Design and simulation of hybrid power system with wind turbines,photovoltaics and fuel cells

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***Abstract*- In this paper we present a hybrid system that combines wind turbines, photovoltaics and fuel cells for the production of energy for a remote load.The wind turbines and solar panels are used as the main energy sources and fuel cellsare used to store the produced energy. Aremote site of five houses was used to study during the summer, which is a period of high consumption, and the winter,a low consumption period. The operating system is simulated with real weather data and all the curves functionsare calculated.**

***Index Terms*- hybrid system, wind turbine, photovoltaics, pemfc, simulation, Simulink, remote load,autonomous.**

I. INTRODUCTION

Wind turbine and solar panel hybrid energy systemshave proven to be a popular area of research and development[1]. Nowadays, the benefits of solar panels are being exploited, and governments assist in this regard, through subsidies, and other incentives.[2]. On the other hand, the use of wind turbines has reached a plateau in recent years, which means that more research has gone into the optimized use of photovoltaics and fuel cell. One of the main areas belies in the fact that wind turbines and solar panels work efficiently for a period between 20 and 30 years, whereas batteries needs replacement every 4-5 years [3].

n this study, fuel cells are used for energy storage instead of the more common discharge-type lead acid batteries.The energy necessary for the electrolytic generationof hydrogen can be produced both by wind turbines and solar panels, but photovoltaics have an advantage in that they work directly with the electrolyte, as opposed to wind turbines in which the ac voltage must be converted to dc. The main disadvantage of using photovoltaics is that they need to be installed over a large area of land, as opposed to wind turbines. Forapplicationsin such systems, solar photovoltaics are used in combination with fuel cells.[4]. In this work, we have simulated and analysedthe function of an autonomous hybrid system consisting of wind turbines, solar panels and PEMfuel cells. A complex of five houses, which is isolated far away from the mains electricity, is used; these houses serve as holiday homes from May to September, during which thehigh-energy consumption is high. On the other hand, the winter is characterised by low energy consumption as the houses are used only on the weekends. The aim of this work is to create an autonomous, reliable and economic system. The hybrid system is located on the island of Kea, an island in the Northern Cyclades in Greece. Kea is used because it is an island with relatively high wind speed and high solar radiation The PEM type fuel cells used in this study have the following advantages [5]: electricity is produced without environmental pollution, they are commonly availability, have relatively low cost for small applications, they operate at low temperatures and are mostly recycled. Wind turbines have long life and high efficiency. The solar panels have longlife,
zero maintenance and reliable operation.

II. ENERGY REQUIREMENTS AND LOAD CONTROL

Thefive houses havethe usual energy requirements of rural residences. The island's climate is quite mild with average temperature of 120C in the winter and remains below250C in the summer; the atmosphere remains cool because of the winds and the sea. Solar water heaters are used to heat the water; the heating system and the natural lighting of the houses are designed with passive solar architecture in mind.Table 1 shows the estimated consumption of the five houses. The maximum power consumption during a summer day is 28275W.This amount of energy must be produced under any weather conditions in order

for the system to have enough power for minimum operating conditions. For the simulation of the system, add 10% to the demand for power, so for Recent Advances in Energy, Environment and Development ISBN: 978-1-61804-157-9 19 example the maximum power consumption on a summer-day power becomes 31,1kW. The energy management is done by a controller, which provides high loads to relevant appliances. Table 1. Description of the energy needed to run the houses

CONSUMPTIONS	**Hours/month**	**Watt (W)**	**kWh/month**	**kW h/H. Seas**	**kWh/L.Seas**
Refrigerator	180	2100	378000	1890000	756000
Kitchen	60	3500	210000	1050000	420000
Lights	270	100	27000	135000	54000
Peripheral Lighting	270	30	8100	40500	16200
Washing machine (kitchen)	60	1200	72000	360000	144000
Microwave	15	900	13500	67500	27000
Washing machine	30	800	24000	120000	48000
Coffee machine	15	1200	18000	90000	36000
TV	180	120	21600	108000	43200
Mobile charger	180	5	900	4500	1800
Control system	720	50	36000	180000	72000
Hair brush	15	2000	30000	150000	60000
PC	30	600	18000	90000	36000
TOTAL IN KW	**2.025**	**12.605**	**857.1**	**4285.5**	**1714.2**
TOTAL 5 HOUSES	**10.125**	**63.025**	**4285.5**	**21427.5**	**8571**

The priorities for the operation of loads in the houses are: control system, refrigerators, interior lighting, electrical kitchen, etc., with the controller being the main unit that must operated continuously since the controller (through software) determines the priority of loads of the lighting, refrigerator, kitchen, etc.

III. SYSTEM DESCRIPTION

For proper simulation and analysis of energy sources, wind speed and solar radiation are measured at hourly intervals. The time series show that parameters c and k of the Weibull distribution are: k = 2 and c = 7.96, while the average solar radiation during the summer months would be 930 Wp/m2. The wind turbine must be operational and provide the necessary energy for 60% of the time. For safety reasons, three (3) 10kW wind turbines are used instead of one 30 kW turbine. In order to describe the operation of the turbines, the kinetic energy of the wind must be calculated. The useful kinetic energy E of the wind is given by the formula[7]:

E = 0.5ρA*Vw*2 (1) where, *V w* is the wind speed (m/s), ρ is the density of the wind (Kgr/m3) and A is the contested area (m2) The power generated by the wind i given by the formula [7]: 3 0.5 *t p w P* = ρA*C V*(2) whereCp is the aerodynamic efficiency of the wind turbine.Cp is the amount of energy derived from the wind according to the wind's kinetic energy due to its motion. The maximum power factor is [8]:()max160.59327 *p C* = =(3)and called limit of Betz.The maximum value of wind turbine is given by the following relationship [9]:2 0.5 / *t P w T* = ρ *ARC V* λ (4) whereR is the radius of blade (m) andλis the tip speed ratio, which can be calculated according to:*twRV*ωλ = (5)ωt is the angular velocity of otation of the tip (rad /sec).The quantity Cp depends on the speed and the construction of the wind turbines and is given by relationships 5 and 6:16.51 1160.5 0.4 51 *p C* β *e* λλ− = □ − − □ □ □ □ (6) where ( ) (3)111 0,0350,098 1λλ β=−+ +(7)Moreover β is the angle of blade pitch in egrees.Using the mathematical formulas (1) to 7), the Simulink software has been used to roduce the model.The photovoltaic panels are elected on the basis that they should produce the maximum power in the summer months because he wind speed is less during the summer onths; he power generated bywind turbines is also ower. The required energy is provided by solar panels and if there is a greater necessity for energy, it is provided by the fuel cells.

IV. SIMULATION OF THE SYSTEM AND OPERATION RESULTS

The energy produced by the wind turbines and solar panels is controlled by the system administrator. A circuit breaker is installed for safety. The energy that is generated is then converted into a DC voltage for use by the electrolyte. The electrolyte converts the stored water into hydrogen and oxygen, and the hydrogen is compressed and storedin a high-pressure tank and the oxygen is released into the environment. Then hydrogen is used to generate energy as determined by the controller.

Figure 1. The topology of the system

When the power of the wind turbines is below the load's required power, then the controller (which is basically a chip with the appropriate software), checks if the load can be covered by solar panels, otherwise power is also supplied by the cells fuel. When the power of solar and wind turbines is greater than that required by the load, the electrolyte is activated and hydrogen is produced and stored. The stored hydrogen will be used when the fuel cells are active. The energy needed to cover the needs of the load must be greater than 5% of the requirements.

The cycle for the process simulation is one hour.

The total time simulation is 8,760 hours - the total hours in a year. The extra energy, whichis generated and cannot be stored, remains unused. In order to utilise the extra power, the following solutions, which raises the costs of the system, can be used:• Larger capacity hydrogen tank to store more hydrogen. The disadvantage in this situation is that we need more space for the installation of the tank. • Storage in batteries. The lifetime of batteries is limited to five years.

• Storage in ultra-capacitors. This technology is not yet ready for use and has a relatively high cost.

• Storage utilizing a flywheel. This technology is not widespread and has not got the demanded efficiency.

The simulation was started on the first of January, in the low power-consuming period. Data such as wind speed, temperature and solar radiation were obtained from the meteorological station in Kea. The load curves in Table 4 were producedover a year. Upon starting the simulation, the power generated by the wind turbines is compared to the power requirement of the load. If the power output of wind turbine is greater than 5% of the loads, the wind turbine is used. However, if the power from the wind turbine is less than the load's required power, the power being generated by the photovoltaics is determined; ifit is greater than 5% of the load's required power, the photovoltaics are used. If the load's demands are not covered by either the wind turbines or the solar panels,the fuel cells are used to power the load.The operation of the system is presented in the logical diagram shown in Figure 2.

As seen in figure 3,thewind speed area, the solar radiation, the temperature and the consumption of loads are used in the model. The wind speed is the input of "Wind Generator", where the appropriate conversion of the wind's kinetic energy into electrical energy is done using the necessary mathematical relationships.

The "Wind Generator" is composed of tree wind turbines. The energy generated by each turbine, is added and inserted into the controller for evaluation.Finally, the required loads determined is input into the controller's Load input; this introduces the consumption of the complex of houses in a year into the controller.Therefore, the energy that is produced by the wind turbines and the photovoltaics and the demanded energy of the load are input into the controller (Figure 3), which selects the best power generator for storage and future use. Actually in this part, the controller implements the algorithm in Figure 7 from the energy produced by the wind turbines and solar panels. Also the energy used by the appliances is removed from the system.In the blocks below, u1 is the energy from the wind turbines and u2 is the energy from the photovoltaics From the study of the Logical function diagram, we have the following three cases, which are illustrated in figure 2:1. if u1> = 0 then the demands of the load are covered by the wind turbines. The comman for this is given by the block "If Action Subsystem1".2. if u1 <0 and u2> = 0. In this case,the energy produced by the wind turbines is less that required by the load and the energy generated by PV is greater than the energy of the loads. Therefore theenergy of the loads is covered by the solar panels and the energy produced by wind turbine is fed into the electrolyte for production of hydrogen.

3. Finally, the sub-case of u1 <0 and u2 <0. In this case, both the energy generated by solar panels and the energy produced by wind turbines is less than the energy required by the load. The loads are therefore covered by the fuel cells.The dump energy.

V. RESULTS

Entering the data of wind speed, temperature, solar radiation and requirement of loads and simulating for the entire of 8,760 hours, we have the following results:

Wind turbine: 85,253 KWh
Fuel Cell: 17,316 KWh
Photovoltaics: 34,056 KWh
Electrolyte: 1,213 KWh
Dump Energy: 20,510 KWh
Consumption: 103,694 KWh

Figure 4. The different curves.

Seven different curves are presented in figure 4. The first curve shows a graph of the load, the second the energy produced by the wind turbines, the third, the energy generated by the solar panels, the fourth, the wind turbine energy used by the load, the fifth, the solar energy used to power the load, the sixth, the fuel cell energy used to power the load load, and the seventh, the unused energy. As shown in figure 5 a demand from the load is highlighted in circle '1' and the energy produced by the wind turbines is indicated by circle '2'. The load covered by the wind turbines, PV and fuel cells are illustrated respectively in 3, 4 and 5.

VI. CONCLUSIONS

In this paper, the study and the simulation of the energy demands of a block of houses is presented.These demands are covered by a hybrid system,consisting of wind turbines, solar panels and fuel cells.The data was captured and the simulation run over 8,760 hours of operation.

The study of the hybrid system and the results of the simulations show that both the controller model and the individual models describing the renewable energy sources are in agreement with the theoretical models.

The results of simulations show that the energy produced by wind turbines is 85,253 KWh, by photovoltaics is 34,056 KWh and by fuel cell is 17,316 KWh. The unused energy is quite high and may be stored in other forms, which would drive up the cost of the system. It is important to note that the simulations demonstrate that the system always produces the energy required by the loads, and successfully performs the tasks for which it was designed.

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