HYBRID SOLAR/WIND (PVT/WT) BUILDING INTEGRATED SYSTEMS

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1. INTRODUCTION

Solar energy and wind energy can be effectively combined to produce electrical power by photovoltaics (PV) and wind turbines (WT) respectively. The combination of the PV module with a water or an air heat extraction unit constitutes the hybrid photovoltaic/thermal (PVT) solar system, by which electrical and thermal output is simultaneously provided. In this paper we present the concept of the hybrid PVT/WT systems, which combine photovoltaic, thermal and small wind turbine subsystems, aiming to cover effectively electrical and thermal needs of buildings. The integration of wind turbines (WT) on buildings is not considered practical enough and small size wind turbines are necessary. The dimensions and the weight of the wind energy systems are two important factors that must be taken into consideration for the Building Integrated Wind Turbines (BIWT) and mainly small size systems are suitable for it. WTs of horizontal or vertical axis must be of low cut-in wind speed and also aesthetically compatible with the building architecture. PV panels are more flexible than WTs regarding size and installation requirements and have been already applied successfully in several buildings. Solar and wind energies vary with time and energy storage is usually necessary to adapt the time of energy conversion with the demand profile. Considering thermal energy, it is usually stored in water storage tanks for liquid type PVT systems, in stones (or other material) for air type PVT systems and also in phase change materials (PCM), while electrical energy is mainly stored in batteries. The development of fuel cells has resulted to consider now the hydrogen as an effective chemical storage to use it later for electricity production.

2. HYBRID PVT/WT SYSTEMS

Photovoltaic panels of amorphous silicon (a-Si), polycrystalline silicon (pc-Si) or crystalline silicon (c-Si) are the most usual PV modules for building integration, presenting efficiencies in the range of 5% to 14% respectively. Their performance is decreased for higher operation temperature and PV module heat extraction is necessary to keep a satisfactory efficiency level. In case of direct PV mounting on building façade or inclined roof, PV cooling avoids undesirable building heating mainly during summer. The hybrid PVT systems combine two devices in one unit and this can be effective in installation requirements, using the available external building surface area. In the urban environment the direct connection of buildings to electricity grid makes the use of batteries or the production of hydrogen less significant, because of the low energy excess from the small size of the installed electricity generators. In countries where there is no special electricity buy-back tariff as well as in stand-alone applications (provided that the battery storage unit is charged), when there is surplus of electricity, then the electricity can be transformed to thermal energy and stored by the PVT system. The combination of PVT and WT systems is the suggested new concept and the multiple energy conversion systems can be called hybrid solar (electric and thermal)/wind (electric) systems (PVT/WT).

In PVT/WT systems the output from the solar part depends on the incoming solar radiation and is obtained during sunshine. On the other hand the output of the wind turbine part depends on the wind speed at the location of the installation and is obtained any time of the day or night that the wind speed is over a lower limit. Therefore the PVT and WT subsystems can supplement each other, being primarily used to cover building electrical load and secondary to increase the temperature of the existing thermal storage tank of PVT system by their surplus electrical energy. Horizontal Axis WTs (HAWT) are widely used systems, but the tracking of the wind direction is necessary to be considered, although building designs with stationary mounted HAWT systems have been suggested. Vertical Axis WTs (VAWT) are more practical, as they use a fixed rotation axis and have their motor – generator at low position. The Savonius and Darrieus wind turbine types are the most usual VAWT systems and some small size commercial models are already in the market.

3. PVT/WT ENERGY AND COST CALCULATIONS

In our concept the small power WTs are introduced into the built environment and although vertical axis systems have harmonic blending with the houses, they are still of high cost (~7000 € per m^2 of rotor swept area). The horizontal axis wind turbines are in practice many years and due to their lower cost (~1000 € per m^2 of swept area) they could be used as cost effective BIWTs in the suggested concept of PVT/WT systems. The wind speed bin size used in the calculations was 1 m/sec and the hourly wind speed data were for a site in Athens in Greece with an average annual wind speed of 5.16 m/sec. We consider the complement of the PV and wind electric energy, where there is an amount of electricity produced by the wind turbine at times other than the daytime (when there is electricity production by the PV system). The electricity produced is normalized over the aperture surface area of the PV array (per m^2) and also for the thermal energy output of the heat extraction subsystem. The same is done for the wind turbine (maximum energy per m^2 of swept area), considering the electricity produced per swept area of the used WT rotor.

The energy and cost analysis considers grid-connected domestic systems in Athens, one with a hybrid PV array of pc-Si with integrated water heating system and a small HAWT and a second system, where the PV array is from a-Si. The energy performance of the two PVT systems is based on experimental data from constructed and tested prototypes [1], while the electrical energy output of the HAWT is based on the performance data of the turbine, considering also our experience from a short period operation of a similar HAWT model. In TABLE 1 we give for all months the values of the mean wind speed (m/s) and the corresponding wind and solar energy (kWh/m^2mo) on 1 m^2 of WT rotor swept area and on 1 of PVT system aperture surface area m^2 (at a slope of 40^o). In addition, we include the calculated values (kWh/m^2mo) of electrical output from the WT and the pc-Si and a-Si PV systems and also of the thermal output from the two corresponding water heat extraction subsystems. The economic analysis follows the principles worked out in a similar effort for PV and PVT systems [2,3] and is referred to small size domestic systems, which consist of typical PV modules with water heat exchanger on their rear surface and are connected to a separate hot water storage tank.

In our work, the analysis is performed on an annual basis and it assumes that the domestic user avoids the use of equivalent amount of electric energy for water heating and electrical appliances according to the system's output. The excess of electricity produced over the instantaneous electricity consumption is converted into thermal energy. To this effect the wind turbine contributes significantly the winter months when the PV electric and thermal supply is reduced and also during windy periods of low sunshine and during nights. The economic evaluation runs for several years, until the initial investment and the yearly sum of benefits and charges are nullified. The last year that the investment is negative is considered as the year that the total amount paid for the system is amortized. The starting cost for electricity per kWh electric and thermal produced, for the first year in the analysis, is taken to be as: 0.0851 €/kWhe and 0.0587 €/kWhth, correspondingly. For the domestic users that buy a RES system a single time tax rebate is applied during the first year of the system operation. The tax rebate is taken as 26,25% of the initial investment (average case) [2]. The cost of money is also included in the cash flow, by subtracting the amount that the user would have made as a profit, if the money were gaining the discount interest rate. The inflation in Greece runs annually at 3,5%.

TABLE 1

Month	Average wind speed	Maximum Wind Energy	Maximum WT Electrical	Solar Insolation at 40^o	PVT (pc-Si) kWh/m^2		PVT (a-Si) kWh/m^2	
	m/s	kWh/m^2 per month	kWh/m^2 per month	kWh/m^2 per month	Electric energy	Therm energy	Electric energy	Therm energy
Jan	5.28	100.18	24.18	84.70	10.22	29.64	4.14	33.12
Feb	6.82	210.05	43.64	101.31	12.81	37.16	5.23	41.63
Mar	5.28	100.22	24.24	127.99	15.84	45.69	6.53	51.28
Apr	4.81	71.64	17.51	147.92	18.72	54.45	7.76	61.17
May	4.31	52.49	12.88	172.83	21.93	63.15	9.21	71.21
Jun	4.80	71.11	17.29	175.98	22.36	62.51	9.47	70.80
Jul	4.80	73.59	18.08	191.40	24.57	67.01	10.42	76.14
Aug	4.79	73.54	18.20	197.43	25.38	69.32	10.76	78.74
Sep	4.79	71.13	17.20	168.84	21.38	59.93	9.05	67.85
Oct	6.34	182.49	41.37	131.33	16.46	47.84	6.92	53.89
Nov	4.79	71.08	17.08	102.49	12.68	37.49	5.26	42.07
Dec	5.28	100.20	24.29	84.66	10.36	30.22	4.21	33.80
Total	**5.16**	**1177.71**	**275.95**	**1686.87**	**212.73**	**604.41**	**88.96**	**681.71**

The calculations are based on the assumption that electricity prices are increased by 3,5% every year, the interest rate for personal saving accounts is assumed to be 1%. The discount interest rate is taken as the savings account rate minus the inflation rate (-2,5%) and considering that the cost of the PVT system with pc-Si PV modules is 1116 €/m^2 and with a-Si PV modules 698 €/m^2, while the cost of the HAWT system is 900 €/m^2, giving therefore total costs 2016 €/m^2 and 1598 €/m^2 respectively, including 18% VAT. The maximum possible energy efficiency for the turbine per month varies between 20 and 24%, but the WT is considered installed in the built environment and wind turbulence and direction variation may significantly affect its final efficiency. It is also noted that under the considered conditions in Athens, at times when the PV array is not contributing to the user, the WT will produce over a year 168 kWh/m^2 out of an annual total of 276 kWh/m^2 (about 61%).

4. CONCLUSIONS

The economic analysis has shown that the time for the amortization of the pc-Si PVT system with the HAWT is 9 years, while that of a-Si PVT system with same WT is 7 years. This is considered to be the minimum possible under the conditions mentioned earlier, but it can be further reduced to 6 and 5 years respectively in case of 50% WT price drop. If we consider the use of VAWT instead of HAWT systems, the pay back period of the PVT/WT system is about 18 years. In this case the price of the VAWT must be reduced by 8 times to achieve same payback time as using HAWT system.

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