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Energy Management Strategy: Microgrid Integrated with Hybrid PV-T, EV, and Battery

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***Abstract*— This study presents an analysis of a microgrid with the integration of photovoltaic glass (PV-glass), hybrid thermal photovoltaic (HPV-T), and a battery as a storage system. Also, as a novel energy management strategy, PV-glass (car body PV) is used to maintain the state of charge (SOC) of an EV's battery; on the other hand, in this paper, V2G is used as an energy management strategy. This topology covers the demand of the house on the longest day of the year, in summer, with the assumption that the battery bank is initially discharged. Furthermore, genetic algorithms (GA) and particle swarm optimization (PSO) are used to calculate the optimal cost of HPV-T and PV-glass. So, the optimal sizes of HPV-T and PV-glass are 10 m^2 and 7.3 m^2, respectively.**

***Index Terms*—Smart grid, optimization, hybrid PV/T, EV, V2G.**

I. Introduction

A variety of reasons have contributed to the growing importance of distributed generation (DG) in recent years. One of the primary causes is the rising demand for electricity, which has put pressure on the infrastructure and electrical networks already in place. By producing electricity near the point of use, DG technologies, which include solar panels, wind turbines, and other small-scale power generation devices, can help ease this burden. DG may help boost energy efficiency and minimize transmission losses in addition to improving grid stability, which will ultimately lead to a more robust and sustainable energy system. Moreover, DG can be extremely important in supplying dependable electricity in outlying locations and during emergencies. As the global move to a more sustainable energy source continues. Not only is DG a perfect solution for residential consumers, but this technology is also used in industry, [1] has studied industrial consumers. Although DG technology has advantages for both consumers and the grid, it also has some drawbacks, like poor power quality (PQ). [2] claims that PQ is one of the most significant challenges for microgrids, and it analyses some solutions for this challenge. Also, [3] compares the new protection methods with the conventional ones for microgrids. Integration of renewable resources such as photovoltaic (PV), wind turbine (WT), batteries, and combined heat and power (CHP) with microgrids has been analyzed in many studies [4–6].

In comparison to separate photovoltaic and solar thermal systems, hybrid photovoltaic-thermal (PV-T) collectors produce thermal energy and electricity from the same space with better efficiency and fewer emissions. They offer greater potential for lowering dependency on fossil fuels and preventing climate change, as well as being more space-efficient [7]. In [8], the benefits and categories of hybrid PV-T have been studied.

Peak shaving, or moving energy usage out of peak hours, is a technique for lowering the peak demand for power. Energy storage, demand response plans, or providing incentives to users to cut back on usage during peak periods can all help. This supports a more sustainable energy future by making the electrical system less taxed and by promoting more dependable and cost-effective power for users There are many articles that study peak shaving; for example, [9] has reviewed peak shaving strategies that utilize EVs' batteries. Peak shaving has some challenges, and [10] analyses these challenges and categorizes peak shaving. Also, there are a lot of studies that introduce the EV's battery as a storage system and utilize V2G and G2V as an energy management strategy in order to peak shaving [11–16].

Recently, there has been an increase in interest in using photovoltaic technology on car roofs to achieve the dual aim of maintaining a consistent level of charge in EV batteries while reducing reliance on fossil fuels. Furthermore, the integration of photovoltaic systems into car roofs also aims to reduce the frequency of required battery charging, providing an eco-friendly and cost-effective solution to sustainable transportation. [17] claims that 70% of passengers can run on car roof PV without needing to be charged. So many articles study the shape and the curve of the car roof to make it optimal [18–20] and correct the roof curve by the Monte Carlo method. [21] analyses the Hyundai Sonata with car roof PV and discusses the materials.

This paper is a study on the integration of hybrid PVT, EV, and battery banks. This paper considers a new innovative way to convert sunlight into power called PV-glass. Scientists have innovated this technology that can absorb the photons and transfer some of them at the same time. This kind of solar cell absorbs selective sunlight and allows other visible light to pass through itself. PV-glass is made of two glass sheets with resin between them and solar cells. As we can see, this technology has a significant advantage that makes us use it where we couldn't apply solar cells before. For example, windows, smartphones, sunroofs, etc. Furthermore, this type of solar cell is flexible, and for this reason, PV-glass is the best choice for the EV's body. Selected PV-glass in this project has a capacity of 7%–10%, and it is considered 10% in ideal situations [22].

The system description is studied in Section II; the methodology is in Section III; and in Section IV, the results are discussed. Conclusion is in Section V.

II. System Discription

As shown in Fig. 1, the proposed system in this study consists of a solar conversion system composed of PV-glass, HPV-T, EV, and a battery bank that is placed in the house. The heat produced by HPV-T supplies the house's thermal energy. The electrical energy generated by the HPV-T charges the storage system, which plays the role of a storage system. On the other side, PV-glass on the EV's body keeps the EV battery's state of charge (SOC) high through the day, and at peak time, the EV battery will be connected to the main battery bank for domestic use. Eventually, at midnight (non-peak time), the EV's battery was charged again for tomorrow. Also considered that the produced electric energy hasn't been sold to the grid, but the EV's battery has been installed in the storage system (the battery bank) to charge it at peak times.

In this study, the selected day is June 22 (n = 173, selected summer day, Rome). Table I shows the clearness index and daily radiation of Rome that were extracted from Homer Energy software.

A photovoltaic thermal panel, or PV-T, was created by scientists by combining photovoltaic (PV) panels with thermal collectors at the same time. We are aware that heat collectors and PV panels were previously used independently [23]. We have been using this new technology recently [24], since it offers several benefits. The ability of HPV-T to simultaneously produce electrical and thermal energy is its most important benefit.

HPV-T could be used as an air collector, a water collector, or in Combi technology [24]. In this study, the Combi technology is considered HPV-T. By collecting the HPV-T air-based and HPV-T water-based technologies, the flowing material will be both water and air, so it helps increase efficiency. This single device is called an HPV-T combi collector. The idea of the HPV-T combi technology was first presented by Tripanagnostopoulos [25].

Table II shows the monthly average temperature of Rome, which was extracted from Homer Energy software.

TABLE I. Monthly Clearness Index and Radiation, Rome, Italy (Homer Energy)

Month	Clearness Index	Daily Radiation (kWh/m^2 /day)
Jan	0.506	1.980
Feb	0.548	2.920
Mar	0.586	4.320
Apr	0.578	5.480
May	0.618	6.780
Jun	0.659	7.640
Jul	0.681	7.670
Aug	0.670	6.710
Sep	0.629	5.080
Oct	0.574	3.400
Nov	0.500	2.110
Dec	0.484	1.690

III. Methodology

In this section, the formulation of objective functions and constant amounts for system components for solar irradiation, PV-glass, and HPV-T systems is presented.

A. System Components Modeling

1) Solar Irradiation

The whole annual radiation on a sloped surface, E is:

$$E = \sum_{m=1}^{12} \sum_{n_{month}} H_T \tag{1}$$

Where, H_T is radiation on a slope panel in daylight:

$$H_T = \sum_{N} I_T \tag{2}$$

Where, I_T is hourly radiation on a tilted surface:

$$I_T = I_b . R_b + I_d . F_{c-s} + I . \rho_g . F_{c-g} \tag{3}$$

Where:

$$I_d = \begin{cases} I * 1 - \overline{K_T} & \overline{K_T} \le 0.22 \\ I[(0.95 - 0.16\overline{K_T} + 4.3 * (\overline{K_T})^2 - 16.6(\overline{K_T})^3 + 12.3(\overline{K_T})^4] & 0.22 < \overline{K_T} < 0.8 \\ 0.1651 & \overline{K_T} \ge 0.8 \end{cases} \tag{4}$$

$$I_b = I - I_d \tag{5}$$

$$F_{c-s} = \frac{1 + \cos\beta}{2} \tag{6}$$

$$F_{c-g} = \frac{1 - \cos\beta}{2} \tag{7}$$

$$R_b = \frac{\cos\theta}{\cos\theta_z} \tag{8}$$

$$\cos\theta = \sin\varphi . \sin\delta . \cos\beta - \sin\delta . \cos\gamma . \sin\beta . \cos\varphi + \cos\varphi . \cos\delta . \cos\omega . \cos\delta + \cos\delta . \sin\beta . \sin\varphi . \cos\gamma . \cos\omega + \cos\delta . \sin\beta . \sin\gamma . \sin\omega \tag{9}$$

$$\cos\theta_z = \sin\delta . \sin\varphi + \cos\delta . \cos\varphi . \cos\omega \tag{10}$$

$$I = \overline{K_T} . I_o \tag{11}$$

$$I_o = \frac{12 \times 3600}{\pi} . G_{on} . cos\, \varphi . cos\, \delta$$
$$(sin\, \omega_1 - sin\, \omega_2) + \pi \left(\frac{\omega_1 - \omega_2}{180}\right) . sin\, \varphi . sin\, \delta \quad (12)$$

$$G_{on} = G_{sc} \left[1 + 0.033\, cos(\frac{360n}{365})\right] \quad (13)$$

$$\omega_1 = 15(h_1 - 12)$$
$$\omega_2 = 15(h_2 - 12) \quad (14)$$

Constant parameters for solar radiation, HPV-T, battery, and constant parameters for costs are presented in tables III and IV, respectively.

On the chosen summer day, the home used a total of 5849 kWh of energy. The EV battery draws 1700 kWh, while HPV-T provides the remaining 4149 kWh (this is just in case you connect the EV to the battery bank; otherwise, the energy is supplied by the battery bank and main grid).

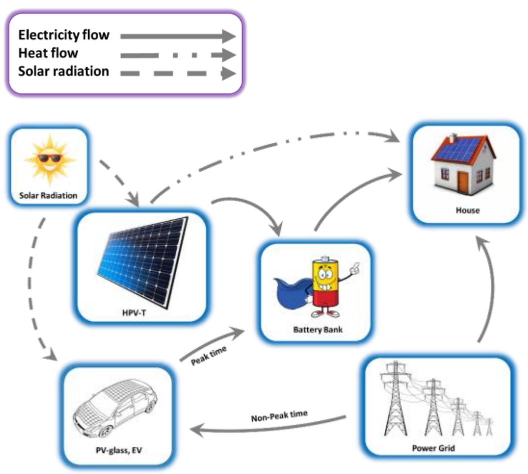

Figure 1. Example of a figure caption.

TABLE II. MONTHLY AVERAGE TEMPERATURE, ROME, ITALY.

Month	**Temperature (°C)**
Jan	9.68
Feb	9.58
Mar	11.46
Apr	13.84
May	17.89
Jun	21.59
Jul	24.73
Aug	25.3
Sep	21.94
Oct	18.5
Nov	14.17
Dec	10.8

TABLE III. CONSTANT PARAMETERS FOR RADIATION.

$\beta = 41.89$	$G_{sc} = 1367 \left(\frac{W}{m^2}\right)$
$\gamma = 0°$	$\varphi = 41.89°$
$\rho_g = 0.2$ n≤ 60 (Winter)	$\rho_g = 0.6$ n≥ 61 (Other Seasons)

TABLE IV. CONSTANT PARAMETERS FOR PV/T AND BATTERY COSTS.

$C_{a,PV/T} = 285 \frac{€}{m^2}$	$\eta_{PV/T} = 0.16$
$C_{a,batt} = 200 \frac{€}{kWh}$	$n_b = 10\ year$
i=0.1	*n*=20

2) Photovoltaic

Totally, the generated energy by HPV-T supplies the demand energy of the house (electrical and thermal); in this project, it has been considered that extra electrical energy has been saved with a storage system (battery bank).

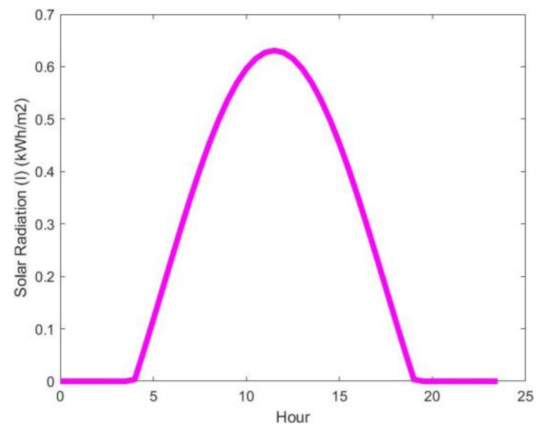

Figure 2. Solar Radiation for Selected Day (n=173, Rome).

TABLE V. CONSTANT PARAMETERS FOR PV-GLASS COSTS.

$C_{a,PV-glass} = 490 \frac{€}{m^2}$	$\eta_{PV/T} = 0.10$
n=20	$n_b = 10\ year$
i=0.1	

Tables III, IV, and V show the constants for radiation, HPV/T and battery costs, and PV-glass costs, respectively.

η_T is overall efficiency and calculated by [10-12].

$$\eta_T = \eta_{th} + \eta_{elec} \quad (15)$$

The η_T of HPV-T collector is calculated as:

$$\eta_{th} = \frac{Q_u}{G.A_{PV/T}} \quad (16)$$

Where, G is solar radiation intensity ($\frac{W}{m^2}$), $A_{PV/T}$is area of HPV-T collector (m^2), and Q_u is the usable collected heat which is:

$$Q_u = m_f . C_p(T_{out} - T_{in}) \quad (17)$$

The η_{elec} of HPV-T collector is calculated as:

$$\eta_{elec} = \frac{V_m I_m}{A_{PV/T}.G} \quad (18)$$

The η_{th}, η_{elec}, and η_T of the system were found to be 46%, 9.4%, and 55%, respectively.

The explanation of exergy balance in an HPV-T is given by [13]:

$$\sum Ex_{th} = Q_u - m_f C_p T_0 . \ln \frac{T_{out}}{T_{in}} \quad (19)$$

$$\sum Ex_{elec} = \left[\frac{\eta_{elec} A_{PV/T} G}{1000}\right] \quad (20)$$

Where, m_f is the mass of fluid flow rate ($\frac{kg}{s}$), C_p is the specific heat of fluid, and it is equal to 4190 ($\frac{J}{kg.°C}$) for water.

B. Objective Function

Because the optimizations for HPV/T with battery and PV-glass have been done separately, two objective functions are considered:

1. The objective function of HPV/T and battery is defined by the following formula:

Where, TC of HPV/T and battery is calculated by:

$$TC1 = TC_{PV/T} + TC_{batt} \quad (21)$$

Where, total cost of HPV-T is:

$$TC_{PV/T} = C_{I,PV/T} + C_{M\&O,PV/T} - SV_{PV/T} \quad (22)$$

$C_{I,PV/T}$ is initial cost of HPV-T (€), $C_{M\&O,PV/T}$ is maintenance and operation cost of HPV-T (€), and $SV_{PV/T}$ is salvage value of HPV-T (€):

$$C_{I,PV/T} = C_{a,PV/T} A_{PV/T} \quad (23)$$

$$C_{M\&OPV/T} = 0.02 C_{I,PV/T} \quad (24)$$

$$SV_{PV/T} = 0.2 C_{I,PV/T} \quad (25)$$

The equivalent annual cost is given by [13]:

$$C_{ea,PV/T} = TC_{PV/T}\left[\frac{(1+i)^n - 1}{i.(1+i)^n}\right] \quad (26)$$

In economics, the phrase "annual depreciation cost" refers to the amount of money that a property or project costs its owner on a yearly basis during the term of its expected lifetime.

$$TC_{batt} = C_{I,batt} + C_{M\&O,Batt} - SV_{batt} \quad (27)$$

$C_{I,batt}$ is initial cost of battery (€), $C_{M\&O,batt}$ is maintenance and operation cost of battery (€), and SV_{batt} is salvage value of battery (€):

$$C_{I,batt} = C_{a,batt} . E_{max,batt} \quad (28)$$

$$E_{max,batt} = \sum_h (E_{PV/T}(h) - E_l(h))^+ \quad (29)$$

h, represents the summer day hours.

$$C_{M\&O,batt} = 0.01 C_{I,batt} \quad (30)$$

$$SV_{batt} = 0.2 C_{I,batt} \quad (31)$$

The equivalent annual cost of battery is given by [13]:

$$C_{ea,batt} = TC_{batt}\left[\frac{(1+i)^n - 1}{i.(1+i)^n}\right] \quad (32)$$

2. The objective function of PV-glass is defined by:

Where, TC of PV-glass is calculated by:

$$TC2 = TC_{PV-glass} \quad (33)$$

Where, total cost of PV-glass is:

$$TC_{PV-glass} = C_{I,PV-glass} + C_{M\&O,PV-glass} - SV_{PV-glass} \quad (34)$$

$C_{I,PV-glass}$ is initial cost of Amorphous Silicon PV-glass (€), $C_{M\&O,PV-glass}$ is maintenance and operation cost of PV-glass (€), and $SV_{PV-glass}$ is salvage value of PV-glass (€):

$$C_{I,PV-glass} = C_{a,PV-glass} A_{PV-glass} \quad (35)$$

$$C_{M\&OPV-glass} = 0.02 C_{I,PV-glass} \quad (36)$$

$$SV_{PV/T} = 0.2 C_{I,PV/T} \quad (37)$$

The equivalent annual cost is given by [13]:

$$C_{ea,PV-glass} = TC_{PV-glass}\left[\frac{(1+i)^n - 1}{i.(1+i)^n}\right] \quad (38)$$

C. Constraints

The Volvo-XC-90 was chosen as the EV for his project, and the applicable constraint is the size of its body, which defines the area of PV-glass.

$$A_{PV-glass} < 7.3\ m^2 \quad (39)$$

D. Optimization Algorithms

Recently, genetic algorithms (GA) and particle swarm optimization (PSO) have been more noteworthy in studies because of different modern heuristic optimization techniques. So, in this study, GA and PSO are used for two purposes: first, to compare the final best solution, and second, to find out which one is faster and better. The objective functions are Eqs. (21, 32), which MATLAB optimized separately.

1) Genetic Algorithm (GA)

Genetic algorithms (GA), which were created many years ago and are widely used by academics, are briefly defined in this section. This method starts with an initial population rather than simply a single point since it is population-based. Every iteration, also known as a generation, updates the beginning group, and each generation has a population. Each point is represented by a chromosome, which also contains the values for all design variables, and each design variable is represented by a gene.

To complete a mating pool of points, the selection procedure is repeated to produce $N_p/2$ additional points. The values of crossover and mutation in this research are 0.9 and 0.1, respectively. The population size (pop-size) is 10.

2) Particle Swarm Optimizatio (PSO)

Particle Swarm Optimization (PSO), which is based on the principle of “swarm intelligence,” is a randomized population-based optimization method that takes its inspiration from the behaviour of flocks of fish and birds.

The weight here includes a constant c_1, and a random parameter r_1 in the interval [0, 1] that presents a randomly generated component to the algorithm. The relative values of c_1 and c_2 control the tendency towards local versus global search, and the values of them are 2 and 2, respectively.

Where, $f(x)$ is the objective function for optimization in Eqs. (21 and 32). Then, utilize this step to adjust the location of the particles for the nest iteration. In this research, there are 10 particles as population size (n-pop).

IV. Results

In this paper, the input to the algorithm is solar radiation, electricity loads, hourly data, energy from HPV-T, total and average radiation, extraterrestrial normal radiation, solar constant radiation, HPV-T efficiency, latitude, angle of incidence, hours' number of the day, the number of the day in year, radiation view factor amongst ground and panel, radiation view factor amongst panel and sky, and specification of each component (which contains initial costs, area dependence cost of HPV-T array, capacity dependence cost of battery, maintenance cost of battery, and useful life).

As it is shown in Fig. 3, the minimum cost of PSO and GA optimizations for PV-glass on an EV's body is 625.1€ and 654.4€, respectively. With these results, the optimal size of PV-glass is 10 m^2. The measured area of the car (Volvo-XC-90) is 7.3 m^2. By assuming the A=7.3 m^2 and putting this value as a constant in MATLAB, the final value for cost will be 621.9€. In this part, according to Eq. (32), the best cost is the total cost of PV-glass.

As shown in Fig. 4, the minimum costs of PSO and GA optimizations for HPV-T are 1501.2€ and 1528.9€, respectively. The optimal size of the HPV-T is 9.4 m^2, and there are no constraints on the area of the HPV-T on the roof of the house. We should pay attention according to objective function 1 in Eq. (21), the best cost is about the sum of the total costs of HPV/T and battery.

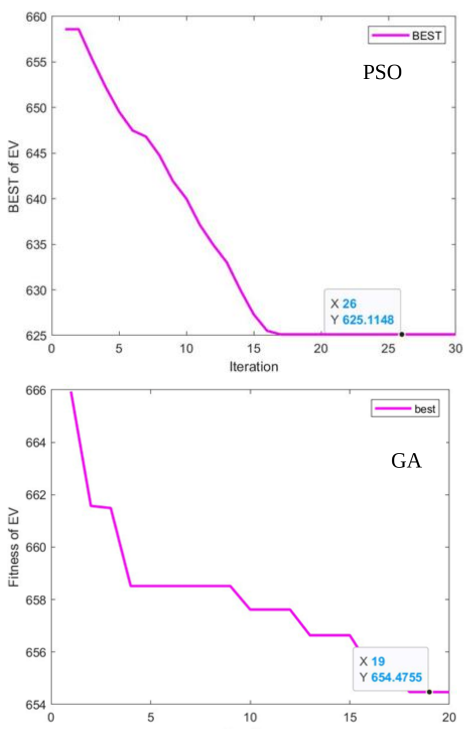

Figure 3. PSO and GA Optimization for PV-glass on EV.

V. Conclusion

In this paper, in order to keep the level of the EV battery's SOC higher, a PV-glass is applied to the EV's car body, so that not only during the driving time in daylight hours is the SOC level higher, but also at peak time in the evening when the EV is parked in the house parking lot, the SOC of the EV's battery will be higher than whenever there is no PV-glass on the EV's body. So, this EV's battery could be used as an extra storage device that is integrated with the battery bank that is placed at home. On the other hand, the HPV-T on the roof of the house produces electrical and thermal energy at the same time, and the electrical energy can charge the battery bank too. The EV's battery after peak-time has reached its minimum level of SOC, so it can get charged again after midnight (non-peak time) by the grid. In addition, the house is connected to the grid, which can supply its demand in case there is not enough energy for the house's demand in the battery bank.

The total scenario in this study is using solar energy and storing it with a storage system in order to supply peak time demand. On the other hand, the significant goal in energy management and smart grids is peak shaving.

The house demanded 5849 kWh on the selected summer day. 4149 kWh are provided by HPV/T, while the EV battery gives 1700 kWh (this is just in case you connect the EV to the battery bank; otherwise, the energy is supplied by the battery bank and main grid). As seen by reading power bills from the previous two years, this day has the highest demand. This method has covered the whole demand of the house if we assume that the battery bank had no charge in the morning. Since this is a worst-case scenario, it implies that the battery is initially discharged at the beginning of the day.

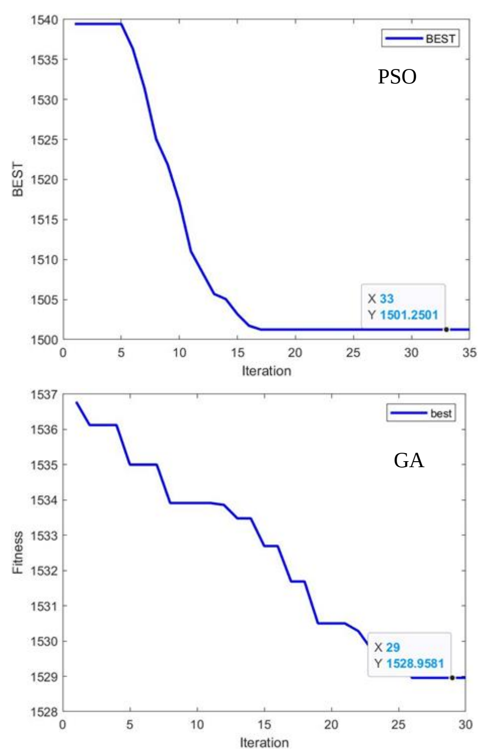

Figure 4. PSO and GA Optimization for HPV-T.

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