Efficiency Analysis of Isolated Wind-Photovoltaic Hybrid Power System with Battery Storage for Laboratory General Illumination for Education Purposes

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Abstract- In this paper, an isolated wind-photovoltaic hybrid power system with battery storage will be presented that can supply electricity to two laboratories with a capacity of 1072 W peak electrical power depending on the need at the laboratory illuminating where used. A 1170W hybrid power generation system consists of a 190W 24V 3 pieces mono crystal solar panel and 600W 3-phase permanent magnet synchronized generator (PMSG) wind power generation system, rotating 3600 according to direction of wind, was installed. Besides, to store the consumption excessive electric energy or in case of lack of generation, to ensure energy continuity via renewable power system, 100 Ah 12V 6 pieces gel jeep cycle accumulator groups were installed on the wind-solar hybrid power generation system. In the hybrid power generation system, the data record in 10 second intervals (as kWh) was realized separately from each generation system. Monthly totals of obtained data were arranged separately in tables and graphics. When these obtained data were analyzed, the monthly total electric energy generated by the hybrid power system and monthly total electric energy used by consumers were compared according to the 6-month data. As a result of the comparisons made, it was determined that the generation power of battery storage hybrid power generation system was above its consumption power and at the same time, consumption excessive electric energy was stored in proportional to its battery capacity.

Keywords- wind turbine, PV panel; battery, hybrid system, efficiency analysis.

1. Introduction

Fossil fuels are widely used in the world in many fields, mainly in electric generation and then in industrial field, heating, transportation and other areas. However, as a result of combustion of fossil fuels, CO_2 rate it emits in the atmosphere has reached to dangerous limits. Besides, with excessive increase in consumption of fossil fuels in recent years, reserves are being consumed rapidly [1]. Because of these reasons, the dependency on fossil fuels must be decreased to minimum. The only way to decrease CO_2 rate emitted into atmosphere and obtain the needed clean energy is the renewable energy sources. However, the most important barrier in front of the electric energy generation from the renewable energy sources is non-existence of generated energy [2]. According to the results obtained from the researches, using of complementary alternative energy sources will increase reliability of the system [3]. To realize a convenient hybrid power generation system, economy, reliability, physical, operational strategies and environmental measures must be considered [4]. When the hybrid energy systems are dimensioned and their control strategy is selected well, the cost of system may be kept in optimum level [5].

In the literature, there are many studies made in the real time and simulation environment related to hybrid wind-solar power generation systems. Most of the hybrid wind power generation systems contain regional studies. Installation of solar panel part of the solar-wind hybrid power generation system planned to be installed in Söke vocational higher school in Turkey was realized. In total, 4 solar panels in power of 560W power and 9 armatures were fed. With the obtained data, amortization periods of the solar panel and wind turbine were respectively calculated 12 years and 8 years [6]. In Ref [7], the electric generation from hybrid energy systems depended to the network and independent from the network consists of wind and solar energies within Center Campus Area of KütahyaDumlupınar University was examined theoretically. According to the results obtained from the data analysis related to the wind and solar energy potential in the region, dimensioning of the hybrid energy generation system was made and total 16 different sceneries- 10 independent from the network between 1-10kW and 6 dependent to the network between 15kW and 45kW- were established.

The hybrid energy generation systems, independent from the network, generally meet the power demand in the region and they are economic. By considering the energy potential of the region or other traditional energy generation units (diesel, gas), cost analysis can be made. A method based on genetic algorithm is improved to size of hybrid solar-wind system optimally. Power requirement of telecommunication relay station which is placed on a remote island along south-east coast of China, is provided from hybrid system [8]. Ref. [9], A PV/wind hybrid system is suggested and simulated for three different regions in Iraq. The proposed system is a grid-connected system, which has the ability to power small village with required electric power or as a black start power source during total shut- down time. In the study realized by Muralikrishna M. and his colleagues, they made examinations on decreasing of energy storing requirements of hybrid power systems [10]. For this purpose, they prepared a simulink model of a solar panel system, wind turbine system and solar-wind hybrid power generation system in proportion to need of load and by establishing a life cycle cost for economical evaluation of the hybrid system, they examined the comparative cost analysis of the energy sources in detail.

Simulated annealing approach for optimizing size of a PV/wind hybrid energy conversion system with battery storage is presented in [11]. The methodology described provides an important and systematic approach for design and analysis of hybrid energy systems. This ability is especially helpful if there are various decision variables and large search space to optimize an energy system. Analyzing all possible sizes by simulation is time consuming [11]. The wind-PV-diesel hybrid system coupling is studied and the interactions of these sources are analyzed [12]. The renewable sources (PV and WGE) are operated at their maximum power point. Interactions between sources are studied and the need of storage units is shown in aims to ensure good performance and stability of the hybrid system [12].

In the hybrid power generation systems, renewable energy systems, traditional fossil energy systems and storing systems have different kinds in various combinations [13]. However, the most preferred energy sources in the hybrid power generation system applications are the wind and solar energies. Though both of them are the renewable energy sources, their effective operative hours are generally different and only if they are used together, sustainability can be obtained in energy generation [14].

When the above stated reasons were considered, it was aimed to meet the electric energy required to illuminate (1072W) the electric laboratory I and electric laboratory II (under climate conditions of Afyonkarahisar province) from 1170W solar-wind hybrid power generation system with battery storage. The data of hybrid power generation system were recorded in the computer environment and compared to total electric energy spent by lamp groups existed at laboratories to realize the productivity analysis.

2. Installation and Operation of Isolated Wind-PV Hybrid Power System with Battery Storage

General view of battery storage solar-wind hybrid generation system is given in Figure 1 and its open-connection schema in Figure 2. The 1170W wind-solar hybrid power generation system consists of a 190W 24V 3 pieces mono crystal solar panel and 600W 3-phase permanent magnet synchronous generator (PMGS) wind tribune, rotating 3600 according to the direction of wind. Besides, to store the consumption excessive electric energy or in case of lack of generation, to ensure energy continuity via renewable power system, 100 Ah 12V 6 pieces gel jeep cycle accumulator groups were installed on the wind-solar hybrid power generation system. Electric energy generated in the system is regulated with the charge control unit to charge the battery groups. Energy generated in the system via charge control unit is followed in 10 second intervals and recorded by means of a computer. Energy generated in the system is inverted to AC power by means of 3kW full sinus inverter and energy required by our loads is provided.

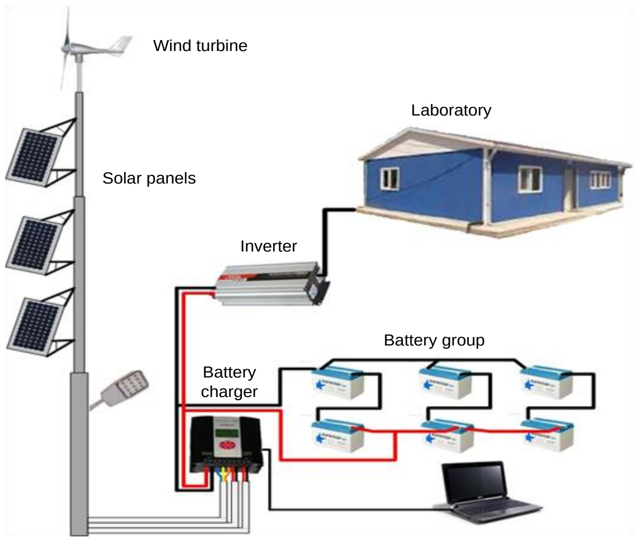

Fig. 1. General view of the installed wind-solar hybrid power generation system

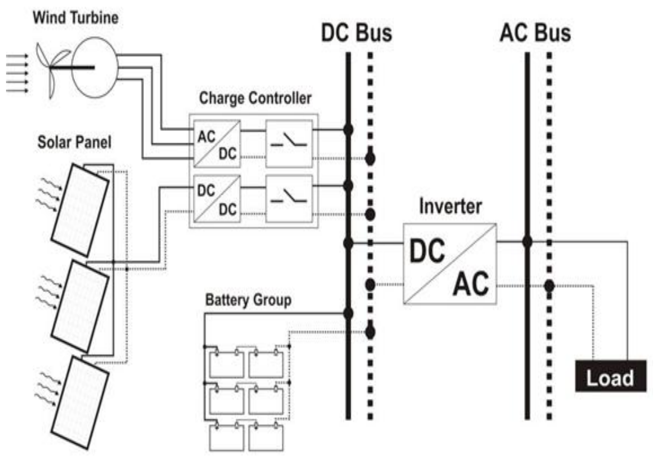

Fig. 2. Open connection schema of installed wind-solar hybrid power generation system units

Technical characteristics of the elements contained in the hybrid system are shown in Table 1. In addition to technical information related to wind tribune given in Table 1, when the power curve of VIND EFS600 wind tribune in Figure 3 is examined, while our wind tribune start generation in 3/sec speed, it brakes itself in 25m/sec speed [15]. Braking process lasts 1 minute and at the end of that period, it starts again. Besides, when the wind tribune battery voltage becomes 28.2 volts, it brakes again and when the battery voltage drops below 28.2 volts, it starts generation again if there is sufficient wind.

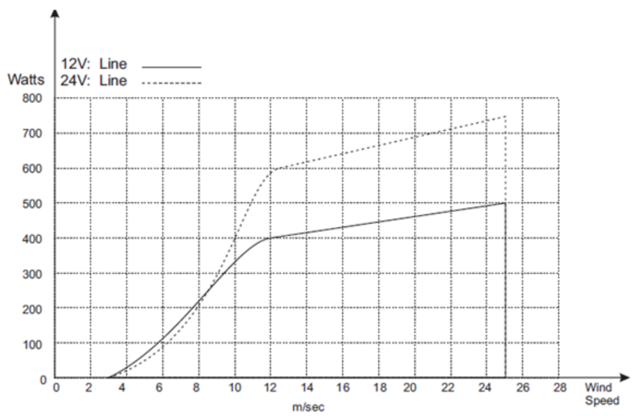

Fig.3. Power Curve of VIND EFS600 Wind Curve [15]

The other important unit in the hybrid power generation system is charge control unit. The connection schema of the charge control unit is given in Figure 4. Technical properties of charge control unit are given in Table 1. Additionally, low voltage property of our charge control unit activates in 4V. In other words, when the wind tribune reaches to speed that generates 4V, unless battery groups are in a voltage value above 28.2V, it starts generation. This property ensures wind tribune to generate energy even low wind speeds. The charge control unit has two DC outputs. First of these outlets makes the DC outputs of the charge control unit active or passive according to intensity of illumination falling on solar panel. The second one makes DC output of the charge control unit active according to intensity of illumination falling on solar panel and makes the DC output passive in the adjusted time. This prevents LED armature used in outdoor illumination to unnecessary energy unnecessarily

Table 1. Technical properties of units in the hybrid system

Wind Turbine	Output Voltage : 12/24V Power: 600W Max Power : 750W
PV Panel	Power: 190WType: Mono crystalline Efficiency: %17.75Max. Power Voltage : 37,08V Max. Power Current : 5.12AOpen Circuit Voltage : 44.48V Short Circuit Current : 5.54A Operating Temperature Range: 40°C / +85°C
Charge Controller	600W WT/600W PV 24V charging control unit WT and PV voltage read LCD display WT and PV current read Immediate data transfer and record feature Battery power read Connect / disconnect wind turbine to circuit short circuit protection High voltage, low voltage protection
Battery Group	Battery Voltage : 12V Type: Gel-type sealed battery Battery Capacity: 100Ah
Inverter	Power : 3kW Immediate Power : 6kW Efficient >85% Type: Exactly Sinus
Pole	Height: 12 m Octagon chronicle pole Hot dipping galvanization covered
Street Lighting (LED)	Power : 40W Lumen: 3000LM Input Voltage: 12 V Operating Frequency : 47-63HZ Operating Temperature: -30 / 40°C Operating Efficient >90%

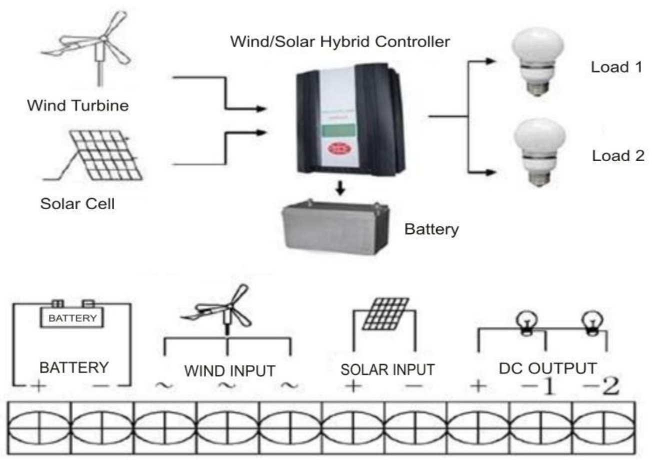

Fig.4. Open connection schema of charge control unit

Technical properties of the inverter used to convert DC energy generated by hybrid power generation system to AC energy were given in Table 1. Other than the stated ones in Table 1, when the energy generated by wind-solar hybrid power generation system or stored by battery groups drops below 20V, inverter pass to low voltage mode and becomes inactivated. In that case, until voltage level of batteries increases above 22V, lamps at the laboratories are fed from the network by means of the automatic control circuit. When the battery voltage increases above 22V, contacts of inverter are turned off by means of automatic control circuit and energy need of lamp groups are met via hybrid power generation system.

3. Determination of Use Period of Battery Groups According to Consumption Power

To store the electric energy obtained from wind-solar hybrid power generation system, a 300Ah accumulator group was established. When no energy is generated in the hybrid power generation system, the energy required to illuminate laboratories will be provided firstly from accumulators. By considering that the accumulator group is fully charged and all lamp groups at both laboratories are active, how long the accumulator group would provide energy to the system was calculated with the following calculations.

In illumination of a laboratory, 16W 2 numbers saving lamp and 18W 28 numbers fluorescent lamps were used. Total power of lamp groups used in illumination of a laboratory is;

Fluorescent Lamp

$$P_{FT} = \text{Number of Lamps x Lamps Power} = 28 \times 18 = 504\ \text{W} \quad (1)$$

Energy Saving Lamp

$$P_{TT} = \text{Number of Lamps x Lamps Power} = 2 \times 16 = 32\ \text{W} \quad (2)$$

Total Lamp Power

$$P_T = P_{FT} + P_{TT} = 504 + 32 = 536\ \text{W} \quad (3)$$

The installed power required for illumination of a laboratory is 536W. As the lamp number and kind at both laboratories are the same, the total power fed by the hybrid system is;

$$\text{Total Power} = 536 \times 2 = 1072\text{W} \quad (4)$$

How long the accumulators will feed the lamp groups can be found with the Eq. (5) below;

$$\text{Time} = \frac{\text{Consumed Total Energy}}{\text{Total Power}}\ \text{(hour)} \quad (5)$$

Total power of lamp groups used in illumination of both laboratories is 1072W. While making accumulator calculation, 20% of accumulator capacity is kept as a security charge in principle and 80% capacity of installed 300Ah accumulator group is found.

$$C = 300 \times 0.8 = 240\ \text{Ah} \quad (6)$$

It will not be correct to select a battery according to the obtained result. Because loss energy occurred in the battery and installation must be added. If we deem that loss energy is 10% in battery and 2% in installation, the correct battery capacity is;

$$C = 240 \times 0.9 \times 0.98 = 211.68\text{Ah} \quad (7)$$

Finally, multiplication of accumulator capacity by system voltage will give the total energy to be consumed.

$$\text{Consumed Total Energy} = C \times \text{Voltage} = 211.68 \times 24 = 5080.32\ \text{VAh} \quad (8)$$

Here, if the value found with Eq. (8) is written its place in Eq. (5), it is found that accumulator groups will feed lamp groups for about 4.5-5 hours, in case all lamp groups are active.

$$\text{Time} = \frac{\text{Consumed Total Energy}}{\text{Total Power}}$$

$$\text{Time} = \frac{5080{,}32}{1072}$$

$$\text{Time} = 4.74\ \text{hours}$$

$$\text{Time} \cong 4.5 - 5\ \text{hours}$$

4. Productivity Analysis According to Generation and Consumption Powers

To enable the productivity analysis of the installed hybrid power generation system, the electric energy consumed for general illumination according to weekly course hours made at both laboratories must be known. Then, it must be determined that how much the electric energy generated by the hybrid power generation system meets the electric energy consumed for the general illumination of laboratories. With the obtained data, it is determined how much saving is made in the electric bill by using the installed hybrid power generation system.

Table 2. Weekly schedule showing laboratory course days and course hours

Days (per week)	Electric-1 Lab.	Electric-2 Lab.
Monday	Control Technique Lab. (3 hours)	Energy Systems Lab. (2 hours)
Tuesday		Electrical Machines Lab. (2 hours)
Wednesday		Control Systems Lab. (2 hours)
Thursday		
Friday		

To find the total electric energy consumed at laboratories according to course days given in Table 2, the electric energy consumed by 1 laboratory per hour must be determined. As it is stated before, armature numbers are equal at both laboratories and at one laboratory, there are 28 number 18W fluorescent lamps and 2 numbers 16W saving lamps. Here, it must be paid attention that power values written on armatures are 1-hour energy consumption values. Accordingly, if we consider that at laboratory hours all of armatures are turned on, the power consumed by a laboratory per hour is 1072W (equation 4).

Table 3. Weekly schedule showing total energy consumed according to laboratory course days

Days per week	Electric-1 Lab.	Electric-2 Lab.	Daily Total
Monday	3216Wh	2144Wh	5360Wh
Tuesday	0	2144Wh	2144Wh
Wednesday	0	2144Wh	2144Wh
Thursday	0	0	0
Friday	0	0	0
Total:	3216Wh	6432Wh	
Weekly Total:	9648Wh		

As the energy consumed by a laboratory per hour is 1072W, the weekly electric energy required to illuminate both laboratories is found as 9648Wh by using daily consumed total energy amounts given in Table 3.

Table 4. Energy generation capacities of wind, solar and battery group according to months

Months	Wind (Wh)	Sun (Wh)	Battery (Wh)
June	468.7499924	28372.28971	28841.0397
July	153.0999983	54324.49828	54477.59828
August	547.3899917	58015.75	58563.13999
September	106.5599976	55303.14844	55409.70844
October	437.6400223	58503.68763	58941.32765
November	135.3099823	43785.42969	44137.3125

When the generation and consumption data of all months are examined, it is seen that generation is higher than consumption in all months except June (Figure 5). Because of the breakdown in the hybrid power generation system in June, no data was obtained for 15 days.

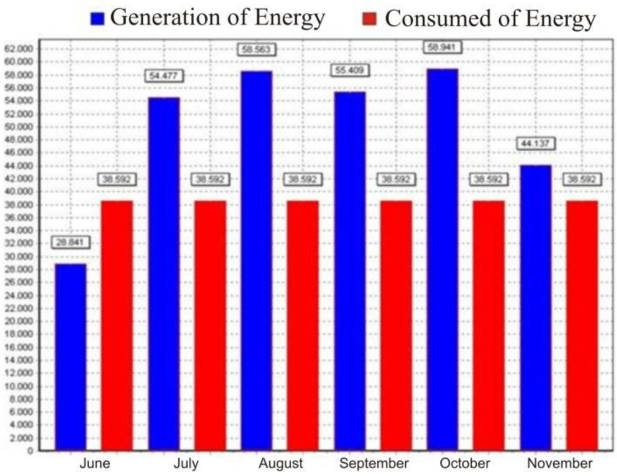

Fig. 5. Total generated energy and total consumed energy according to months

By comparing the total generated energy and total consumed energy, difference between the generation and consumption was determined. Cost comparison of electric energy was made by taking the unit price as 32.515 (Table 5).

Table 5. Saving provided according to the electric energy consumed with using of hybrid power generation system

Data type / Months	Generation (G) (kWh)	Consumption (C) (kWh)	G-C (kWh)	Amount of energy generation (TL)	Amount of energy consumption (TL)	G-C Cost (TL)
June	28.841	38.592	- 9.751	9.38	12.55	- 3.17
July	54.477	38.592	15.885	17.71	12.55	5.16
August	58.563	38.592	19.971	19.03	12.55	6.48
September	55.409	38.592	16.817	18.02	12.55	5.47
October	58.941	38.592	20.349	19.16	12.55	6.61
November	44.137	38.592	5.545	14.35	12.55	1.80
Total	**300.368**	**231.552**	**68.816**	**97.65**	**75.3**	**22.35**

As a result of the calculations, the amount of consumed electric energy for general laboratory illumination for 6 months is 75TL and the amount of generated electric energy is 98TL. As it can be seen in Table 5, with 22.35TL generation excessive, electric energy generated from hybrid power generation system meets consumed electric energy.

When the obtained 6-month data is examined wholly, it can be seen that the electric energy required for illumination of electric-1 and electric-2 laboratories can be easily met by the wind-solar hybrid power generation system. Upon supplying of the power demand of consumers from the hybrid power generation system within that process, both the alternative energy sources were effectively used and it made great contributions to the economy of country.

5. Conclusion

In this study, in Afyonkarahisar University AhmetNecdetSezer Campus, installation of the wind-solar hybrid power generation system with battery storage was realized and equipments forming the system were introduced. The study has two important consequences. One of them is: while monthly average generation of the wind-solar hybrid power generation system installed in Afyonkarahisar province is 50062Wh and monthly consumption is 38592Wh, the hybrid power generation system largely meets the electric energy demand for the fluorescent lamp groups. The second is; the 6-month consumption cost of fluorescent lamp groups is 75TL. The wind-solar hybrid power generation system with battery storage made 98TL electric generation for 6 months and met the need of fluorescent lamp groups.

As it can be seen, if the hybrid power generation system is used for the required electric energy demand, 150TL to be paid for a 1-year electric bill may be used for other educational expenses. Besides, by establishing the “Renewable Energy Systems” postgraduate program and a practicable hybrid power generation system for the Technology Faculty Electric-Electronic Engineering students, it has been made practicable for future education and research activities.

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