THE ROLE OF HYBRID POWER SYSTEMS TO CREATE SELF-SUSTAINING SMART HOMES FOR THE ELDERLY AND DISABLED

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Abstract:

With the increase in the number of the elderly and due to the disabled' demand for independent living, there is significant interest in smart home technologies which can assist the elderly and disabled to continue living at home with independence and safety. The feasibility and effectiveness of smart home technologies for promoting independence, health, and quality of life have been proved in the literature. In recent years, there is increasing interest from care providers to provide caregiving services for the elderly and disabled in their home environments instead of caring them in assisted-living centres due to a number of reasons including costs. Since caregiving services are provided at specific times, a few times a day or week, smart home technologies can help care providers deploy services which trigger alerts when urgent situations occur. However, due to the cost of caregiving services, maintenance costs of smart home systems, and increasing electric energy consumption, generating electricity from renewable energy sources can play an important role for this objective. In this study, we present an environmentally friendly hybrid power system which automatically chooses its energy source(s) without any user input and give the results of simulation study performed using Homer software. The simulation study proves that the proposed hybrid power system can easily generate electricity required by a smart home.

Keywords: Smart homes, renewable energy sources, self-sustainability, the disabled, the elderly.

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Hibrid Güç Üretim Sistemlerinin Yaşlı ve Engelli Bireyler için Kendi Kendine Yetebilen Akıllı Evler Gerçekleştirmede Önemi

Özet:

Yaşlı sayısındaki artış ve engellilerin bağımsız yaşam talepleri nedeniyle, yaşlılara ve engellilere evde bağımsız ve güvenli bir şekilde yaşamlarını devam etmeleri için yardımcı olabilen akıllı ev teknolojilerine büyük bir ilgi vardır. Literatürde akıllı ev teknolojilerinin bağımsızlık, sağlık ve yaşam kalitesini arttırmadaki yapılabilirliği ve etkililiği ispatlanmıştır. Son yıllarda, bakım sağlayıcılar tarafından maliyetleri de içinde bulunduran birçok nedenden dolayı yaşlıların ve engellilerin yaşam merkezlerinde bakımlarının sağlanması yerine kendi ev ortamlarında bakım hizmetlerinin sağlanmasına yönelik artan bir ilgi vardır. Bakıcı hizmetleri belirli zamanlarda sağlanmış olması nedeniyle, günde ya da haftada birkaç kez, akıllı ev teknolojileri bakım sağlayıcılara acil durumlar meydana geldiğinde alarmları harekete geçiren hizmetlerin dağıtılmasıyla yardımcı olabilir. Ancak, bakım hizmetlerinin maliyeti, akıllı ev teknolojilerinin bakım maliyetleri ve artan elektrik enerjisi tüketiminden dolayı, yenilenebilir enerji kaynaklarından üretilen enerji bu amacın gerçekleştirilebilmesi için önemli bir rol oynamaktadır. Bu çalışmada, herhangi bir kullanıcı girişi olmadan otomatik olarak enerji kaynağını seçen çevre dostu hibrid güç sistemini ve Homer yazılımını kullanarak gerçekleştirilen benzetim çalışmasının sonuçlarını sunuyoruz. Benzetim çalışması, önerilen hibrid güç sisteminin akıllı ev için gerekli elektriği kolaylıkla üretebildiğini kanıtlamaktadır.

Anahtar Kelimeler: Akıllı evler, yenilenebilir enerji kaynakları, kendi kendine yetebilirlik, engelliler, yaşlılar.

1   INTRODUCTION

With the rapid population ageing occurring worldwide, there is significant interest in smart technologies which can assist the elderly to continue living at their homes with safety and independence. Most elderly people are not strong enough and therefore prone to accidents. Similarly, disabled individuals are handicapped and therefore cannot perform some movements. Although living in an assisted-living facility may seem attractive, it costs a great deal amount per year and some families cannot afford this. In addition, most of the elderly and disabled individuals prefer living in their homes instead of living in assisted-living facilities.

In recent years, with the advances in information and communications technologies, reliable remote monitoring of the elderly and disabled has become practically and easily available. Therefore, it is now possible to remotely monitor a disabled or old individual and in case of an alert immediate help can be provided by the healthcare provider. In this regard, with their novel features and technological solutions, smart homes can greatly help the elderly and disabled without interrupting their daily lives and making them feel uncomfortable. Smart homes not only provide services for the specific needs of the elderly and disabled but also can help healthcare providers or caregiving providers to improve the quality of their services.

Smart home systems can be easily installed using a set of electronic components with different functions, which are mostly invisible or barely visible [1, 2] to increase the acceptance level. Smart homes generally require noncomplex and inexpensive maintenance. Smart home systems rely on intelligent monitoring software to monitor and control household appliances, collect data from a group of sensors and detectors, recognize the monitored individual's activity pattern, and finally interpret all the essential activities. They typically provide security features, automated timers, warnings and alerts, emergency assistance systems, and fall prevention features [1]. To sum up, with their unique features and advantages, smart homes offer safety, security and independence to the elderly and disabled, and enable the family members and relatives to monitor them remotely.

Self-sustainability is the ability of a system to sustain itself independently without external support. Since one of the most important needs of smart homes is electricity and smart homes designed according to the specific needs of the elderly and disabled include more electronic components, the use of renewable energy sources for electricity generation can

greatly help the householders. Accordingly, in this paper, we review the use of hybrid power systems to provide sustainable smart houses for the elderly and disabled and present its benefits. The rest of the paper is organized as follows. Smart homes and their components are reviewed in Section 2. Section 3 explains the proposed hybrid power system and presents a simulation study carried out to prove the efficiency of the proposed system. Finally, the paper is concluded in Section 4.

2 SMART HOMES FOR THE ELDERLY AND DISABLED

A smart home basically consists of a display acting as the control panel, a group of wireless/wired sensors, a group of audio-visual systems, entrance security system, a remote management tool, and an intelligent self-learning software-based system supported by machine learning algorithms and analytics [1-5]. Some smart home systems also include the ability of monitoring fire and water leakage. Smart homes designed for the elderly and disabled also include distributed motion detectors to monitor movements inside the home, track the status of stovetops and water faucets, and recognize the use of household appliances.

The main aim of smart home systems is to collect information on monitored individuals' daily activity levels in order to learn personal patterns. This way, it is possible to generate alerts and enable taking immediate actions when monitored patterns deviate from the norm patterns [5-10]. In sum, with its state-of-the-art sensor technologies, advanced software tools and self-learning intelligent care solutions, smart homes can take some of the worry off by providing remote monitoring ability to family members of the elderly and disabled.

Since it is aimed to deploy smart home systems rapidly without much disturbance, alterations and damage in home environments, wireless communications technologies can enable sensors to communicate with the smart home systems. Although there are many competitive wireless communications technologies, with its superior features, ZigBee has become de facto standard for smart home systems [11]. Typical major requirements of smart home systems are as follows [2]:

- Smart home systems must be flexible, scalable and open to improvements.
- Sensors to be deployed must be small-sized so that they can be completely invisible.
- Sensors must be highly precise and accurate.
- A set of analyses must be conducted to foresee abnormal situations.

3 PROPOSED HYBRID POWER SYSTEM

Considering the fact that smart homes designed for the elderly and disabled involve more electronic components and it is desirable to reduce electricity costs, the proposed hybrid power system can be of great help. On the other hand, the operations of smart home electrical appliances preferred in smart home homes are generally scheduled for specific time zones. Therefore, electricity generation systems proposed for smart homes must be able to provide the required electricity demand which can be at peak levels sometimes. However, renewable energy sources are not continuously available. Hence, energy storage solutions are required in case of the use of renewable energy sources.

In this paper, we propose a hybrid power system as shown in Figure 1. The proposed hybrid power system consists of a solar panel, a wind turbine, a converter, and a battery to store the excess electricity harvested by the system. The battery stores energy harvested by the solar panel and the wind turbine and is responsible for providing power when the renewable sources are not available. The proposed hybrid power system is supposed to be used in a home in Gebze, Turkey. Accordingly, Figure 2 shows average daily radiation and Figure 3 shows average daily wind speed used in the simulation study. Load demand of the simulated house is shown in Figure 4.
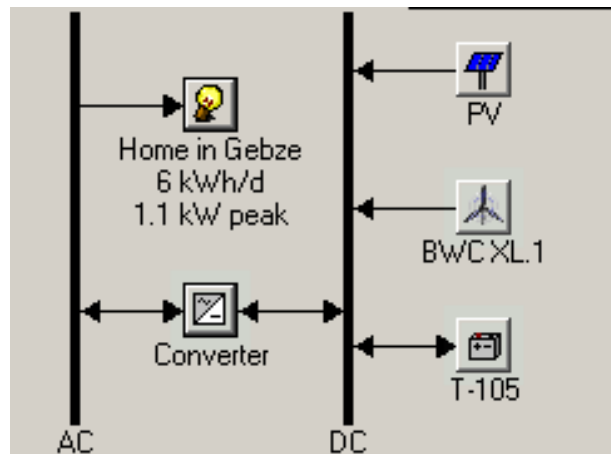

Figure 1: Components of the hybrid power system.

Since solar energy is one of the most abundant renewable energy sources in Turkey, photovoltaic (PV) modules are used in the proposed hybrid power system as one of the power generators. Each PV module in the system is rated at 100 W with a 12 V nominal voltage. However, the PV array can efficiently generate electricity from 6 am to 6 pm. For

economic analysis, the specifications of the PV modules are [12]:

- Each kW of the PV modules costs around $7200.
- Initial and replacement costs of the PV modules are the same.
- Operating and maintenance costs are assumed to be zero.

Since wind energy is also one of the most abundant renewable energy sources, a wind turbine is used in the proposed hybrid power system as one of the power generators. The wind turbine used in the system is BWC XL.1 with output power capacity 7.5 kW and estimated lifetime of 20 years [13]. While the initial cost is $19,000, its replacement cost is $15,000. Additionally, operating and maintaining the wind turbine costs $200 each year. The storage battery used in the hybrid system is T-105 Deep-Cycle Flooded [14]. Its nominal capacity is 185 Ah with nominal voltage of 6 V. The amount of energy stored in one battery is 1.5 kWh. The battery's initial cost, replacement cost, and operating and maintenance cost is $1100, $1000 and $10 each year, respectively [14]. For converting the generated power to AC, an inverter with rated power 2 kW and an efficiency of 90% is used since the maximum peak load of 1.1 kW per hour must be provided for the house. Like the initial cost, the inverter's replacement cost is $900 per kW. There is no estimated operating and maintenance cost except for unexpected situations.
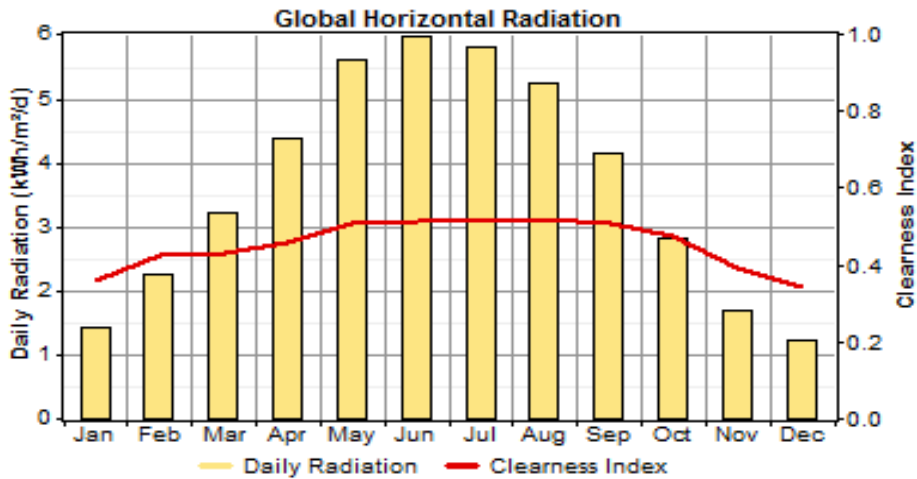

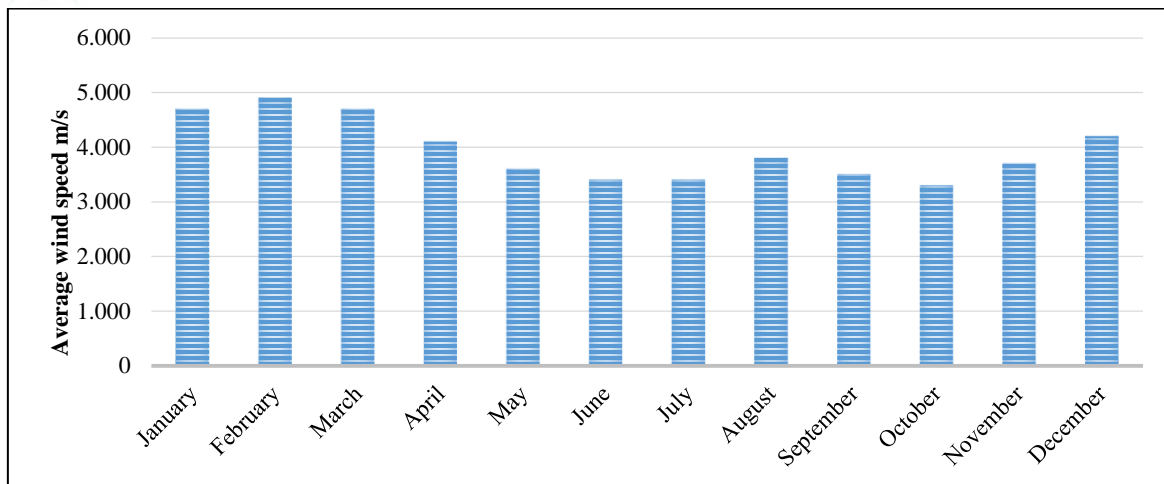Figure 2: Average daily solar radiation in Gebze [15].

Figure 3: Average monthly wind speed values in Gebze [16].

HOMER [17] basically performs three different tasks, namely simulation, optimization, and sensitivity analysis. For renewable energy sources, HOMER can model the performance of a particular hybrid power system configuration to determine its technical feasibility and life-cycle cost. For optimization goals, it can simulate many different power system configurations to find the best one which satisfies the given technical constraints at the lowest life-cycle cost. Finally, in the sensitivity analysis, it can perform multiple optimizations under a range of input assumptions to gauge the effects of uncertainty in the model inputs in order to reveal how sensitive the outputs are to changes in the inputs. In addition to dealing with uncertainty, the sensitivity analysis can be used to evaluate critical trade-offs such as "How much additional capital investment is required to achieve 100% renewable energy production?" [18, 19].
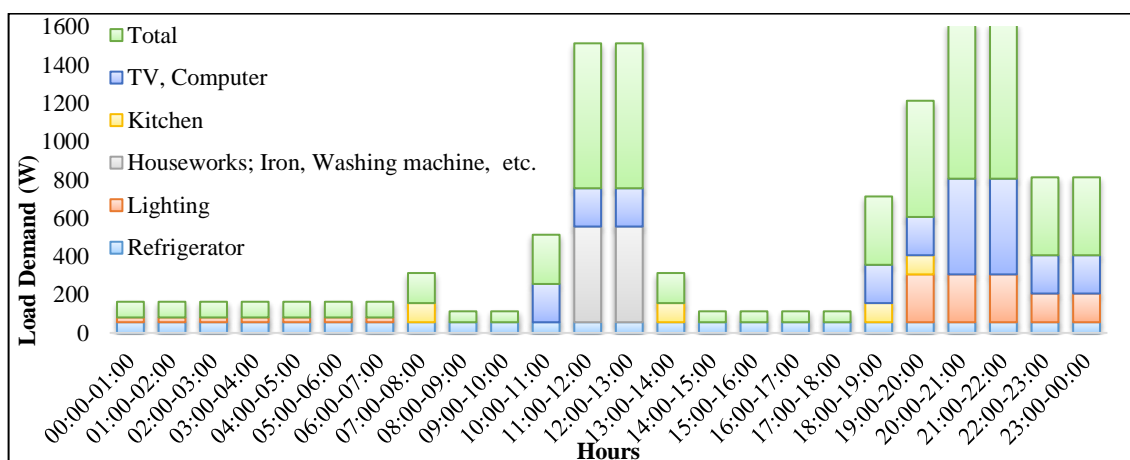

Figure 4: Load demand of the house in Gebze [20].

In the HOMER software, the number of 1kW PV modules varies in the range of 0-3 to determine the most feasible configuration of the hybrid power system. For economic analysis, the number of wind turbines varies in the range of 0-3 kW to determine the most feasible configuration of the hybrid power system. The number of required batteries varies between 10-60 batteries with an increment of 10 batteries. Finally, the number of required converters varies between 0-2 kW. All different configurations of the hybrid power systems proposed for the house whose load demand is shown in Figure 4 are demonstrated in Table 1. As shown in the result of the sensitivity analysis given in Figure 5, the hybrid power system consisting of a PV module, a wind turbine and a battery is the optimal solution since it can efficiently provide the required power under different weather and environmental conditions.
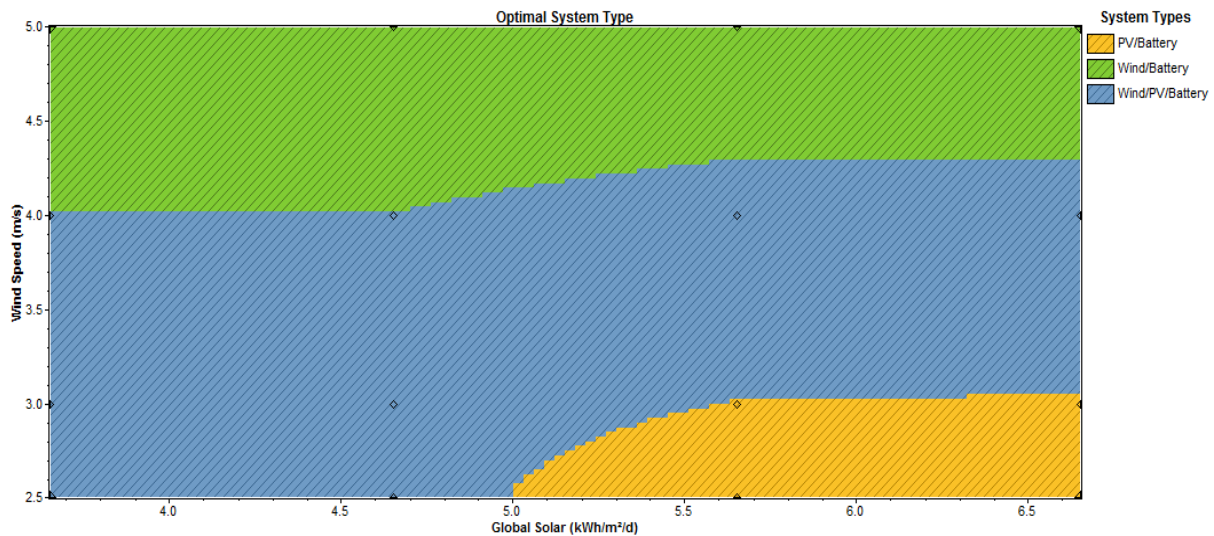

Figure 5: Sensitivity analysis of the hybrid systems: Relationships between wind speed and global solar radiation.

Table 1: Different configurations for the hybrid power system.

Solar (kWh/m^2/d)	Wind (m/s)	PV (kW)	WT	Batt.	Conv.	Disp Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren Frac.
3.650	3.000	2	3	20	1	CC	$23,820	767	$33,630	1.207	1.00
3.650	2.500	3	3	20	1	CC	$29,820	821	$40,316	1.447	1.00
3.650	4.000	1	3	20	1	CC	$17,820	714	$26,945	0.964	1.00
3.650	5.000	-	3	20	1	CC	$11,820	660	$20,260	0.726	1.00
4.650	3.000	1	3	40	2	CC	$21,170	945	$33,256	1.197	1.00
4.650	2.500	2	3	20	1	CC	$23,820	767	$33,630	1.207	1.00
4.650	4.000	1	3	20	1	CC	$17,820	714	$26,945	0.963	1.00
4.650	5.000	-	3	20	1	CC	$11,820	660	$20,260	0.726	1.00
5.650	3.000	2	-	30	1	CC	$20,520	675	$29,143	1.048	1.00
5.650	2.500	2	-	30	1	CC	$20,520	675	$29,143	1.048	1.00
5.650	4.000	1	3	10	1	CC	$16,620	663	$25,101	0.902	1.00
5.650	5.000	-	3	20	1	CC	$11,820	660	$20,260	0.726	1.00
6.650	3.000	2	-	20	1	CC	$19,320	589	$26,847	0.965	1.00
6.650	2.500	2	-	20	1	CC	$19,320	589	$26,847	0.965	1.00
6.650	4.000	1	3	10	1	CC	$16,620	662	$25,083	0.900	1.00
6.650	5.000	-	3	20	1	CC	$11,820	660	$20,260	0.726	1.00

4 CONCLUSION

In the last decade, the number of elderly population and the demand of the disabled for independent living have increased significantly. Therefore, new models of caregiving services which employ sensor and network technologies have been developed including supported self-care and home-based services. Equipped with a set of technological solutions, a smart home provides services which enhance human way of living in terms of many aspects, most importantly entertainment, safety, and security. For the elderly and disabled, a smart home means maintaining living independently in the homes and still in control of the healthcare providers.

Since it is known that expenditures increases severely on long-term care, smart home services are valuable tools for healthcare providers and offer many benefits to the families. To compensate the increase in the expenditures, one of the ways is to reduce the electricity, gas and/or water consumption. In this respect, the use of renewable energy sources, such as solar and wind, for electrical energy generation can greatly reduce the consumer's dependency to the utilities and reduce/eliminate electricity consumption costs. For this aim, this paper presents a hybrid power system consisting of PV energy harvesting, wind energy harvesting, and battery systems. As it is shown with the results of the simulation study, the proposed hybrid power system is sufficient to generate electricity required by a smart home.

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