batteries). Although these combinations are quite close to each other, 8 panels and 12 batteries are the least expensive. Unit cost of energy is calculated as 0.23 Euros.

Optimal operation percentages for PV-battery-diesel generator hybrid power system to supply the energy needed during a year is given in Figure 6. Diesel generator is used only in January, February, November and December. Energy is supplied by PV system, batteries and diesel generator by 65%, 32% and 3%, respectively. Due to the expenses posed by the fuel of diesel generator, it is only used in case of emergency at a minimum level. PV solar system generated 2737 kWh energy annually. Energy surplus is stored in the batteries and 653 kWh energy was supplied by them when needed. When PV system and batteries were insufficient, 54 kWh energy was supplied by the diesel generator.

On average, 173 kWh energy is needed monthly. PV solar energy system generates 228 kWh on average. Although average solar energy exceeds average energy need, it cannot supply sufficient energy. Batteries will be used in case of insufficient solar energy. On average, 55 kWh energy is supplied by batteries monthly. When batteries do not suffice, diesel generator generates supply energy.

Energy generated by PV solar energy system is given in Figure 7. PV system generates 7.49 kWh daily on average. Particularly in summer, it generates 9.33

kWh energy daily on average. Solar energy supplies 5.56 kWh energy daily on average in winter, when solar energy systems are least efficient. A mountain house needs 5.76 kWh energy daily.

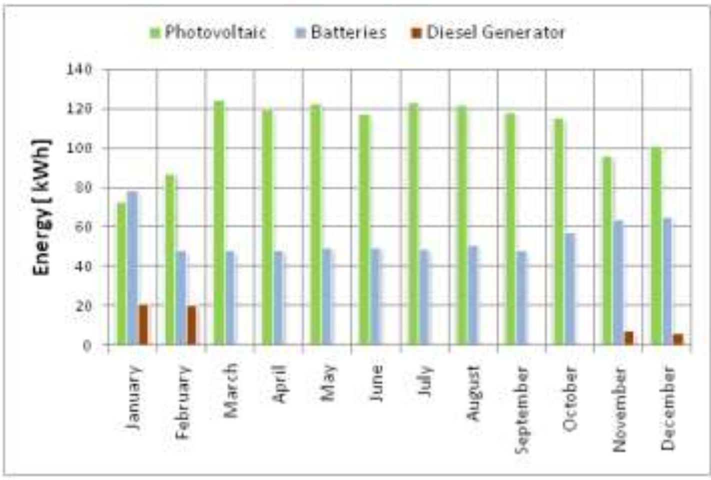

Fig. 6: Hybrid power system distribution

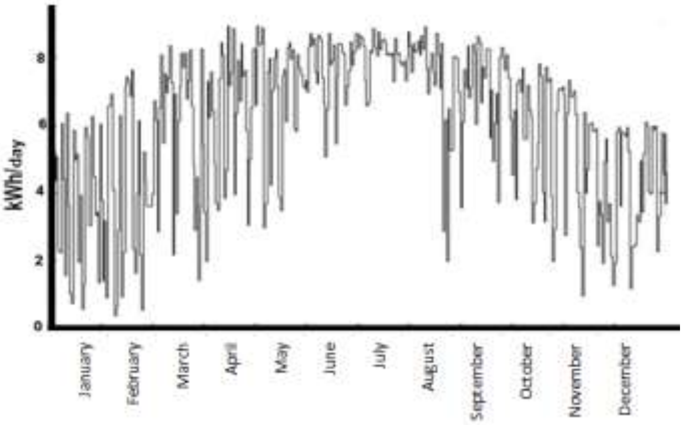

Fig. 7: Energy generated by PV system

In Figure 8, monthly changes in the loads in 12 pieces of 99 Ah batteries are shown. Battery load is at its minimum in February due to radiation and temperature. Batteries were fully charged from March to November. If the mountain house is not used in December, January and February, less battery groups will be needed, reducing installation costs. This system is intended to supply 5760 kWh energy for 12 months and 365 days.

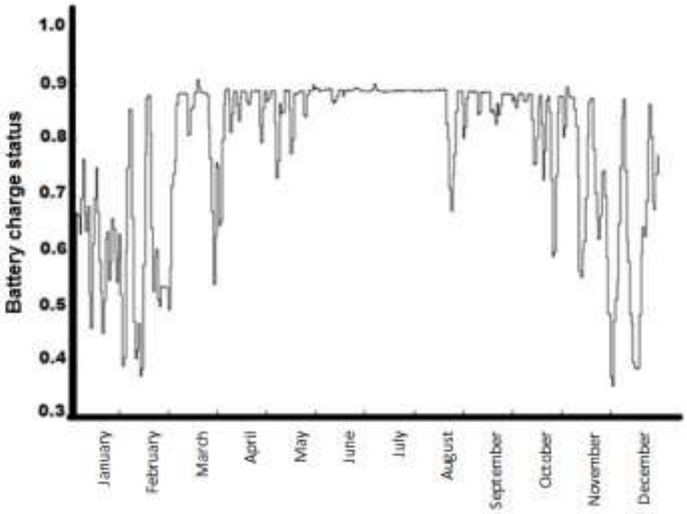

Fig. 8: Daily average battery load

Total cost of the system is 3894 Euros. 24% of investment costs belong to PV panels while 7% is spent on inverters, 54% on batteries, 8% on diesel generator and 7% on other equipment.

CONCLUSION

PV panels cost 0.61 Euros per Watt while the whole system costs 2.6 Euros per Watt. In a 30-year cost analysis of the independent system, unit cost of energy is calculated as 0.23 Euros, which is quite advantageous as it is close to the cost of an electric network. It was found out that A PV- battery-diesel generator hybrid power system which would operate in Kahramanmaras conditions, a rich region in terms of radiation, would generate 60.84 kWh energy and reduce total CO_2 emission by 42.53 tons. Unit cost of energy generated by the system is calculated as 0.23 Euros. In conclusion, a hybrid system which will be installed rapidly and independently from the electric network is not as costly as expected. These systems have become a new prospect in order to improve the life standards of people settled in rural areas. Furthermore, PV-battery-diesel generator hybrid power systems must be supported due to their environment-friendly structure.

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