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Assessment of Economic Viability for PV Based Hybrid Energy System in West Coast of Turkey

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Abstract - In this paper, a pre-feasibility study of using PV-based hybrid energy system to provide electricity to a residential area in west coast of Turkey is examined. The selected case study represents a power demand of 12.6kWh day-1 with a 2.9 kW peak power demand. The power system used in this study contains diesel generator, grid connection and PV modules with backup storage. The energy system was redesigned and optimized as PV based in order to meet the existing user's power demand at a minimum cost of energy. Temperature and solar radiation data obtained from Ege University meteorology station has been used in the simulation process through optimization software, HOMER. Three systems that were considered in this study area are stand-alone PV-diesel, stand-alone PV-battery and grid connected PV system. The proposed systems then were compared regarding on their operational characteristics and cost values. The comparisons prove that grid connected PV energy system had the lowest total net present cost and cost of energy, $53,197 and $0.57/kWh, respectively that makes it the most cost effective system and followed by PV-diesel and stand-alone PV-battery system. It can be concluded that the renewable-based system can become a favorable system without aid from the grid system and bring advantage in technical and economic point of view and also suitable to be applied in the residential application as energy supply if only the current cost of PV arrays and battery system technology have been reduced to its minimum rate.

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ASSESSMENT OF ECONOMIC VIABILITY FOR PV BASED HYBRID ENERGY SYSTEM IN WEST COAST OF TURKEY

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Assessment of Economic Viability for PV Based Hybrid Energy System in West Coast of Turkey

Mustafa Engin [α] & Dilşad Engin [σ]

Abstract - In this paper, a pre-feasibility study of using PV-based hybrid energy system to provide electricity to a residential area in west coast of Turkey is examined. The selected case study represents a power demand of 12.6kWh day-1 with a 2.9 kW peak power demand. The power system used in this study contains diesel generator, grid connection and PV modules with backup storage. The energy system was redesigned and optimized as PV based in order to meet the existing user's power demand at a minimum cost of energy. Temperature and solar radiation data obtained from Ege University meteorology station has been used in the simulation process through optimization software, HOMER. Three systems that were considered in this study area are stand-alone PV-diesel, stand-alone PV-battery and grid connected PV system. The proposed systems then were compared regarding on their operational characteristics and cost values. The comparisons prove that grid connected PV energy system had the lowest total net present cost and cost of energy, $53,197 and $0.57/kWh, respectively that makes it the most cost effective system and followed by PV-diesel and stand-alone PV-battery system. It can be concluded that the renewable-based system can become a favorable system without aid from the grid system and bring advantage in technical and economic point of view and also suitable to be applied in the residential application as energy supply if only the current cost of PV arrays and battery system technology have been reduced to its minimum rate.

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I. Introduction

The technologies for power production from renewable energy sources such as solar are available and reliable. The rapid decrease in the PV module cost during the past few years and the recent escalation in the price of conventional petrochemical fuels used for generating electricity, resulted in the wider usage of PV based energy systems. The advantages of using solar resources to generate electricity include the avoidance of pollutant emissions, silent operation. The amount of annual solar energy reaching the Earth's surface is about 10,000 times more than annual global energy demand [1].

Recently, in order to reach sustainable development, humankind needs to be steady on the path of low-carbon society. For this reason, in order to make an efficient use of electrical energy there is a growing interest in optimizing the design of urban settlements by means of the exploitation of natural sources of energy and the development of building management systems [2]. Additionally, electrical power nets are in a transition stage where these need to be more flexible and dynamical at all levels, from power generation plant to customer level in order to enable distributed generation, to promote efficient use of energy at customer level, and to reach an intelligent demand response [3], [4]. The generation of electrical energy through of alternative sources such wind and solar, has become more attractive [5], [6] and is widely used for substituting fossil fuels in the process of electrical power energy since 1970s because of the crisis oil [7]. Nevertheless, such alternative energy sources have a slow development [8], and the transition into a new phase of evolution in the electrical power generation sector appears to be a complex task because of the different insights of the problem [9], not only due to environmental, and economic issues, also because of social and psychological impacts on people's behavior [10]. Although PV systems are an expensive option of generating electricity when compared to other systems; this technology has been supported due to its potential benefits, which can be classified as customer-related benefits, electric utility-related benefits and environmental benefits. Earning revenue by selling PV electricity can be given as an example for the customer-related benefits. The examples for the electric utility-related benefits are; reduced transmission and distribution costs and losses, peak shaving, and meeting peak demand. CO_2 savings, NO_X and SO_2 savings can be listed as the environmental benefits of PV systems [11].

At the beginning of 2011, Turkish parliament adopted a new feed-in tariff policy of equally limited duration of 10 years, and equally limited objectives of 600 MW of total capacity. The feed-in tariffs for solar photovoltaic (PV), the most costly of the new renewable technologies, are only US$0.13/kWh. One divergence from previous policy, Turkey will now offer incentives for hardware 'Made in Turkey'. Solar PV systems made in Turkey would qualify for a bonus payment of nearly

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US$0.07/kWh [12]. Industry observers have widely penned the new program to be insufficient to create the volume necessary to attract manufacturing.

The present study is proposed to design a PV based hybrid energy system to provide electricity for a residential house in İzmir, Turkey. The system simulation performed to estimate its operational characteristics, such as annual electricity production, annual loads served, excess electricity and capacity shortage. The proposed systems then were compared concerning on their operational characteristics and cost value in order to meet the user's power demand at a minimum cost of energy.

II. Hybrid Power System

A hybrid energy system generally consists of a primary renewable source working in parallel with a standby secondary non-renewable module or grid and storage units. The energy system components are PV module, diesel generator, grid, battery and power converter. Description of these components is given in the following sections.

a) Electrical Loads

The demand for electricity in each area is different and therefore depends on numerous factors, such as the price of electricity, the weather conditions, the time of day, the type of day and the season. The load profiles describe the variation of the electricity demand with time. The hourly load profile provides crucial information on how electricity is used, and thus on where and what demand side management strategies could be potentially effective. Demand side management is the process of managing the consumption of energy to optimize available and planned generation resources.

There are six generic load shape objectives that can be considered during demand-side management planning, namely peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape. The desired changes in the load shape can be obtained by shifting load to a less expensive time period, or by substituting another resource for delivered electricity such as solar PV/Battery systems. [13].

The data were taken from a small house which is located in Izmir near to solar energy institute building. The electrical load components include fluorescent lamps, ceiling fan, television, refrigerator, air conditioner, and also washing and dish washer machines which are the main components for a small house. The home owner uses demand side management by shifting load to inexpensive hours. The seasonal and daily profiles of household electricity demand which is measured power are presented in (Figure 1) and (Figure 2) respectively.

b) Solar Radiation Resources

Renewable energy sources are intermittent and naturally available due to these factors our first choice to meet household electric demand will be solar energy. Weather data are important factor for pre-feasibility study of PV based hybrid energy system for any particular site [14]. Hourly solar radiation data for year 2010 was collected from solar-wind meteorological station which is located on the roof of the Vocational School Building in Ege University for determining the local potentials of both solar and wind energy [15]. Using this data, the monthly average daily solar radiation and calculated clearness index are plotted in (Figure 3).

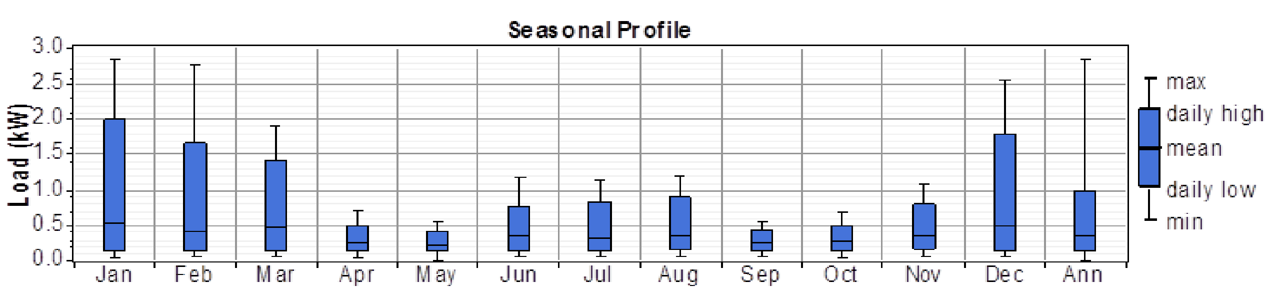

Fig. 1 : Seasonal profile of sample household electricity demand.

c) PV based Hybrid System Components

The installation cost of PV arrays may vary from $3.38 - $3.02 /W. A 1 kW solar energy system installation and replacement costs are taken as $3380 and $3000, respectively [16]. In this study, various sizes were considered, ranging from 0-13.5 kW. The lifetime of the PV arrays are taken as 25 years and no tracking system was included in the PV system.

Battery bank is used as a backup system and it also maintains constant voltage across the load. The battery pack consists of 6V, 360 Ah batteries connected in series of 6. For a 1 kWh battery pack, the installation and replacement costs were taken as $213 and $200, respectively [16]. During simulation, different sizes of batteries capacity (0 through 50 kWh) were considered. Lifetime of a unit was considered to be 10 years with an efficiency of 85%.

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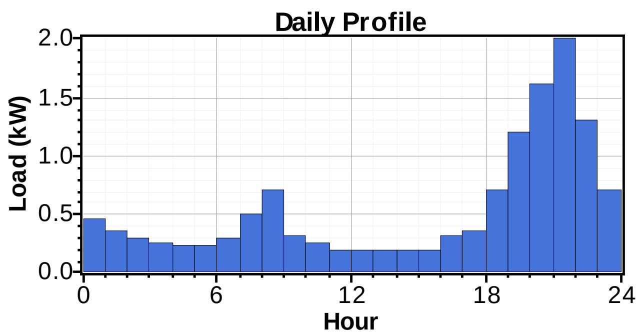


Fig. 2 : Daily profile of sample household electricity demand.

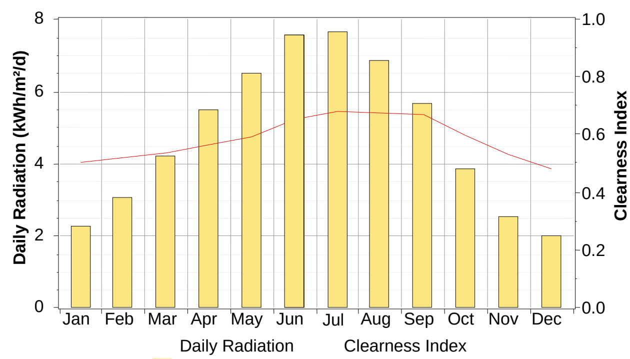


Fig. 3 : Monthly average daily radiation and clearness index.

A power electronic converter needs to maintain flow of energy between the ac and dc components. For a 1 kW system the installation and replacement costs were taken as $715 and $700, respectively [16]. Ten different sizes of converters (0, 1, 2.5, 3, 3.5, 4, 4.5, 5 and 7 kW) were considered for the simulation. Lifetime of a unit was considered to be 15 years with an efficiency of 95%.

d) Homer

HOMER is an optimization software package which simulates varied renewable energy sources system configurations and scales them on the basis of net present cost which is the total cost of installing and operating the system over its lifetime [17]. It firstly assesses the technical feasibility of the RES system. Secondly, it estimates the NPC of the system. HOMER models each individual system configuration by performing an hourly time-step simulation of its operation for one year duration. The available renewable power is calculated and is compared to the required electrical load. Following calculations of one-year duration, any constraints on the system imposed by the user are then assessed; e.g. the fraction of the total electrical demand served or the proportion of power generated by renewable sources. Net present cost (NPC) represents the life cycle cost of the system. The calculation assesses all costs occurring within the project lifetime, including initial set-up costs, component replacements within the project lifetime, maintenance and fuel. Future cash flows are discounted to the present. HOMER assumes that all prices escalate at the same rate, and applies an annual real interest rate rather than a nominal interest rate. NPC estimation in HOMER also takes into account salvage costs, which is the residual value of power system components at the end of the project lifetime.

III. Result and Discussion

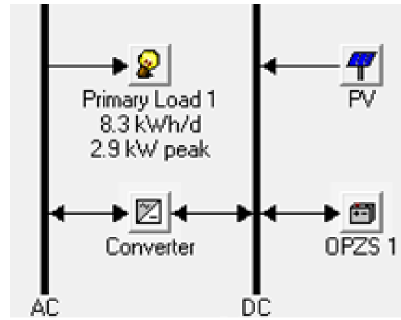
Two different PV based hybrid energy systems are investigated. First one is stand-alone PV based hybrid energy system. In this scenario, household load is supplied with solar energy. HOMER model of the system is given in (Figure 4-a). Second one is PV grid-connected hybrid energy system. In this scenario, household load is supplied with solar energy system connected to the grid. HOMER model of the investigated system is given in (Figure 4-b). In this case, if solar energy is not enough to supply the household load, the needed energy is supplied by purchasing energy from the grid. Otherwise, if the energy produced by PV arrays excesses the energy demand of household, the excess electrical energy production is sold to the grid.

The above proposed PV based hybrid energy systems supply the power to the household continuously throughout the year. For the analysis of these hybrid systems, consider three sensitivity variables: solar irradiation, temperature and renewable energy fraction. For each of the sensitivity values, simulate all the systems in their respective. An hourly time series simulation and configuration for every possible system type is done for a one-year period. A feasible system is defined as a solution for hybrid system configuration that is capable of meeting the load demand of household. It also allows a number of parameters to be displayed against the sensitivity variables for identifying an optimal system type.

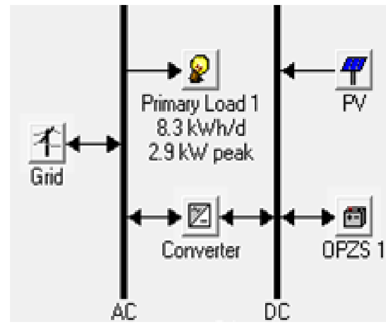
According to the first scenario, net present cost values of optimal system solution for stand-alone system components are given Table 1. Monthly average electricity production of stand-alone PV based hybrid energy system for household demand is shown in (Figure 4). From the simulation results, the installation of PV based hybrid system stand-alone configuration is not suitable for power solutions of residential application in İzmir region. Considering present cost analysis of a PV based hybrid system, stand-alone configuration is suitable for loads which stand more than 10 km far away from the grid. Total net present cost (NPC), capital cost and cost of energy (COE) for such a system is $36,150, $27,469 and $0.940/kWh respectively.

In the second scenario, for the grid connected PV based hybrid energy system, two different solutions are obtained as optimal system configurations. First one is defined according to the lowest energy cost and second one is defined with the highest renewable energy fraction. During simulation, energy purchase price and sellback prices are used as $0.198/kWh, $0.13/kWh [18] respectively. In the first solution, detailed annual electricity production by grid-connected hybrid system components is shown in (Figure 6) and net present cost values of optimal system solution for grid connected configurations are given Table 2. Total net present cost (NPC), capital cost and cost of energy (COE) for grid-connected system is $8,073, $3,735 and $0.208/kWh respectively.

For the second solution, that has the highest renewable fraction with lowest cost of energy, optimal system component size and cost values are given in (table 3) whereas detailed annual electricity production by grid-connected hybrid system components is shown in (figure 7). In this solution, energy cost is obtained as $0.442/kWh with 87% renewable fraction. If we compare this cost of energy which is obtained from grid connected hybrid systems solution with Turkish utility ($0.198/kWh) and fed-in tariff prices ($0.13 kWh), it is relatively high.



(a)



(b)

Fig. 4 : HOMER model of (a) Stand-alone (b) PV-grid connected hybrid energy systems.

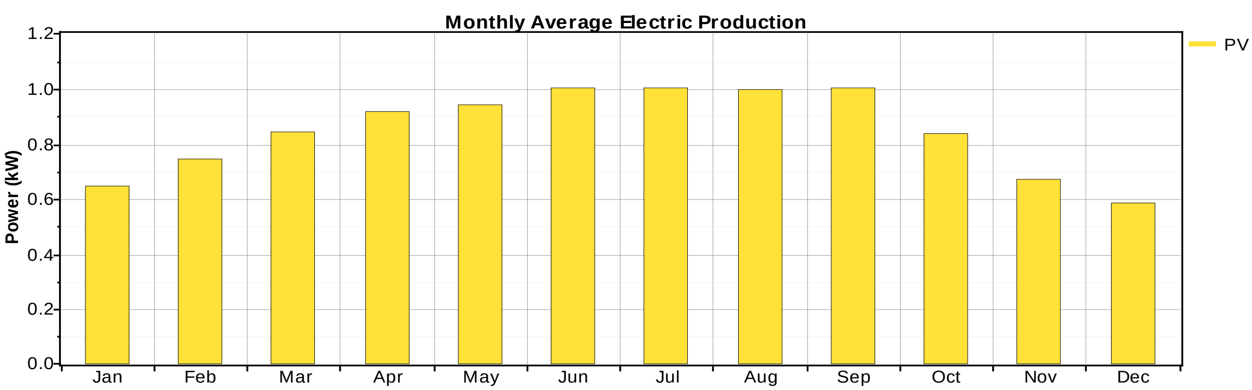


Fig. 5 : Monthly average electricity production of stand-alone PV based hybrid Energy System.

Table 1 : Net present cost of stand-alone system.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	15,100	0	64	0	0	15,164
STATIONARY BATTERY	10,224	8,772	307	0	-1,174	18,128
Converter	2,145	876	0	0	-163	2,858
System	27,469	9,648	371	0	-1,337	36,150

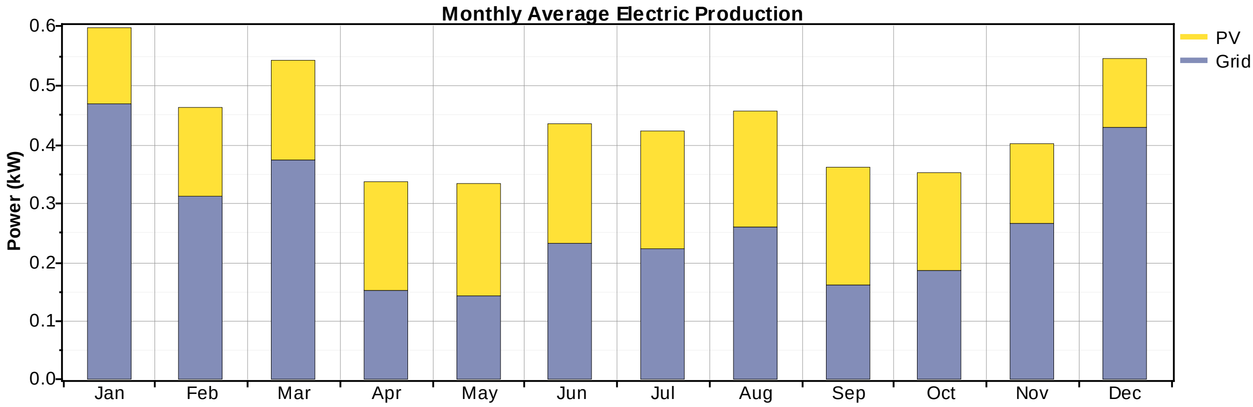


Fig. 6 : Monthly average electricity production of grid-connected PV based hybrid Energy System.

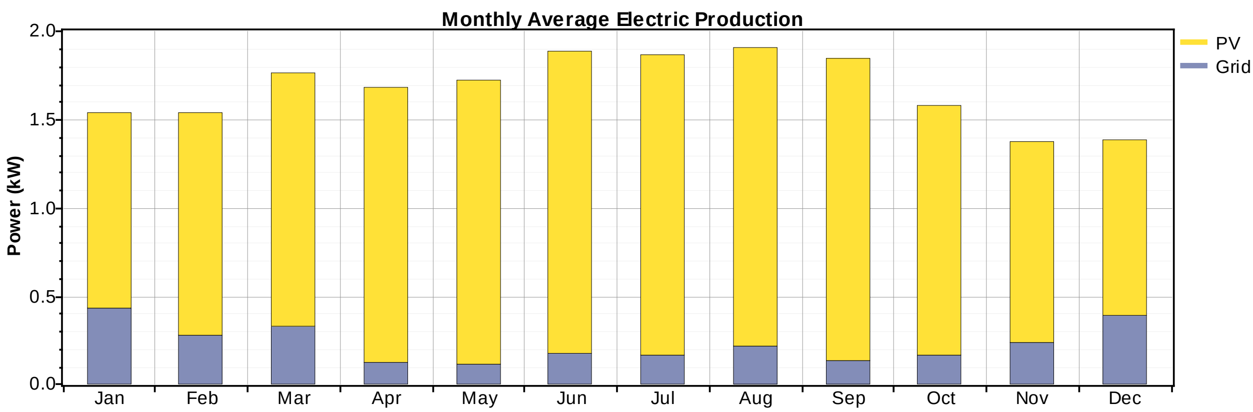


Figure 7 : Monthly average electricity production of grid-connected PV based hybrid Energy System.

Table 2 : System component size and net present cost of grid-connected system with lowest energy cost.

Component	Size	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	1 kW	3,020	0	13	0	0	3,033
Grid	-	0	0	4,087	0	0	4,087
Converter	1 kW	715	292	0	0	-54	953
System		3,735	292	4,100	0	-54	8,073

Table 3 : System component size and net present cost of grid-connected system with highest renewable fraction.

Component	Size	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	9 kW	27,180	0	115	0	0	27,295
Grid	1 kW	0	0	-15,859	0	0	-15,859
Converter	6 kW	4,290	1,753	0	0	-326	5,716
System	-	31,740	1,753	-15,744	0	-326	17,152

II. Conclusion

Alternative power solutions are not commonly used in residential applications in cities today, but are actively used for remote and isolated areas worldwide. The circumstances of each site are studied in order to decide the feasible combination of alternative energy resources. With the aid of above mentioned pre-feasibility study, the PV based hybrid energy system is found to be an inadequate power solution for household electricity demand for the selected site over conventional grid connection. Although the net present cost is high, the running and maintenance costs are low as compared to the grid connection. With decreasing PV module prices, payback times on the PV based hybrid energy system investment are continuously decreasing. Considering operating and maintenance costs, an autonomous site powered by PV based hybrid system pay-off after 6-8 years in a good sunny location. Also newly announced Turkish grid connected PV feed-in tariff prices will descend to a feasible level for investor.

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