DESIGN AND ANALYSIS OF HYBRID GENERATOR SYSTEMS HYBRID GENERATOR SYSTEM

Hybrid generator system is an uninterruptible power supply which consists of a double-cycle diesel engine, a DC alternator, photovoltaic panels, a wind turbine and a battery bank, and operates at a nominal voltage of 48VDC. The system is designed to handle an average load of 1.5 kW and to operate at maximum efficiency under optimum operating conditions. Given the environmental conditions and system intensities, the system load varies and hence the working load is determined as maximum 2.3 kW. Antalya province was taken as basis in the design as the necessary operating conditions for the system.

The operating principle of the system is based on the DC supply voltage and the operating voltage is 48VDC. Solar energy and wind energy among the renewable energy sources are set at the optimum level and are suitable for supplying the load without the need for the generator to be commissioned under suitable conditions. However, only the daytime electricity is available from the sun and the load cannot be energized at night. Although the wind energy cannot be defined as clear as the solar energy, it is possible to generate power and supply load at certain hours of a day (Engin, 2010). The load is supplied from the battery bank due to the variations in the solar and wind energy. The solar and wind energy feed the battery bank and hence enable the batteries to have a longer cycle life.

When the solar and wind energy is insufficient, the battery bank feeds the load as discharged and the energy continuity is ensured. At the point where the battery bank drops to a certain depth of discharge, the diesel generator is activated to ensure the continuity of the energy transferred to the load, and the battery bank is recharged and becomes reusable. However, battery discharge limitations were introduced to make the battery bank longer lasting. By preventing the battery bank from falling below the depth of discharge of 50%, both the battery life is ensured to be longer and the operating period of the generator is kept at minimum level.

In addition, an inverter is adapted to system for the system-mounted cabinet air conditioner and also the lightning and the auxiliary AC power outlet in order to prevent the battery bank to be affected by the temperature factory negatively.

The cabinet air conditioner is designed to keep the temperature of the compartment divided for the battery bank below 20°C regardless of the ambient temperature.

A diagram showing the operating principle of the hybrid generator system is given below.

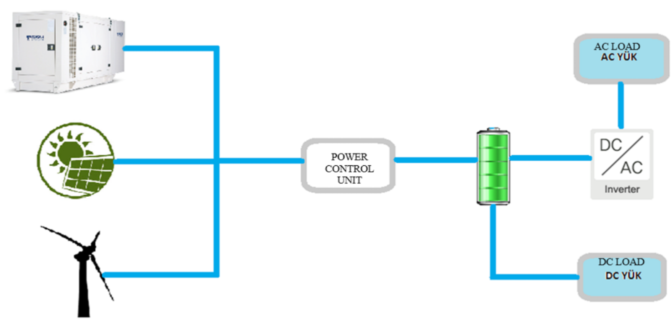


Figure-1: Operating principle of the hybrid generator system

Telecom systems were chosen as a base load for the hybrid generator. In our studies, the load power was selected as an average of 1.5 kW to ensure operation between 1-2 kW. 0.3 kW cooling and lighting loads were also included in the system.

SYSTEM COMPONENTS

1. Diesel Generator

The double-cycle diesel generator which is the main power source of the hybrid generator system is designed to operate at two different speed levels as 1500/1800 rpm. In order to meet the power requirements of the battery bank due to the high current value and charge, an engine with a capacity to provide a prime power of 10.3 kW at 1800 rpm was used. The potential frequency problems due to the different reference speeds were eliminated by using a DC alternator that can operate in consistency with variable circuit as an alternator. The generator starts at 1500 rpm and switches to 1800 rpm when it reaches high power points and hence provides the advantage of same power with a smaller engine and also less power consumption.

In this operating mode, the system switches it cycle depending on the load requirement as 1500 rpm in low power demands and as 1800 rpm in high power demands and hence the engine is ensured to remain at the most efficient points in terms of fuel consumption.

In Figure-2, a graph showing the comparison of the double-cycle diesel generator and standard generator operating in island mode at different powers is given. Due to the variable characteristic of the charging current, a load curve at different powers due to the charging and a constant average system load of 1.5 kW was obtained in the graph. The advantage of the hybrid generator for cases with different power is shown in the graph.

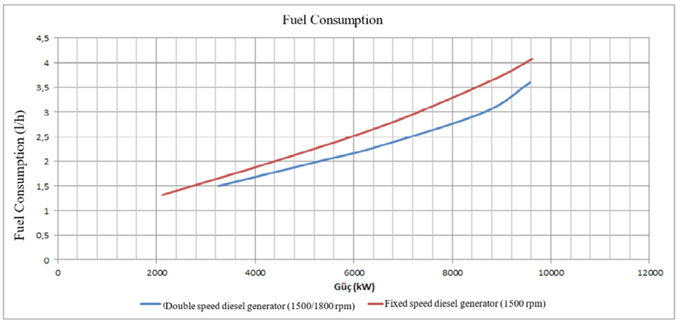


Figure-2: Fuel consumption – Power curve

2. PV Panel

Solar cells are equipment converting the photon energy from solar rays into electric energy. The energy is generated as DC voltage in solar panels. However, increases and decreases are seen in the generated voltage depending on the solar radiation during the day.

Turkey has a better position than the European countries in terms of annual sunshine duration and amount. Even in the provinces in the northern sections of our country, the annual solar radiation was measured as 1400-1500 kWh/m2-year (GEPA). These values show that our country is efficient in terms of solar power when compared with most of the European countries. However, our country falls behind the European countries in terms of using solar power.

In Figure-3 and Figure-4, the solar maps of Turkey and Antalya province are given.

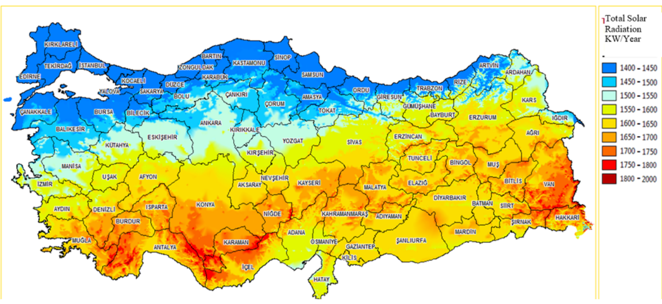


Figure-3: Solar power potential atlas for Turkey (GEPA)

In the hybrid generator design, the important parameters such as the solar radiation, sunshine hour, etc. in the operating region of the generator must be taken into consideration and the design must be carried out in accordance with these parameters.

The graphs showing the solar data of the Antalya province are given in the figures below.

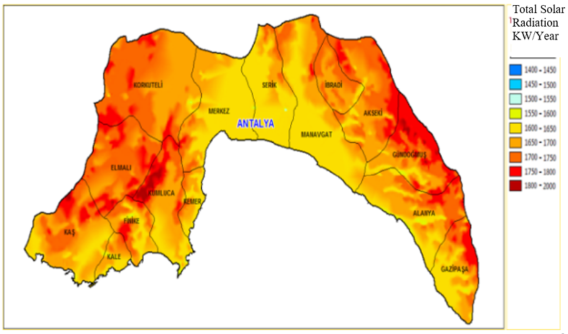
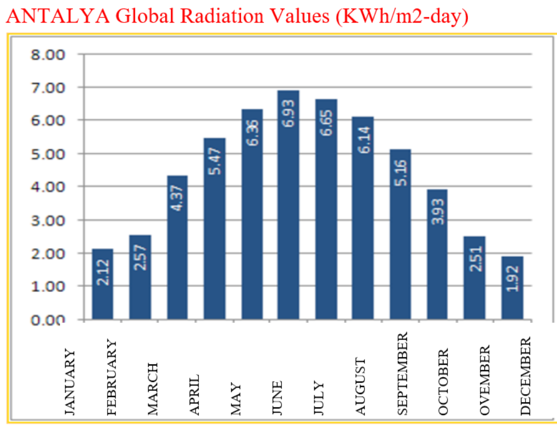


Figure-4: Solar power potential atlas for Antalya province (GEPA)



Şekil-5: Variance of the daily solar radiation of the Antalya province (GEPA)

The month with the highest daily solar radiation per m2 for Antalya province is June with 6.93 kWh/m2-day. Similarly, the month with the lowest daily solar radiation is December with 1.92 kWh/m2-day. In Figure-5, a graph showing these values is given.

Given the sunshine durations of Antalya province, the highest sunshine duration was 11.8 hours in July and the lowest sunshine duration was 4. 55 hours in December and these are shown in Figure-6.

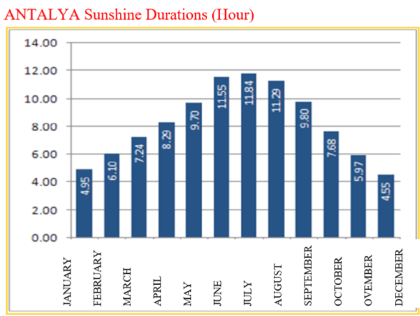


Figure-6: Sunshine durations by months for Antalya province (GEPA)

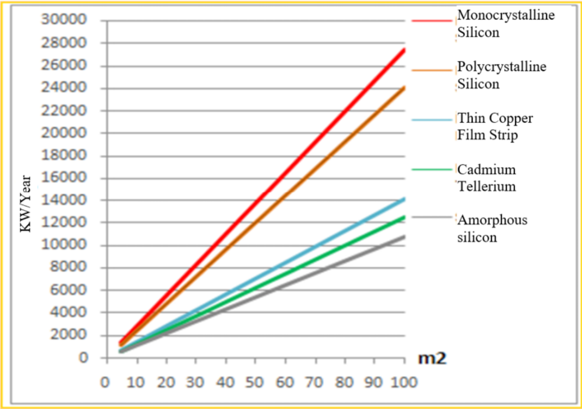


Figure-7: Energy that can be generated by different PV types for Antalya province (GEPA)

The solar panels used in the hybrid generator system are 14 units, each with 240 Wp power. The system power of solar panels is 3360 Wp. The open circuit voltage of the panels is 74VDC and the used 40A charge regulators can adjust the panel voltage according to the charging characteristic in the range of 48-56 VDC.

The solar panels used are of the polycrystalline silicon type and the total module efficiency is up to 14.7% under favorable conditions.

The panel slope, a factor that increases panel efficiency, shows large seasonal changes. Therefore, the annual optimum slope value was used for stationary systems. (Şenpınar,2006).
The technical values for the solar panels are given in the table below.

Table-1: Technical values for the solar panels

PV Panel Technical Data		
Solar Cell Type	-	polycrystalline silicon
Nominal Power	W	240
Nominal Voltage	V	29.73
Open Circuit Voltage	V	37.56
Short Circuit Current	A	Ağu.85
Cell Count	-	60 (6x10)
Module Count	-	14
Nominal Module Power	W	3360
Nominal Module Voltage	V	48
Dimensions (LxWxD)	mm	1670x1000x50
Cell Efficiency	%	17.20
Module Efficiency	%	14.Tem
* The parameters depend on the standard test conditions : 1000W/m^2 radiation		

3. Wind Turbine

Wind turbines are equipment converting the kinetic energy of the air into mechanic energy and generating electric energy via a connected alternator. The voltage generated by wind turbines is variable since it depends on the wind speed. In order to obtain high benefit from wind turbines, the turbine must be installed in regions with continuous wind and no obstructions to block the air flow to the turbine blades must be present.

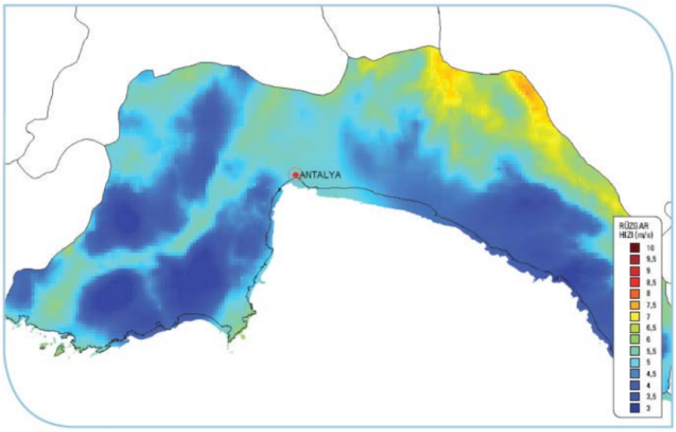


Figure-8: Wind map of Antalya (REPA)

The data used in the design of the hybrid generator was measured by considering the wind data of the Antalya province. The annual wind average for Antalya is between 5.5-6.5 m/s at 50 m (REPA). The wind data of the region where the system is to be operated will be considered during the system design and the design will be formed accordingly.

The wind turbine used in the hybrid generator system has a nominal power of 1 kW and used as an auxiliary power in the hybrid generator system. The wind turbine generated alternating AC voltage due to the variable wind speed. In order to adapt this variable voltage to the system, the voltage is made appropriate for the system voltage via AC-DC converter.

PMG alternator was used as an alternator in the used wind turbine. Therefore, the efficiency of the wind turbine is high. The table including the technical data of the wind turbine and the operating curve of the turbine are given in the figure below.

Table-2: Technical data of the wind turbine

Technical Data of The Wind Turbine		
Turbine Type	-	3 phase PMG
Nominal Power	W	1000
Nominal Voltage	V	48
Operating Wind Speed	m/s	Mar.25
Starting Wind Speed	m/s	2,5
Nominal Wind Speed	m/s	8
Gear Box	-	Yok

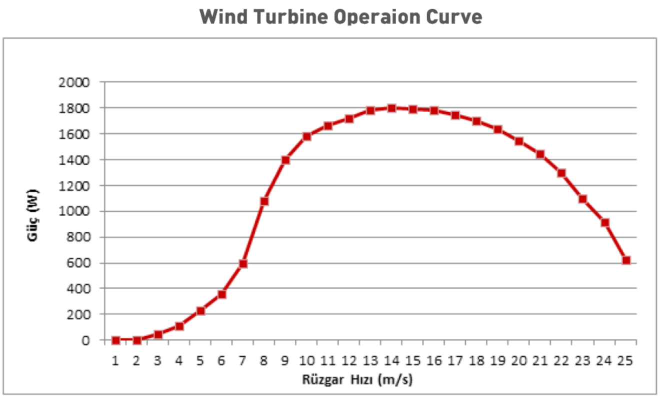


Figure-9: Turbine operating power

4. Battery Bank

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

24 pcs of hybrid 2V, 600Ah OPzV type batteries are used in the hybrid generator system. In order to reach the system voltage of 48VDC, 24 pcs of batteries are connected in series and the system voltage is reached. The current capacity is the capacity to operate an average of 1.5 kW load at a 50% discharge depth for about 10 hours without any external energy source. In case of emergency, even if the diesel generator and renewable energy sources are deactivated, it is possible to feed the system load for up to 20 hours by fully discharging the battery.

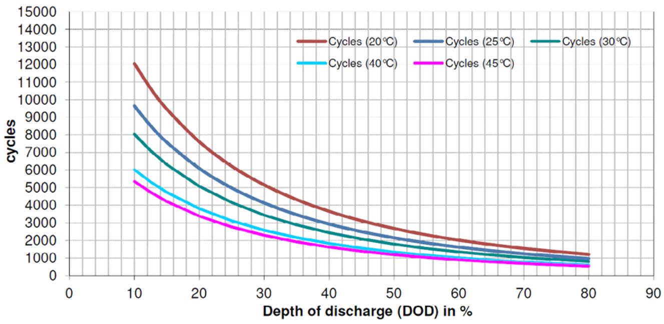


Figure-10: Discharge depth – cycle count graph

Given the current system design, the battery life is foreseen as 2800 cycles at 20°C and a discharge depth of 50%

5. Hybrid Control Unit

The hybrid control unit is an electronic control mechanism that manages the hybrid generator system, provides continuity of the 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 controls the operation of the system by monitoring electrical parameters such as current, voltage, and power.

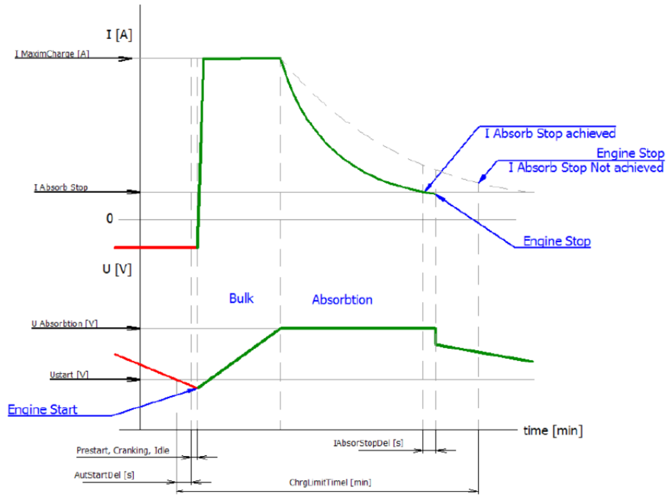


Figure-11: Battery charge cycle graph

The hybrid control unit keeps track of the battery bank and controls the charging and discharging status of the system. After the device input settings are made, the system monitors the discharged voltage with the system voltage during operation and automatically activates the generator when the battery falls below the specified voltage or capacity level. The activated generator supplies the load while charging the batteries.

As the charging procedure is seen in the figure given above, the battery charging is performed with constant current until the battery voltage absorption reaches to charge voltage following the activation of the generator. The constant current charge is input to the system as 100A and the batteries are charged with this current value until the system voltage reaches the absorption voltage. When the battery voltage reaches the absorption voltage (56.4 V), charging continues with constant absorption voltage. In this phase, the charging current gradually decreases and charging ends when the specified charge finishing current value is reached.

The same charging phases are applied to both the energy obtained from the sun and the wind and to its own charging regulators, and it is transmitted to the DC distribution bus bar.

6. Inverter

Inverter is a power equipment that converts the DC battery voltage into AC mains voltage. In common, it is used in applications when the DC voltage generated in the renewable energy systems is desired to be connected to the mains.

In our system, the inverter is used to eliminate the need of mains in loads requiring AC voltages in addition to DC working load such as air conditioners and lighting used for the batteries.

In addition, it can be used as auxiliary AC power output in power demands up to 1 kW with the auxiliary power outputs on the inverter without the need of mains connection.

SYSTEM SIMULATION

The hybrid generator system was designed with an optimization program used for hybrid systems and system simulation was done. The meteorological values of the Antalya region where the system will work were taken into consideration during the design in order to obtain simulation results close to real values. Thus, the simulation results were intended to contain more accurate values.

The design of the hybrid generator system began with the addition of system components. Subsequently, the data of each component was transferred to the optimization program. Here are the reasons for adding 2 generators; one represents the existing hybrid generator, and the other represents a standard diesel generator operating in island mode.

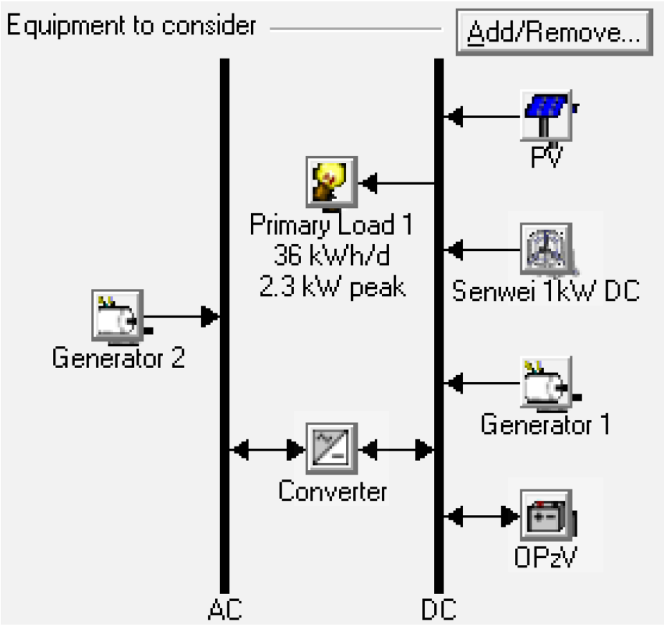


Figure-12: Addition of the system components

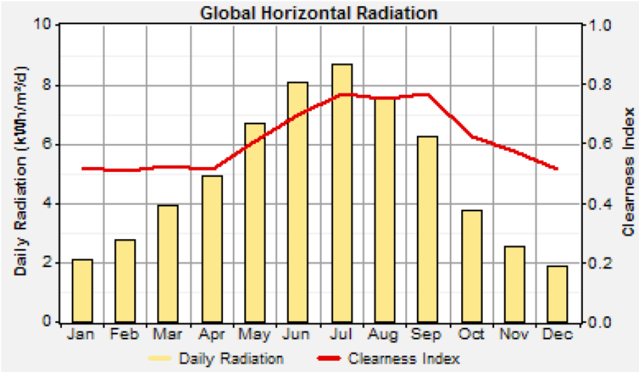


Figure-13: Distribution of the daily solar radiation by months

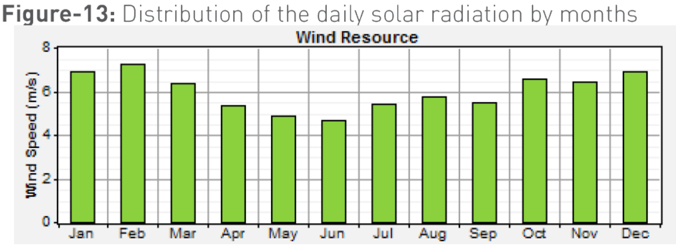


Figure-14: Monthly average values of the wind speed

Following the addition of the components, the data for each component was transferred to the optimization program. In this context, the design process was continued by inputting PV panel capacity and costs; wind turbine capacity, cost and wind power curve data; power, cost, longevity and fuel consumption values of generators; voltage and capacity values of battery bank.

Following these operations, parameters belonging to the energy sources constituting the system working conditions were entered into the program.

The behavior of the system during the year is determined by entering the distribution of solar energy over the year and the openness index factor of the atmosphere into the optimization program.

Similarly, the distribution of the wind speed of wind energy by months was entered into the optimization program and the system design was continued.

Finally, a behavior model is defined for system optimization by defining a load profile in the system. 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 minimum load value during the year is set at 1 kW and the maximum load value is set at 2.3 kW.

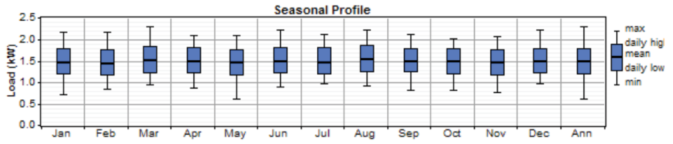


Figure-15: Annual load profile

Following the system design, the simulation process was started. The hybrid generator system including a double-speed diesel generator, solar panels and a wind turbine, and a standard diesel generator operating in island mode were compared in the simulation.

The system was compared in terms of economy and service life and the operating periods, emission values of the generator and the depreciation time of the system was obtained.

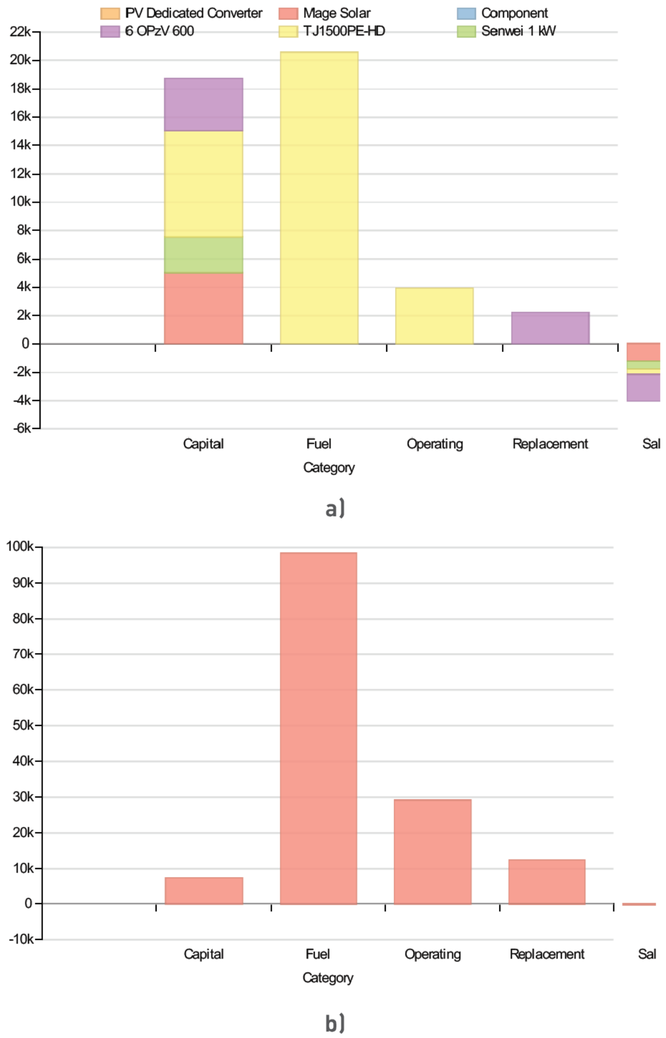


Figure-16: Cost statements a) Hybrid generator cost items b) Standard generator cost items.

The system is designed for more than 10 years and the above figures show the costs incurred on different items over 10 years. These costs include installation and operating costs. After the installation costs, the cost of the two systems were compared by considering the fuel and maintenance and battery replacement costs occurred during the operating life.

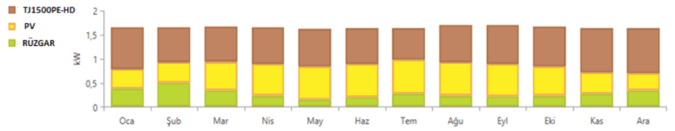


Figure-17: Electricity generation distribution by months

The graph shows the distribution of the rate of providing the average load values by months of the energy sources. Given the annual electricity generation of the hybrid generator system, 48% is obtained from the hybrid generator, 35% from the solar panels and 17% from the wind turbine.

When the hybrid generator system and standard generator system are compared in terms of economy, the hybrid generator system provides a significant advantage up to 79% in fuel costs, up to 86% in operating and maintenance costs and up to 78% in total costs for a project period of 10 years. The depreciation of the system will be a very short period such as 1.6 years when the hybrid generator system is used and this period is accepted as a very good period for long term investments.

Table-3: Comparison of the operating conditions

COMPARISON OF THE OPERATING CONDITIONS			
	HYBRID SYSTEMS	STANDARD GENSET	ADVANTAGE OF THE HYBRID SYSTEM (%)
Fuel consumption (L/year)	2597	12421	79%
Generator operating hours (hour/year)	1184	8760	86%
Carbon dioxide emission (kg/year)	6815	32599	79%
Carbon mono oxide emission (kg/year)	29	137	79%

The hybrid generator transfers the required energy amount for the system in shorter periods with the high charging current and hence the maintenance and fuel costs are reduced to minimum level. When the hybrid generator system and the standard generator operating in island mode are compared in terms of operating conditions, the hybrid generator system has a significant superiority over the standard generator.

The hybrid generator system provides significant advantage with decreases by 79% in fuel consumption, 86% in generator operating hours, and up to 79% in carbon dioxide and carbon monoxide emissions.

CONCLUSION

In this study, a comparison of the operating conditions of the hybrid generator system with the standard generator operating in island mode, under an average load of 1.5 kW were examined. The initial installation cost for the hybrid generator for a project period of 10 years for this study is high. However, when the costs such as installation, operation, maintenance-repair and renewal made within 10 years are examined, it is seen that the hybrid generator is much more advantageous than the standard generator. Within the scope of this study, the hybrid generator eliminates the investment cost in a short period of time like 1.6 years and presents great profit to the investor in the following period. Given all these advantages, it would be more appropriate to use an efficient, low fuel consumption and environmentally sensitive hybrid generator system in regions which are distant to the network.

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GEPA, Solar Energy Potential Atlas

REPA, Wind potential atlas for Antalya

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