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Dynamic Simulation of a PV-Diesel-Battery Hybrid Plant for Off Grid Electricity Supply

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Abstract

Mountain houses abound in particularly Mediterranean region of Turkey. The development of photovoltaic (PV) solar cells has offered an opportunity to supply electricity to these houses. In addition to mountain houses, transmitter stations in remote areas, sales points by the highways, nomadic communities and farmers may also benefit from PV systems for electricity. In case of insufficient radiation, diesel generators are used for this need. This study focuses on planning, modeling and cost analysis of energy supply to a off-grid house via an optimal hybrid system.

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1. Introduction

Fossil fuels are preferred in order to fulfill the need for energy. However, their finite and harmful content for the environment have led people to seek for new sources of energy [1]. Although most of the people live in metropolitan cities in the world, the number of those settled in rural areas are also remarkable [2]. Electricity is needed in order to supply energy people's basic needs in a rural region. Off-grid PV systems are used for supplying electricity to rural areas. Although their costs are considered as high, off-grid systems are more economical compared to on-grid ones [3]. Even on-grid electricity are quite prevalent, mountain houses, farm houses, transmitter stations, construction sites, sales points by the highways, nomadic communities and farmers cannot benefit from them. 20 percent of the world population, most of which live in underdeveloped countries, resides in remote regions where no electricity networks exist [4]. The cost of installation of an electricity network in those regions with a low population is significantly high. Electricity is of utmost importance in terms of social equality and rural development [5]. Energy is an indispensable element for economic growth and social development.

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Therefore, its use is of vital importance. However, fossil fuels contaminate the environment and causes global warming.

Diesel generators, which are not cost-effective systems, operate in remote regions without an electricity network. The developments in biogas, PV systems, wind energy and micro- and hydroelectric sources offer new chances for energy needs in a rural region. PV systems are quite important because they are off-grid and sustainable in the long term. It can also be installed and customized in a very short time [6,7]. The installation cost of PV system is less than that of an electric line as well as its low operation cost [8]. The installation of an electricity network in a rural region is not an economical solution. The cost sometimes reaches 6340 US dollars per kilometer [9]. Electrification in rural areas has so far been influenced by various political, economic, social and environmental factors. Enlargement of electricity network bears importance for rural settlements. However, widespread electrical breakdown resulted in high losses and costs within time [10]. Renewable energy sources which can be used independently of electricity network reduce costs as well as protecting the environment [11]. PV systems independent of electricity network are installed in rural areas of Cambodia [12], Latin America [13], Iran [14], Nepal [15], Kyrgyzstan [20] and China [19] as well as Maltese islands [16], Republic of Djibouti [17], Republic of Botswana [18], Ethiopia [21], Bangladesh [22], South Africa [23], Peru [24], Nigeria [25] and Brazil [26].

The term "hybrid renewable energy system" (HRES) is used to define any energy system composed of more than one type of generators. The usual configuration is comprised of a conventional diesel-powered generator connected to a renewable energy source such as PV, wind, or even PV/wind. Although the initial cost of solar or wind energy systems is higher than diesel engine generator in comparable size, operating and maintenance costs are always significantly lower for renewable systems. Over the last decade, HRES has become a viable alternative for power production because they allow designers to capitalize on the strengths of both conventional and renewable energy sources [27].

In this study, electricity was supplied to a remote region located in Karagöl district of Kahramanmaraş Province of Turkey without an electricity network, and a cost analysis of this system was performed.

2. Energy Need

Karagöl is located on Ahir Mountain in the southern region of Kahramanmaraş located in Mediterranean region of Turkey (Latitude 37.64° N, Longitude 36.95° E and Altitude 1696 m.). A hybrid system with PV/diesel generator was planned in order to supply energy to a mountain house of 105 m² near Karagöl, which is far from electricity network, with permanent electricity power. This house needs 5562 Wh energy per day. It is assumed that 6 led lamps run for 6 hours, TV and computer for 4 hours, refrigerator permanently, small house appliances for 3 hours, dishwasher for 1.5 hours per day and washing machine 4.5 per week. Given that mountain houses are used more frequently during summer and radiation is much higher during this time of the year, the system will be more successful.

3. Hybrid power system

PV system consists of 6 Suntech 250 W poly crystal panels, 12 Concorde 12 W 99 Ah batteries, 1 Generic 1.5 kW inverter with MPPT and 1 Datsu 1.5 kVA single phase diesel generator. Scheme of hybrid power system is given in Figure 1.

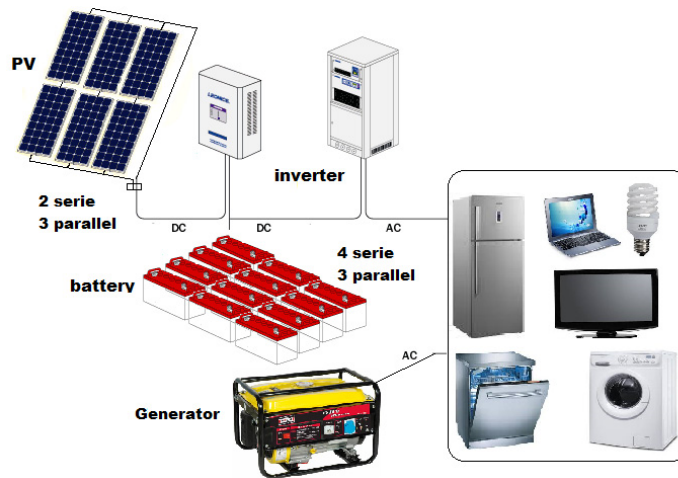


Fig. 1. Scheme of Hybrid power system

Electricity for basic energy needs in a mountain house for a refrigerator, TV, washing machine, dishwasher, computer, small house appliances and illumination are supplied by 6 PV panels. Electricity generated by these panels is converted to alternative current through the inverter and energy surplus is stored in the batteries. As the system is planned at a minimum cost, the number of panels and batteries was limited to a minimum level. In PV power system, 6 pieces of Suntence 250 W poly crystal panels were used. While its nominal voltage is 30.7 V, its nominal current is 8.15 A and its efficiency is 17.13 percent. 12 pieces of Concorde, 12 V, and 99 Ah lead-acid batteries were used in PV power system. Maintenance-free lead-acid batteries are small and light and also quite economical as their performance is remarkably high. They do not require adding water or electrolyte due to their hermetic and maintenance-free structure. Since these batteries are designed for constant charging-discharging, they are suitable as a main and instant source of energy. Their life span is around 5-10 years. As one of the basic components of uninterrupted power supply, it is also used in telecommunication, security systems, wind energy systems, defense industry and rectifiers. Batteries gain more and more importance in a world where renewable energy sources become widespread. The battery is charged within 6.2 hours by 20-A current, within 12.5 hours by 10-A current and within 57.7 hours by 2-A current. A Generic 1.5 kW inverter with Maximum Power Point Tracking (MPPT) was used in PV power system. Direct current generated from PV panels through the inverter is converted to alternative current. The inverter is a phase operating independently of electricity network and its efficiency is 96 percent. Its input is between 44 and 72 volts while its output is 220 Volts and 50 Hz. MPPT voltage is 48 volts.

4. System Operation

PV-Diesel-Battery Hybrid Plant system was modeled via TRNSYS, Polysun and particularly PVSYST. Optimal usage percentages required for providing sufficient electricity annually thanks to the operation of solar PV- diesel - battery hybrid power system is given in Figure 10. Diesel generator is used only in January, February, November and December. Diesel generator obtains 54 kWh energy, i.e. the amount needed. 74 percent of this energy is obtained from PV system, 25 percent from batteries and 1 percent from diesel generator. As the fuel consumed by diesel generator is considerably expensive, it is only used in urgent situations and at a minimum level. PV solar energy system generated 2737 kWh annually. Surplus energy is stored in the batteries and 909 kWh energy was provided by batteries when needed. 54 kWh was provided by diesel generator if PV system and batteries were insufficient.

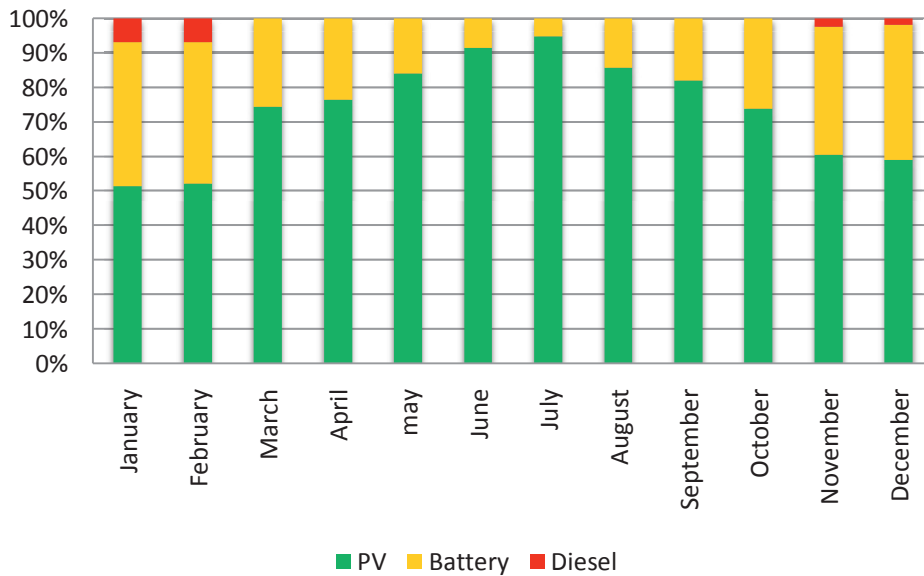


Fig. 2. Hybrid power system distribution

173 kWh energy is needed per month. PV solar energy system generates 228 kWh energy on average. Although average solar energy is higher than average need, it does not supply sufficient energy. Batteries are designed for when no radiation is available. Batteries provide 75 kWh energy on average per month. When batteries are insufficient, diesel generator operated Kahramanmaras is an important region with a monthly average radiation of 131.875 kWh/m² and an average temperature of 16.405 °C along with an annual average sunshine duration of 2874 hours. Kahramanmaras is a productive area in terms of solar energy with an annual radiation rate of 1582.5 kWh/m². The system generates 7.49 kWh energy per day. Particularly, it generates 9.33 kWh energy during summer. During winter, when solar energy systems generate least efficiently, it generates 5.76 kWh per day. Daily energy needed by the mountain house is 5.76 kWh. The charging level was at its minimum in February due to the radiation and temperature. The batteries were fully charged from March to November. Since mountain houses are not used in December, January and February, fewer batteries can offer a solution and thus reduce costs. The system was planned to operate for 12 months and 365 days to permanently generate 5760 kWh energy.

5. Cost Analysis

Cost analysis of solar PV- diesel - battery hybrid power system is given in Table 4. The system totally costs 3894 Euro. 24 percent of this cost was for PV panels, 7 percent for inverters, 54 percent for batteries, 8 percent for diesel generator and 7 percent for other equipment.

PV panels cost 0.61 Euro per Watt. The whole system costs 2.6 Euro per Watt. Unit cost of energy was found as 0.24 Euro in a cost analysis performed for the next 30 years. This value, which is close to electricity network tariffs, is definitely more efficient as far as the cost of installation of an electricity network is concerned.

Table 1. Cost analysis of the system

PV Modules	130 €	6	780 €
Supports	20 €	6	120 €
Batteries	150 €	12	1800 €
Inverter	250 €	1	250 €
Others	100 €	1	100 €
Diesel Generator	250 €		
Total			3300 €
Taxes			594 €
Net Investment			3894 €
PV costs (€/W)			0.61 €
System costs (€/W)			2.60 €
Production [kWh](1 year)			2028
Production [kWh](30 year)			60840
Fuel consumption (Year)			120 €
Maintenance cost (Year)			300 €
Unit cost of energy [€/kWh]			0.24 €

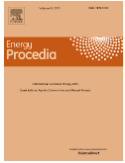
6. Conclusions

It was found out that solar PV-diesel-battery hybrid power system to be active in Kahramanmaraş, a region which is quite rich in terms of solar energy, would produce 60.84 MWh energy and reduces CO₂ emission by 42.53 tons. Unit cost of energy generated was calculated as 0.24 Euro. In conclusion, a hybrid off-grid system which can be installed rapidly is not as costly as they were considered. These systems offer a new solution for people living in rural areas to improve their living standards. In addition, in terms of environmental issues, the proliferation of solar PV- diesel - battery hybrid power systems must be supported.

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Biography

The biography of the corresponding author. (50 words)

Saban YILMAZ

He was born in 1970. He graduate from Istanbul Technical University, Sakarya Faculty of Engineering, Department of Electric and Electronic Engineering in 1993. He was awarded Master of Science in Kahramanmaras Sutcu Imam University in 2001. He currently studies PhD on solar energy at Kahramanmaras Sutcu Imam University.

Appendix A. An example appendix

Authors including an appendix section should do so after References. They will be ordered A, B, C etc.

A.1. Example of a sub-heading within an appendix

There is also the option to include a subheading within the Appendix if you wish.