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Design and Analysis of Hybrid Generator Systems

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Abstract: Hybrid generator system, in which renewable energy sources such as solar and wind energy are used in addition to fossil fuel genset, is an efficient, environment-friendly and economical system. In this system, double speed diesel genset is used as main source. Power is produced from different type of energy sources and it is transferred to the load by using 48VDC battery bank to provide stable operation. Hybrid system was simulated with hybrid optimization software and compared to traditional island mode AC genset for technical and economical situations under 1.5 kW average load conditions. According to simulation results, the system benefits are discussed. The results show that the use of Hybrid Generator system in place of traditional island mode generator in areas where the mains is not available is more advantageous in many respects.

Key words: hybrid generator, renewable energy, environmentally friendly system

1. Introduction

Today, the energy demand has increased compared to the past years and the energy sustainability has become very important. Various energy production methods have been developed to ensure the continuity of the energy. However, many of these energy production methods are based on fossil fuels.

About 90% of the energy needed in the world depends on fossil-based resources. The largest share among these sources is petroleum with approximately 35% [1]. However, the fossil fuels' damage to the environment and the ever-diminishing reserves push the world into new quests for their energy needs. In this context, research has focused on energy resources that are not harmful to the environment and can renew themselves.

Although renewable energy sources are environmentally sensitive, they vary throughout the day and year depending on environmental and atmospheric conditions. Wind or solar energy alone is not sufficient these days when energy sustainability is important. We need a method to maximize the use of renewable energy sources.

Systems that use two or more complementary energy sources that have become widespread in recent years are called hybrid energy systems [2]. Hybrid energy systems increase system reliability and continuity. Due to the variable nature of the solar and wind energy, diesel generators are added to ensure continuity of the hybrid systems. Thus, while continuity of the system is ensured, damage to the environment is minimized.

The hybrid generator system, which is a combination of diesel generator, solar and wind energy, greatly reduces operating costs such as fuel and maintenance costs. In the remote areas of the network, the unit kWh cost of the energy obtained by the diesel generators is considerably higher than the hybrid generator system. When capacity increases are needed, capacity can be increased by increasing the nominal power of the diesel generator and renewable energy sources. In this context, the use of a hybrid generator system is advantageous both economically and in terms of service and maintenance processes, and provides great convenience to the user.

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2. Hybrid Generator System

The hybrid generator system which consists of a double-speed diesel engine, a DC alternator, a photovoltaic panel, a wind turbine and a battery bank, and operates at a nominal voltage of 48VDC is an uninterrupted power supply. The system is capable of supplying an average load of 1.5 kW and is designed to operate at maximum efficiency under optimum operating conditions. Considering the effects of environmental conditions and changes on the load side, the system load changes. Therefore, the maximum working load is determined 2.3 kW. The environmental conditions of system are based on the province of Antalya in Turkey.

The operating principle of the system is based on DC supply voltage and the operating voltage is 48VDC. Renewable energy sources such as solar and wind energy are determined at the optimum level and, under favourable conditions, the system can continue to feed the load without having to start diesel engine. However, only the daytime electricity is available from the sun and at the night, load is left without electricity. For wind energy, cannot be drawn limits as clear as solar energy. However, when the atmospheric conditions are appropriate, energy can be generated and the load can be supplied [3]. Due to these variations in the energy of the sun and wind, the load is supplied from the battery bank. On the other hand, the solar and wind energy, feeds the battery bank to ensure that the battery has a longer cycle life.

When the solar and wind energy is insufficient, the battery bank discharges to the load and provides the continuity of the energy. When the battery bank is lowered to a certain depth of discharge, the diesel generator starts to ensure the continuity of the energy transferred to the load. While the load is supplying by the generator, at the same time, battery bank is recharged to be usable again. However, in order to make the battery bank longer lasting, battery discharge restrictions are imposed. The battery bank is prevented decreasing below the 50% depth of discharge. In this way, it is ensured that the battery life is longer and the working time of the generator is kept at optimum level.

An air conditioner that keeps the battery room temperature at 20°C to protect the battery bank from high temperatures is added to the system. An AC/DC inverter is added to the system to meet the air conditioner, lighting and auxiliary AC power needs.

Fig. 1 describing the operating principle of the hybrid generator system is shown below.

Telecom systems are chosen as the basic load for the hybrid generator system. In our work, the average load power is chosen 1.5 kW. The hybrid generator system is designed to work efficiently in 1-2 kW load range. The maximum system load after the addition of 0.3 kW cooling load is determined to 2.3 kW.

3. System Components

3.1 Diesel Generator

The dual-speed diesel generator, the main energy source of the hybrid generator system, is designed to operate at two different speeds, as 1500/1800 rpm. In order to meet the power requirements of the battery bank due to the high current value charging, a motor with a capacity of 10.3 kW prime power at 1800 rpm is used. The generator starts at 1500 rpm for the first run. As the battery charge starts with high current, the generator automatically raises the speed to 1800 rpm. When the power demand decreases towards the end of charging, the generator speed falls again to 1500 rpm. With this mode of operation, the power demand can be achieved by using a smaller generator, and at the

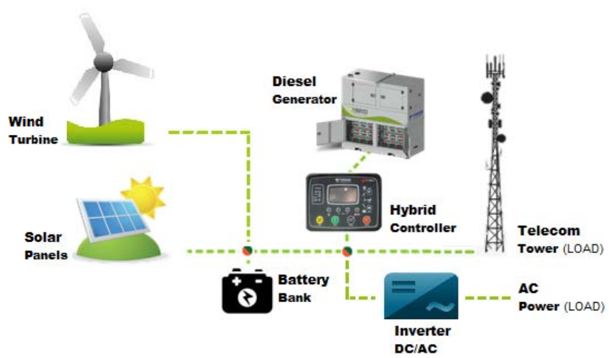


Fig. 1 Hybrid generator system operating principle.

same time, less fuel consumption is provided. By using DC alternator which can be used in variable speeds, frequency problems caused by different reference speeds are eliminated.

In this operating mode, the system operates at 1500 rpm for lower power needs and 1800 rpm for higher power needs by changing the operating speed according to the required load. Thanks to this, the engine works at the most efficient points in terms of fuel consumption.

Fig. 2 shows the comparison of the double-speed diesel generator with a standard generator operating in island mode. Due to the variable nature of the charging current, a load curve of different powers originating from charging and constant average 1.5 kW system load is obtained in the graph. The graph shows the advantage of the Hybrid Generator for different power values.

3.2 Photovoltaic Panel

Solar batteries are semiconductor materials that convert photon energy from solar rays into electricity. Panel efficiency is between 15-20% depending on the type of panel. A panel may produce rated power values if environmental conditions are favourable. Factors such as pollution, oblique light angle, unfavourable weather conditions cause panel efficiency to decrease. The biggest factor that determines the maximum energy level that can be taken from a solar panel is the area where the panel is installed. If the area where the solar panel is installed is a region with a low level of sunshine, this panel cannot provide sufficient efficiency.

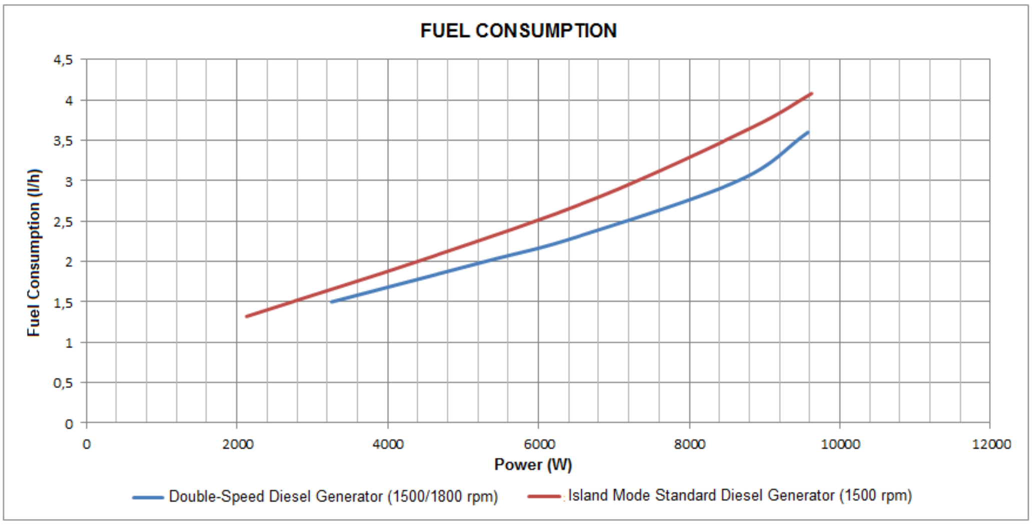


Fig. 2 Fuel Consumption – Power Curve.

Turkey is in better position than most European countries in terms of annual isolation and sunshine duration. Annual solar radiation is measured as 1400-1500 kWh/m^2-year even in the northern parts of the country [4]. These values show that our country is suitable for solar energy. Nevertheless, our country is far behind European countries in the use of solar energy.

Fig. 3 and Fig. 4 show maps of solar radiation of Turkey and European countries.

In the hybrid generator design, important parameters of the system working area such as solar radiation, sunshine duration is taken into account and the design is made according to these parameters. The application area of the hybrid generator system is determined as Antalya province of Turkey. The figures showing the solar data of Antalya are shown below.

The highest monthly solar radiation per m^2 for Antalya is June with 6.93 kWh/m^2-day. Likewise, the month in which daily solar radiation is least visible is

December with 1.92 kWh/m^2-day. These values are shown in Fig. 6.Taking into consideration the sunshine periods for Antalya, the highest sunshine duration is 11.84 hours in July and the lowest sunshine duration is 4.55 hours in December. These values are also shown in Fig. 7.

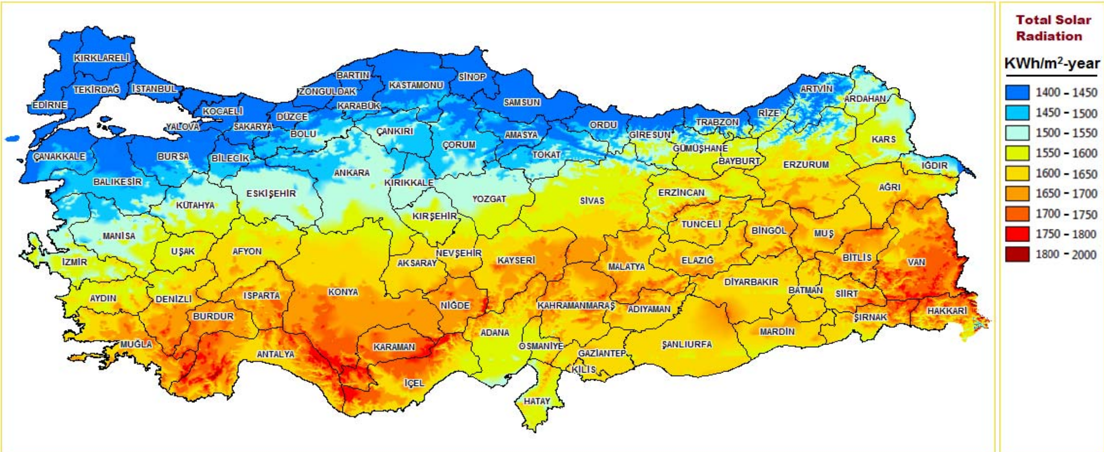


Fig. 3 Solar energy potential map for Turkey [4].

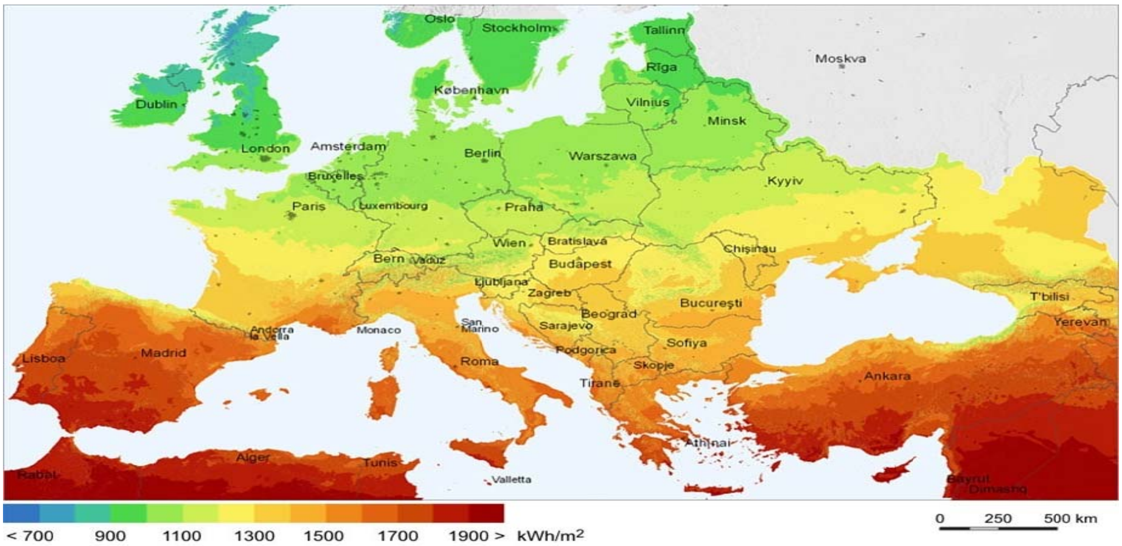


Fig. 4 Solar energy potential map for Europa [7].

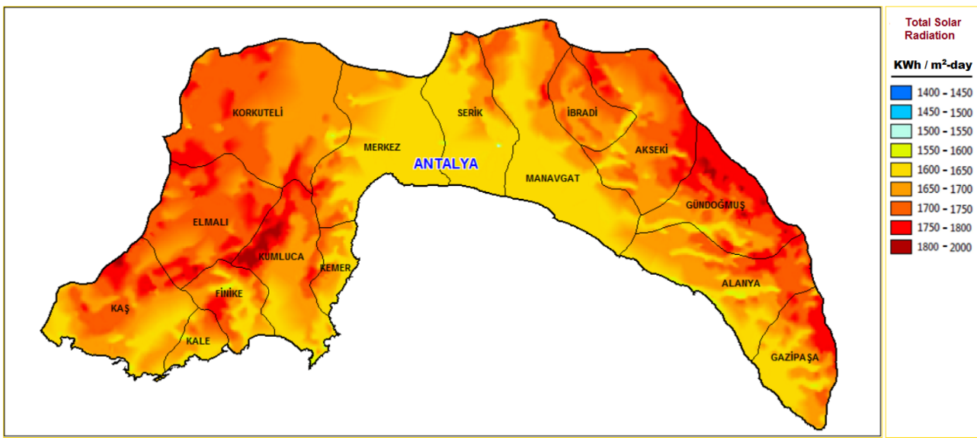


Fig. 5 Solar energy potential map for Antalya [8].

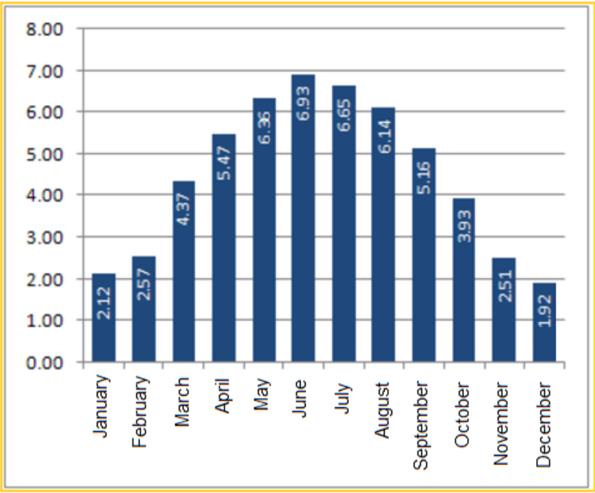


Fig. 6 Solar radiation values for Antalya [8].

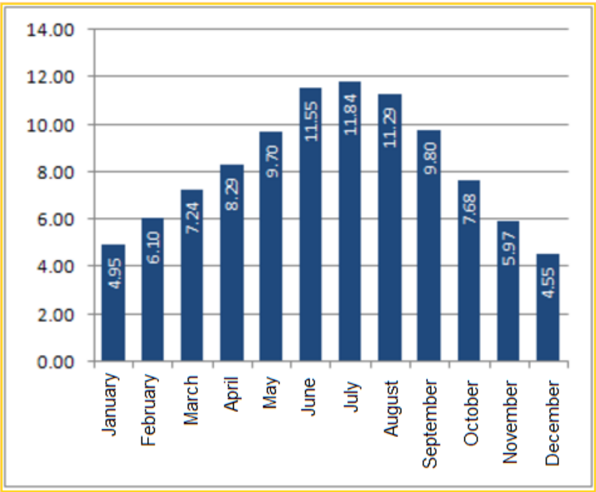


Fig. 7 Sunshine durations for Antalya [8].

The solar panels which used in the hybrid generator system have 240 Wp power and it have 14 units. The total panel power is 3360 Wp. The open circuit voltage of the panels is 74VDC. The solar system voltage can be adjusted according to the charging characteristic in the range of 48-56VDC with using 40A solar charge regulators.

Polycrystalline silicon type panels are used in the solar energy system. The total module efficiency is up to 14.7% in favourable conditions. The panel layout angle, a factor that increases the efficiency of the panel, shows seasonal significant changes. Therefore, the annual optimum angle value is used for stationary systems [5]. Table 1 shows the technical data of solar panels.

3.3 Wind Turbine

Wind turbines are systems that produce electricity by mechanical energy obtained from the kinetic energy of the air. In order to obtain high benefit from wind turbines, turbines must be installed in open areas with high wind densities.

The data used in the design of the hybrid generator is calculated considering Antalya wind data. Annual wind speed average for Antalya is between 5.5-6.5 m/sec at 50 m altitude [6]. When designing the system, the wind power of the zone where the system will work will be taken into consideration and the design will be shaped accordingly.

The nominal power of the wind turbine which used in the hybrid generator system is 1 kW. The wind turbine cannot provide a stable output voltage due to the variable nature of the wind speed. For the adaptation of this variable voltage to the system, the voltage is adjusted to the system with the AC-DC converter.

PMG alternator is used in the wind turbine. Therefore, the efficiency of the wind turbine is higher than the conventional wind turbines.

Fig. 8 showing Antalya's wind speed distribution is shown below. In addition, Table 2 containing the technical data of the wind turbine and Fig. 9 showing the turbine operating curve are also shown below.

Table 1 Technical data of solar panels.

Specification	Unit	Value
Cell type	-	Polycrystalline Silicon
Nominal power	W	240
Nominal voltage	V	29.73
Open circuit voltage	V	37.56
Short circuit current	A	8.85
Number of modules	-	14
Module power	W	3360
Module voltage	V	48
Module efficiency	%	14.7
*Typical parameters at standard test conditions: 1000 W/m^2 irradiation at 25°C module temperature		

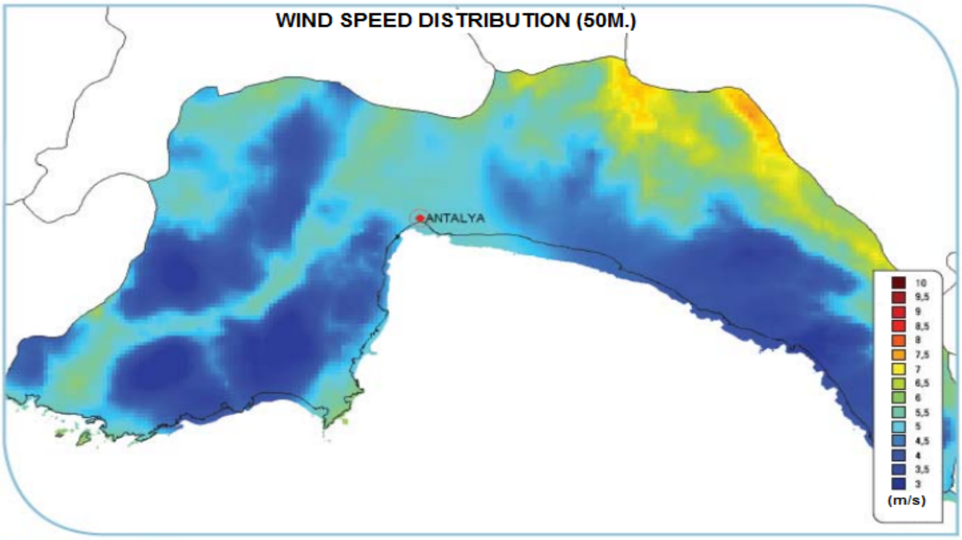


Fig. 8 Wind speed distribution map for Antalya [6].

Table 2 Technical data of wind turbine.

Specification	Unit	Value
Turbine type	-	3 phase PMG
Nominal power	W	1000
Nominal voltage	V	48
Operating wind speed	m/s	3-25
Starting wind speed	m/s	2.5
Nominal wind speed	m/s	8
Gearbox	-	None

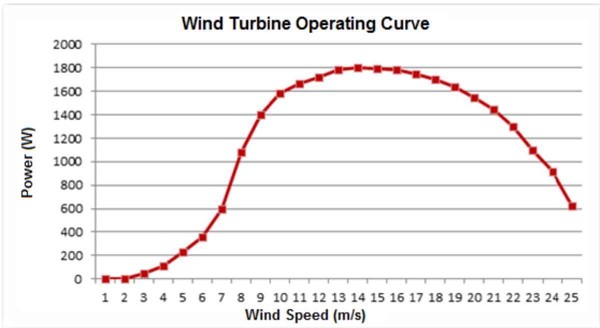


Fig. 9 Wind turbine operating curve.

3.4 Battery Bank

Batteries are electrochemical elements that store electrical energy in the form of chemical energy. The most widely used type of batteries in renewable energy applications are OPzV gel type batteries which enable deep discharge. These batteries can be connected to serial and parallel to reach desired voltage and capacity values.

24 pieces of 2V 600Ah OPzV type batteries are used in the hybrid generator system. 24 batteries are connected in series to reach 48VDC system voltage. With the current capacity at 50% depth of discharge, the average 1.5 kW load can run for about 10 hours without any external power source. In case of emergency, even if the diesel generator and renewable energy sources are out of system, the system load can be fed for up to 20 hours by fully discharging the battery.

Considering the current system design, battery life is about 2800 cycles at 50% depth of discharge and 20°C ambient temperature. Fig. 10 showed the battery cycle life.

3.5 Hybrid Control Unit

The hybrid control unit is an electronic control mechanism that manages the hybrid generator system, provides continuity of charge and discharge phases, and provides remote monitoring and control of the system.

The hybrid control unit monitors the engine parameters and ensures that the engine operates safely against the fault. It also monitors the operation of the system by monitoring electrical parameters such as current, voltage, and power.

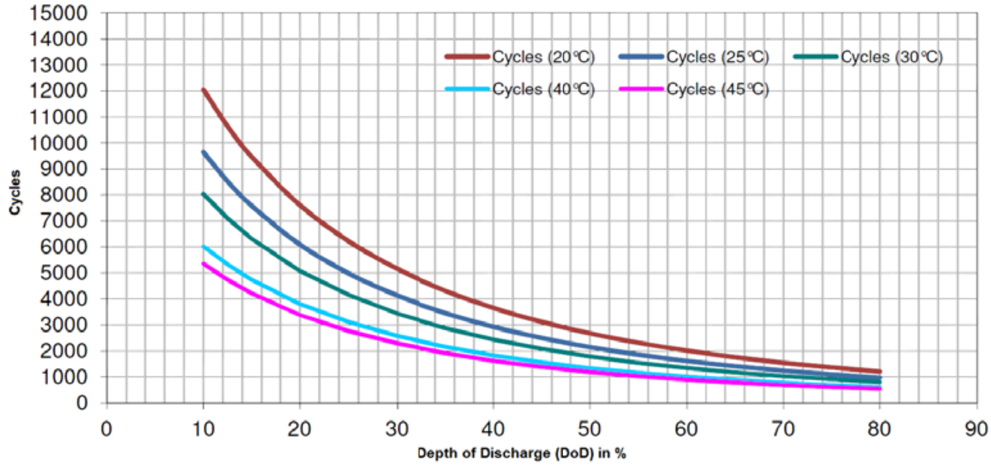


Fig. 10 Depth of discharge — Cycle life curve at different ambient temperatures.

The hybrid control unit monitors the battery bank and controls the charging and discharging status of the system. After the device input settings are made, the device monitors both the system voltage and discharge capacity during operation and automatically activates the generator when the battery falls below the specified voltage or capacity level. When the generator starts to charging the battery bank, it also supplies the system load.

As shown in Fig. 11, the charging phase continues with constant current until the battery voltage reaches the absorption charge voltage after the generator starts. The constant current charge value is input to the system as 100A and the battery bank is charged with this current value until the absorption voltage is reached. When the battery voltage reaches the absorption voltage 56.4V, charging continues with constant absorption voltage. In this phase, the charging current gradually decreases and charging ends when the specified charging end current value is reached.

The energy obtained from the sun and wind is also applied to the same charging stages, and is transferred to the DC distribution busbar.

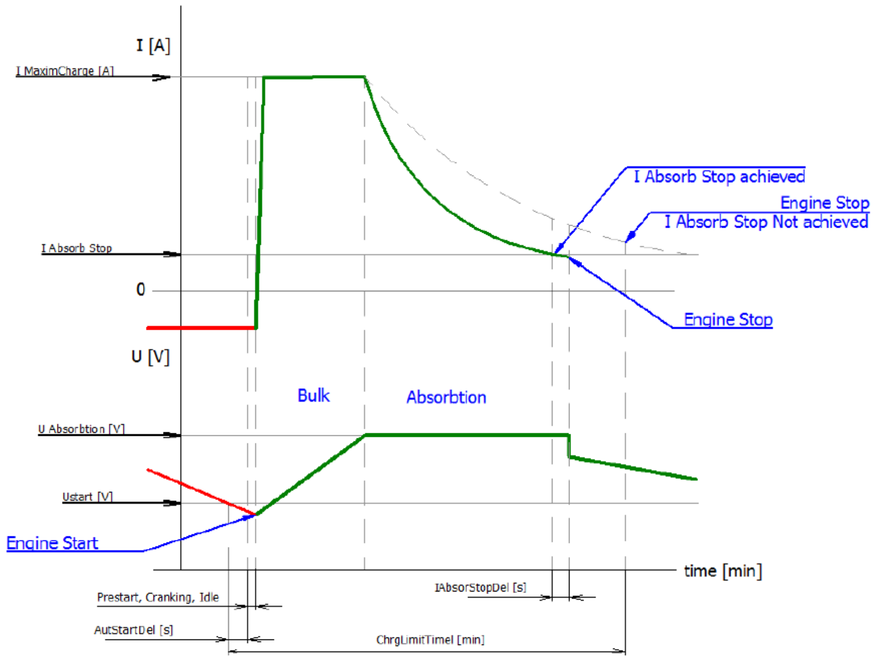


Fig. 11 Battery charging cycle [9].

4. System Design and Simulation

Hybrid generator system is designed with an optimization program, called HOMER, used for hybrid systems and system simulation is carried out. During the design, the environmental and atmospheric conditions which the system will run in Antalya are taken into consideration in order to give the simulation results close to real. Thus, the simulation results are intended to contain more accurate values.

The design of the hybrid generator system begins with the addition of system components first. Subsequently the datas for each component is transferred to the optimisation program (Fig. 12). The reason for adding 2 generators; one represents the hybrid generator (Generator 1), and the other represents a conventional diesel generator (Generator 2) operating in island mode.

The simulation program is first added generator power, cost, lifetime and fuel consumption data. After that, the capacity and costs of PV panels and wind turbines is added along with energy production curves. Voltage, capacity and cost values of the battery bank are also entered in the program.

After that, the parameters of the energy sources which constitute the system working conditions are entered into the program.

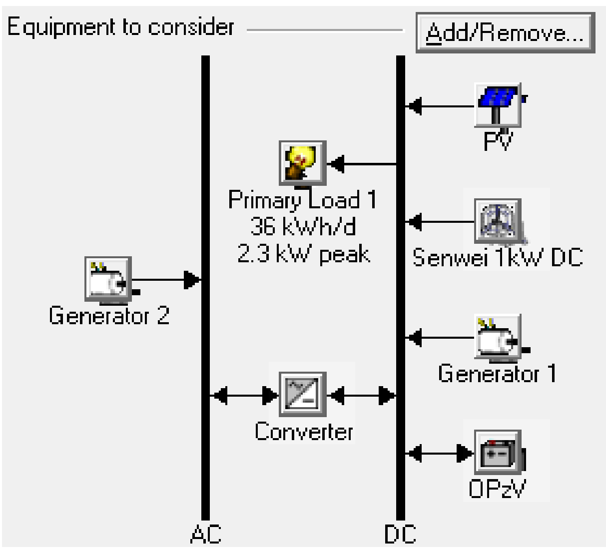


Fig. 12 Adding of system components [10].

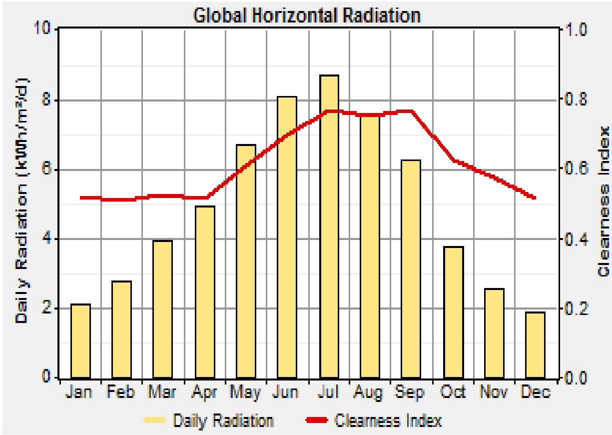


Fig. 13 Daily solar radiation distribution by months.

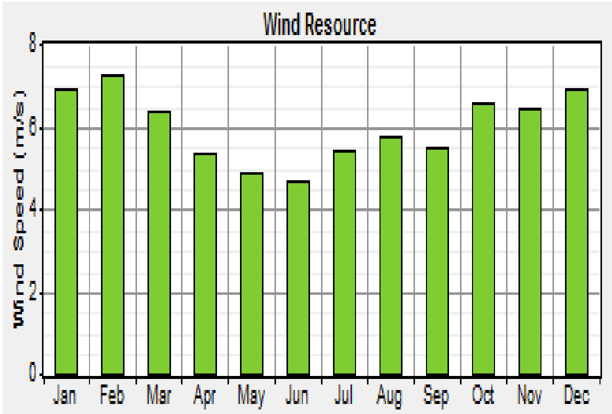


Fig. 14 Daily wind speed distribution by months.

The behaviour of the PV panels during the year, is determined by entering annual solar radiation and the clearness index factor of the atmosphere into the optimization program. In the same way, the distribution of the wind speed according to the months is also entered into the optimization program.

Finally, a load profile is defined to determine a behaviour model in the system optimization. The load profile varies depending on the seasonal air conditioning load and the intensity of the telecom system, which is the basic load, during the year. The load value is set at minimum 1 kW and maximum 2.3 kW during the year.

After completing the system design, the simulation process is started. In the simulation, the hybrid generator system is compared with the traditional diesel generator operating in island mode.

The system has been compared in terms of economic and working life, and the operating time of the generator, emission values and depreciation time is obtained.

The hybrid generator system is design for 10 years. Fig. 16 shows the costs for system components in the 10-year period. These costs include installation, fuel, replacement, operating and maintenance costs. In consideration of these costs, a comparison is made between the hybrid generator system and the conventional diesel generator.

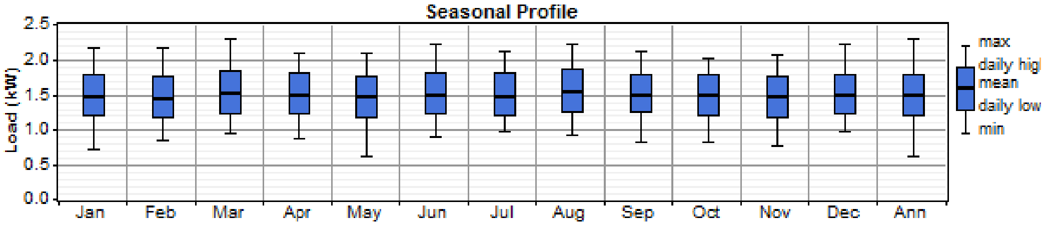
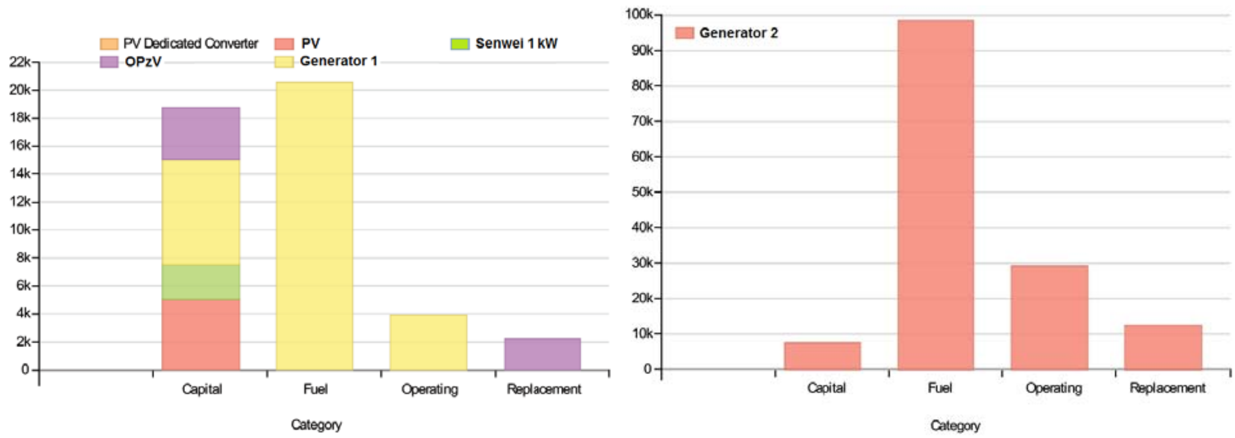


Fig. 15 Annual load profile by months.



(a) (b)

Fig. 16 Cost summary tables: a) Hybrid generator cost items, b) Conventional diesel generator cost items.

Production capacities of energy sources according to the months are shown below. Considering the annual electricity generation of the hybrid generator system, 48% of total production is obtained from the diesel generator, 35% from the solar panels and 17% from the wind turbine.

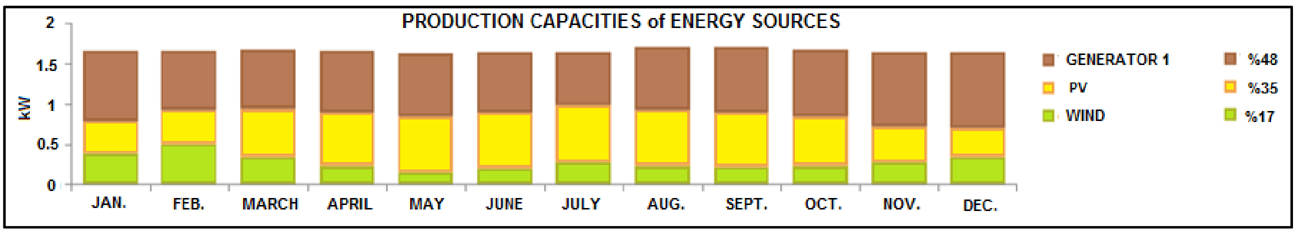


Fig. 17 Distribution of electrical production by months.

In a 10-year project period, the hybrid generator system provides a great advantage by saving up to 79% in fuel costs, 86% in operating and maintenance costs, and 78% in total costs, when compared to conventional generator under economic terms. If the hybrid generator system is used, the depreciation of the system will be a very short period as 1.6 years, which is considered a short time for long-term investments.

With the high charge current, the hybrid generator transfers the amount of energy that needs to be transferred to the system in a shorter period of time, thereby reducing maintenance and fuel costs to a minimum. The hybrid generator system provides significant advantages both in economic and environmental aspects by providing reductions of up to 79% in fuel consumption, 86% in generator operating times, and 79% in carbon dioxide and carbon monoxide emissions. The values are shown in Table 3.

Table 3 Comparison of operating conditions.

Cost items	Hybrid Generator System	Conventional Generator	Hybrid system advantage(%)
Fuel consumption (l/year)	2597	12421	79
Generator running hours (hours/year)	1184	8760	86
Carbon dioxide emissions (kg/year)	6815	32599	79
Carbon monoxide emissions (kg/year)	29	137	79

5. Conclusion

In this study, a hybrid generator system and a conventional generator operating in island mode, are compared under 1.5 kW average load conditions. Project life is determined 10 years in this study.

As a result of the simulation studies, it is seen that the initial installation cost of the hybrid generator system is high. However, in the 10-year period when the costs such as installation, operation, maintenance-repair and renewal are examined, it is seen that the hybrid generator is much more advantageous than the conventional diesel generator. Within the scope of this study, the Hybrid generator is amortized the investment cost as short as 1.6 years and offers great profit to the investor in the following period. Taking all these advantages into consideration, it would be more appropriate to use an efficient, low fuel consumption and environmentally sensitive hybrid generator system in off grid areas.

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