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Article

The Study of an Energy Management Strategy within a Microgrid with Photovoltaic Production of the <<PROPRE.MA>> Project in the City of Tangier and Integrating V2G Technology

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Abstract: The energy stored in an electric vehicle's battery would be drawn and distributed to the electrical grid to better drive energy consumption within a microgrid that includes a renewable generator(s) managed by a specific energy management strategy. This concept, known as vehicle-to-grid technology: V2G, makes the energy stored in the electric vehicle's battery more beneficial by discharging it to the public grid during periods of high demand. In this study, we will consider a vehicle system connected to a microgrid, which includes a photovoltaic generator reported from the <<PROPRE.MA>> project in the city of Tangier. We will elaborate the study of a strategy of the car connected to this V2G network. This allows electricity to be stored when rates are low (off-peak hours) and then used when prices rise (peak hours). Otherwise, the solar energy will cover the owner's needs, and the surplus will be injected into the distribution network. This strategy will manage the solar power, the load power, the state of charge of the EV battery, the time of day and the driving scenario. Using two driving profiles, we will show the performance of the proposed energy management strategy and the percentage contribution of the photovoltaic array of the <<PROPRE.MA>> project in the city of Tangier.

Keywords: Electric vehicle; microgrid; renewable generator; V2G; management strategy

1. Introduction

The use of batteries to charge during surplus generation, and to cover the energy need during shortage of generation is a common microgrid technology. However, the electrical power generated from renewable energy resources is fluctuating and unpredictable, in addition to the high demand for electricity during peak hours, unbalances the main distribution network. This can be remedied with solutions for storage and redistribution of the energy produced. One example is pumped storage: Water is pumped continuously to produce energy and indirectly store the energy in clean form. Since this storage solution is expensive, the use of the battery of an electric vehicle via V2G technology is very promising. On the one hand, V2G technology makes it possible to make better use of renewable energies, thus reducing the energy that produces greenhouse gas emissions. On the other hand, electric vehicles parked at home and at work can be transformed into electricity generators.

Large parking facilities, such as shops, universities and hospitals, can apply V2G technology to reduce power drawn from the grid during peak demand. This will be very beneficial when the price of electricity is high or when there is not enough energy from distribution generation, such as solar cells and wind turbines. When EVs are not in mobility, the energy stored in the batteries will not be

useful. The objective of this study is to propose a strategy for managing the storage of this energy during off-peak hours and to reuse it during the period of high demand (peak hours) in order to regulate the public grid. Studies in this direction have already been carried out and published in the literature. The study presented in [1] proposes a dual-use scheme that uses V2G technology for both peak load and frequency reduction. This work has shown that the benefits to the user in this type of dual-use program are close to or even greater than the benefits achieved in either of the single-use programs but without taking into account the battery degradation related to the number of charge/discharge cycles performed. In order to address this issue, the study published in [2] is a review of V2G technology which has become an important concept due to the high number of electric vehicles on the market. These electric vehicles can be used as storage devices to supply the load. This paper discusses the economic benefits to the electric grid and EV owners as well as battery degradation, bi-directional charging, charging stations and battery management strategies, and in [3], shows that this range of EV battery state of charge [$30\% < \text{SOC} < 90\%$] allows for a slow weakening of the battery. The results of these two works are obtained in a microgrid connected to the distribution network. In contrast, [4], they proposed a two-level scheduling approach for peak load shaving within an isolated microgrid. The work published in [5] proposed a load/unload algorithm to find the number of EVs that minimizes the electrical energy consumption from the grid. The results showed that the suggested algorithm provides energy savings after the installation of electric vehicle charging stations through a case study.

Electric vehicle battery charging can be done with and without wires, charging the electric vehicle battery with a wire disturbs some users and may prevent the development of electric vehicles, so the authors of the paper [6] focused on wireless charging as a technology to increase the use of electric vehicles. They described the state of the art of the wireless V2G concept and presented a perspective on the challenges for fast development of this technology. In the concept of V2G technology, the battery range of electric vehicle has an important role, the paper [7] proposes a smart cyber-physical multi-source energy system to increase the range of electric vehicle as well as a good self-distributed energy system through NSGA-II genetic algorithm. Furthermore, in [8], the authors studied the environmental side of V2G technology, showing that the integration of this technology in a microgrid allows the reduction of CO₂ emissions. The results show that the integration of controlled EVs results in a reduction of 213.23 kg of CO₂ emissions. And in [9] the authors studied the challenges and benefits of moving from the existing traditional grid model to the new model known as microgrid as a new paradigm for smart cities of the future. They envisaged an energy system architecture that can be applicable to existing and new cities for more benefits such as clean energy production and lower energy costs.

Most of these works do not take into account the contribution of the solar generator for EV charging and mainly use large fleets of EVs in their models. Here we will discuss the small-scale study. The current study proposes an optimal energy management strategy within a microgrid to charge the battery of a single EV during off-peak hours when the energy cost is low and to discharge them for driving purposes during peak hours when the energy cost is high in order to regulate the grid during high demand. Furthermore, compared to previous work related to V2G technology, the current study contributes in a very different way. A case study that targets the contribution of a photovoltaic generator reported from the <<PROPRE.MA>> project in the city of Tangier [10], [11] will be proposed. It will involve two scenarios in the form of two different electric vehicle driving profiles. One of the relevant observations of this study is that the redistribution of energy from the vehicle to the grid depends on the profile performed.

The simulation in this study was based on the assumption of a single EV user, with state of charge limits, but with two different driving profiles in a microgrid.

The rest of this paper is organized as follows. Section 2 describes the system used in this study, with a review of the proposed energy management strategy, followed by a detailed description of the different simulation cases. The results are presented in Section 3, followed by a discussion in Section 4 and a conclusion in Section 5, and finally a presentation of the <<PROPRE.MA>> project in the acknowledgement section.

2. Materials and Methods

2.1. Description of the system

The power system consists of a photovoltaic installation of the <<PROPRE.MA>> project in the city of Tangier, which provides a peak installed power of 6 KW, connected to the main AC bus of 230 V (phase voltage) through a DC/DC converter and an inverter. The load is represented by three houses consuming a maximum power of 2.5 KW each, a 100% electric car of the brand Renault Twingo with a Lithium-Ion battery of 22 kWh capacity [12] connected to the AC bus of the microgrid via a DC/DC converter and an inverter, and a bi-directional charging station for EV. All loads are considered AC and the system follows a predefined and deterministic operational strategy. Although each micro-source is interconnected to the system by its own power electronics, which is responsible for its proper operation and maximum power extraction, the control of the overall system operation is centralized. A central converter is responsible for power distribution within the microgrid. Figure 1 shows the microgrid and the different subsystems of the model, which is based on a simplified model of a microgrid in Matlab/Simulink [13].

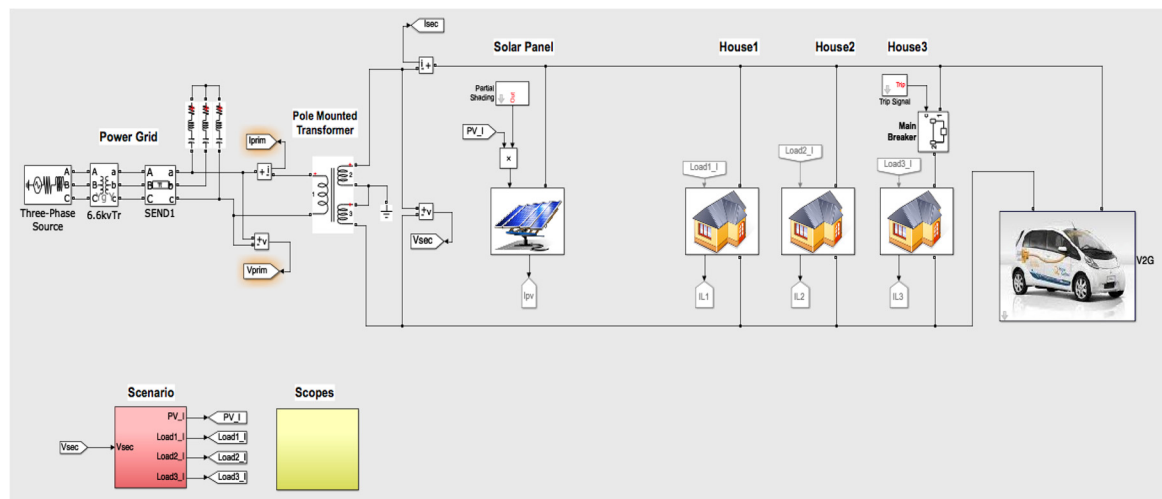


Figure 1. General view of the model in Simulink-MATLAB.

The Scenario subsystem includes the values of the power produced by the PV panels and the load during one day. The Scope subsystem includes all the graphs needed to visualize the results of the microgrid operation and the Chart block, which contains the status diagram of the proposed energy management strategy shown in Figure 2.

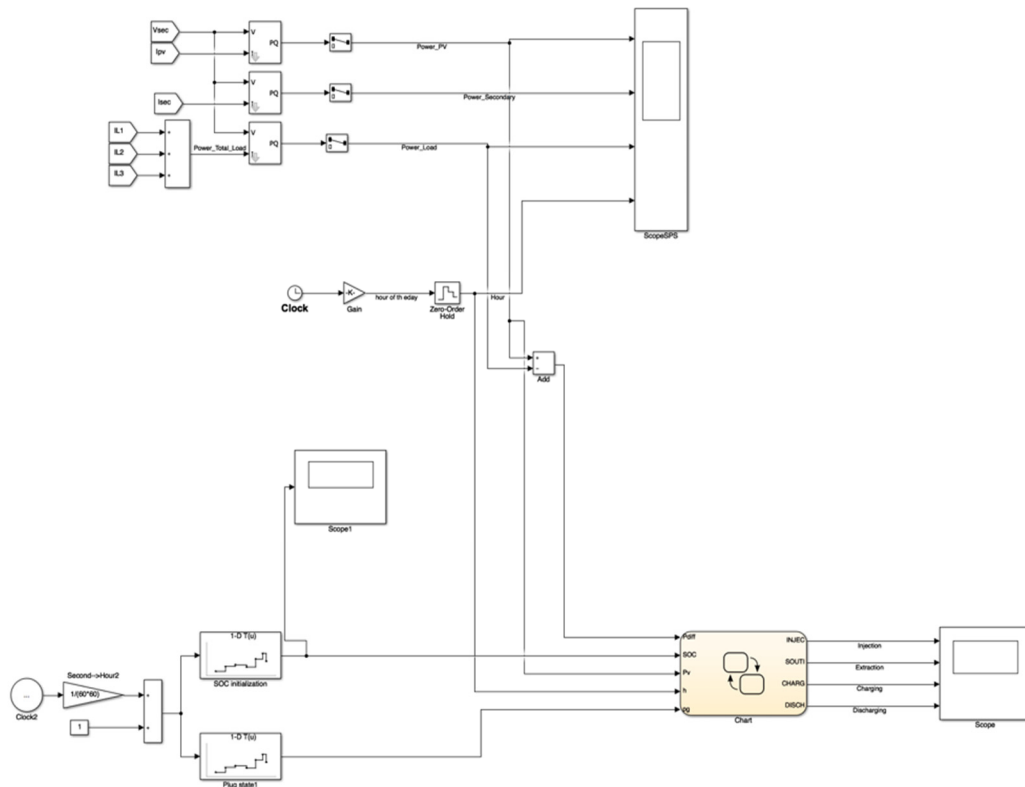


Figure 2. An overview of the scope subsystem.

2.2. Control and operational strategy

In this section, the logic of the operational strategy and its control will be described. During this time, off-peak hours, the electric vehicle is not connected to the V2G terminal and the solar energy produced feeds the load. If there is a surplus of energy within the system, it will be injected into the main grid to be consumed during peak hours by the homeowner. If there is an energy deficit during the same period, electricity will be drawn from the grid to cover the needs of the load.

On the other hand, when the electric vehicle is connected to the V2G terminal, during peak hours, the EV battery will be discharged into the public grid, respecting its minimum state of charge which must not be exceeded. The EV will only be charged from midnight, off-peak hours, so that it can be used in the morning by its owner while respecting the maximum state of charge of the battery.

According to the Office National d'Électricité (ONE), the peak and off-peak hours in Morocco are shown in Table 1.

Table 1. Peak and off-peak hours in Morocco according to ONE.

	Winter from 01/10 to 31/03	Summer from 01/04 to 30/09
Peak hours	5 pm to 10 pm	6 pm to 11 pm
Off-peak hours	from 7 am to 5 pm and from 10 pm to 7 am	from 7 am to 6 pm and from 11 pm to 7 am

The following parameters are the most significant variables in the control of the microgrid:

P_v : The photovoltaic power of the project <<PROPRE.MA>> in the city of Tangier.

P_{char} : The power of the load

P_{diff} : The power of the difference between the photovoltaic power and that of the load.

SoC: The state of charge of the batteries.

SoC_{max} : The maximum state of charge.

SoC_{min} : The minimum state of charge.

h : The time of day.

pg: The state of the car if it is connected to the V2G terminal or not.

There are also signals with Boolean values that enable or disable battery charging or discharging and main grid injection or extraction: CHARG, DISCH, INJEC and SOUTI respectively.

In more detail, the operational energy management strategy is as follows:

In the case where the electric vehicle is not connected to its V2G terminal ($pg=0$), in this case the EV is used to go to work, to return home or to do some shopping. So if the power difference between the photovoltaic power and the load power is greater than zero ($P_{diff}>0$), then there is a surplus of energy inside the microgrid that will be injected into the distribution network for further use, otherwise, if the power difference between the photovoltaic power and the load power is less than zero ($P_{diff}<0$), then there is a deficit of energy, so drawing from the network is necessary to meet the load needs.

In case the electric vehicle is connected to its V2G terminal ($pg=1$), then if the time is greater than or equal to 06 pm ($h \geq 18$), i.e. during peak hours, during this period just the discharge of the EV battery will be performed. If now the battery state of charge is higher than the minimum state of charge ($SoC > SoC_{min}$), then the amount of energy from the EV battery will be made available to the grid, otherwise, if the battery state of charge is less than or equal to the minimum state of charge ($SoC \leq SoC_{min}$), then no action will be activated. When the time is less than 7 am ($h < 7$), since we are in the off-peak hours, during this period just the charging of the battery of the EV will be carried out, but before it is necessary to check the state of charge of the battery, if it is greater than or equal to the maximum state of charge ($SoC \geq SoC_{max}$), then no action will be activated. If it is lower than the maximum state of charge ($SoC < SoC_{max}$), there will be two cases: If the photovoltaic power is greater than zero ($P_v > 0$), then the EV battery will be charged by solar energy, otherwise if the photovoltaic energy is less than or equal to 0 ($P_v \leq 0$), then the EV battery will be charged by energy from the main grid.

The flowchart of the main energy management strategy is shown in Figure 3.

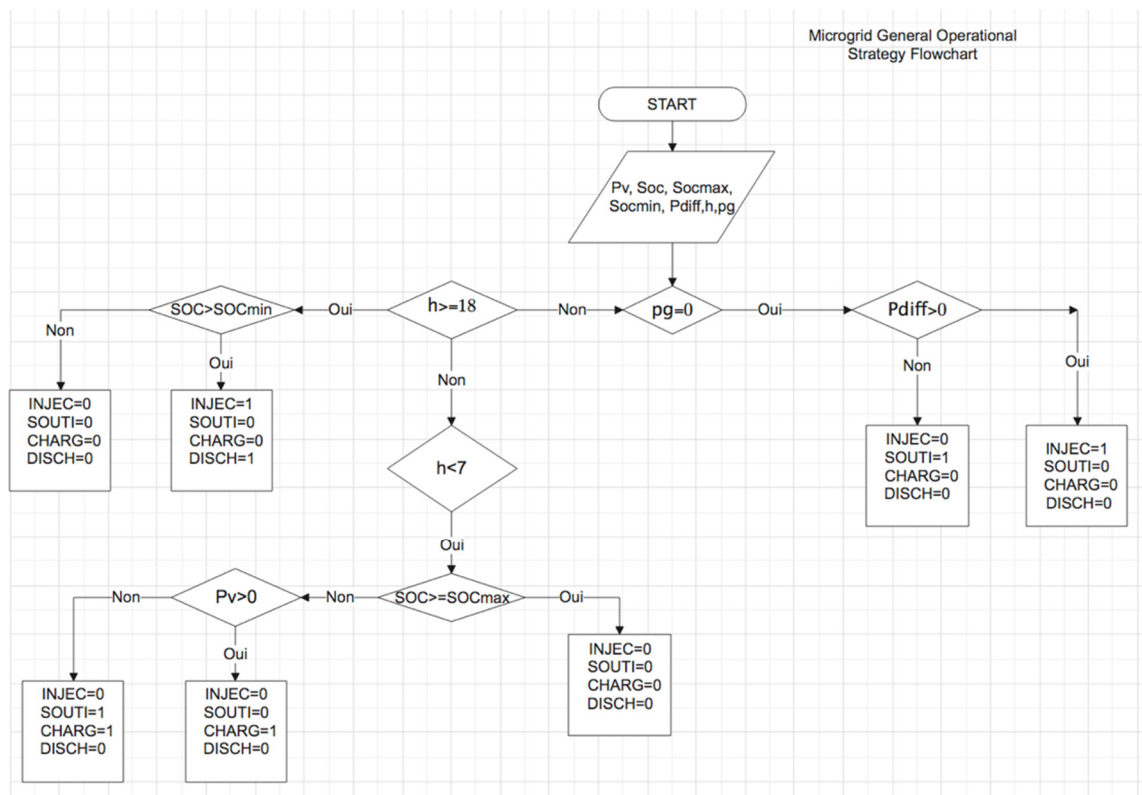


Figure 3. Flow chart of the main operational strategy.

This flowchart will be implemented as a state diagram inserted into the chart block in Simulink and shown in Figure 4. By definition, state diagrams are high-level graphical representations used as a starting point for the design of complex software, as their simplicity allows the different modes of operation to be clearly illustrated [14].

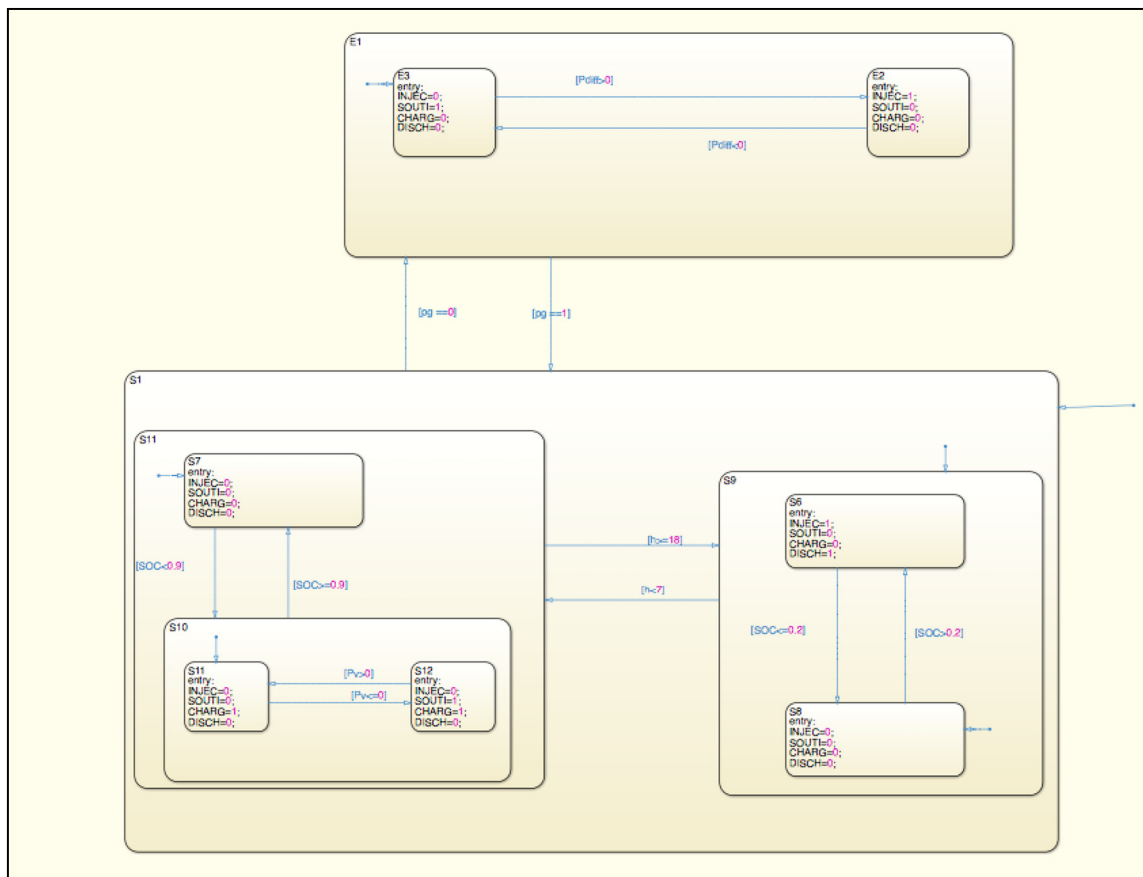


Figure 4. System status diagram.

2.3. Description of the different cases of the simulation

In this section, different driving profiles are specified in order to understand the behavior of the EV battery by analyzing the times of energy withdrawal from the main grid during off-peak hours and energy injection into the grid during peak hours. We also study the contribution of the photovoltaic array to cover the load requirements, including the EV battery.

The simulation is realized with Matlab/Simulink and will cover a period of one day (24 hours), it is a day in April, when the energy efficiency of the solar source reaches its highest values, shown in Figure 5. The load curve is shown in Figure 6. The three houses reach at 9 am a peak consumption of 6,500 W, and at 7 pm and 9 pm a consumption of 7,500 W. The V2G technology is only applied during the peak hours, from 5 pm in winter and 6 pm in summer, in order to balance the network.

We consider a Renault Twingo EV user, with two different driving profiles and state of charge limits that are represented as follows, $VE=[SoC_{min}-SoC_{max}] = [20\%-90\%]$ to limit long-term battery degradation [2].

The main difference in the SoC interval comes from the different driving profiles. The value 1 means that it is connected to the V2G terminal and the value 0 means the opposite, in this case the EV is driven by its user to go to work, to go home or to do some shopping.

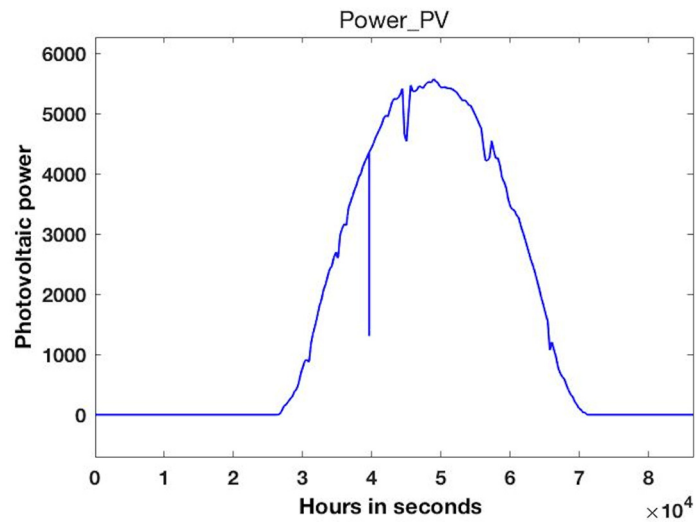


Figure 5. Photovoltaic power on 09 April in Watt.

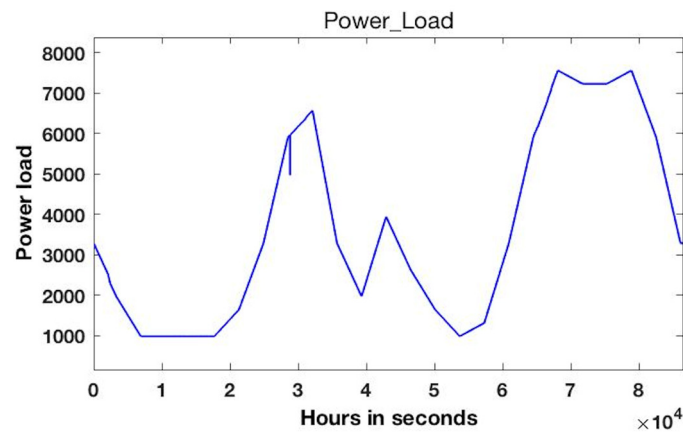


Figure 6. The power of the 09 April load in Watt.

In the first profile (case i), the user of the electric vehicle does not have the possibility to charge it at work. The driving profile determines the state of charge of the battery of the electric vehicle (Figure 7 and Figure 8).

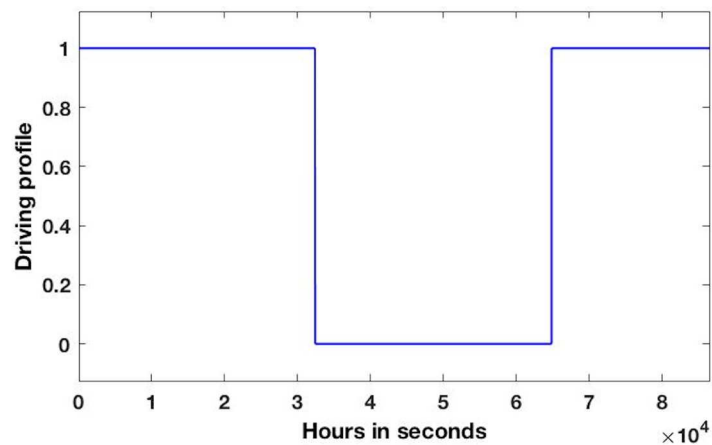


Figure 7. The first daily driving profile of the electric vehicle.

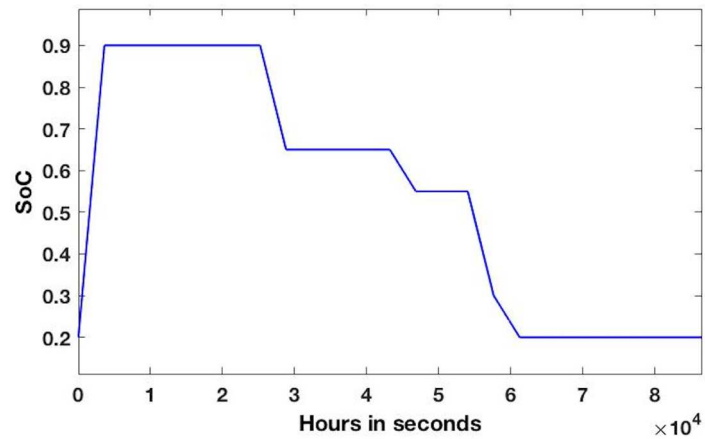


Figure 8. The daily state of charge (SoC) of the electric vehicle battery with the first driving profile.

In the second profile (case ii), the user of the electric vehicle has the possibility to charge it at work. The driving profile determines the state of charge of the battery of the electric vehicle (Figure 9 and Figure 10).

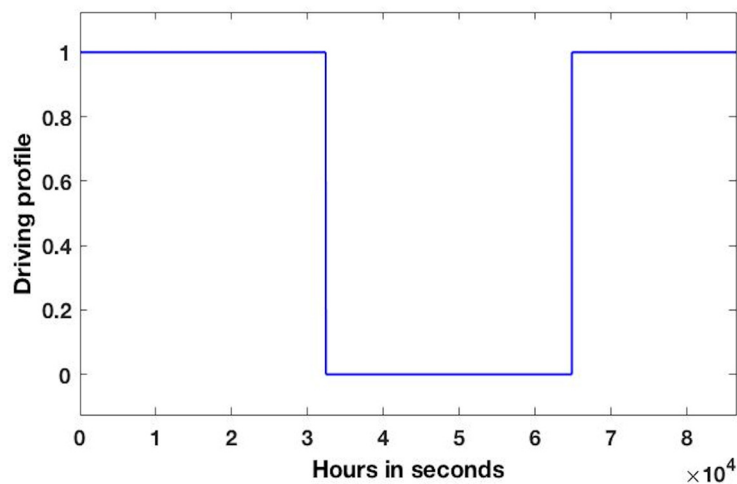


Figure 9. The second daily driving profile of the electric vehicle.

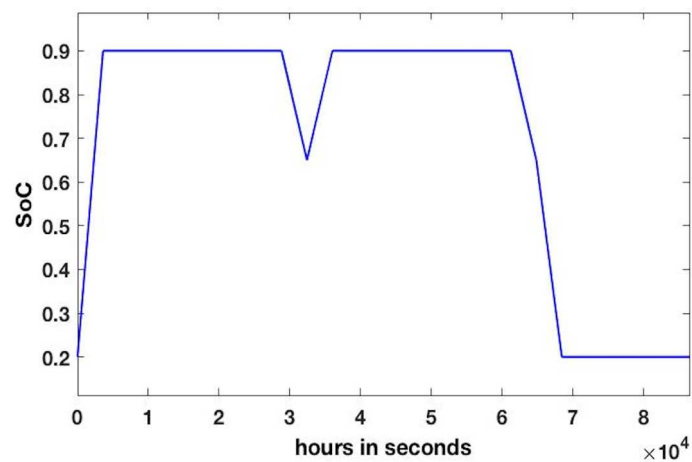


Figure 10. The daily state of charge (SoC) of the electric vehicle battery with the second driving profile.

3. Results

After describing the structure of the model and specifying the different simulation profiles in the previous section, this section focuses on the study of the simulation results. The two basic profiles are simulated and their results are presented. The results of the simulation outputs within the microgrid are shown in Figures 11 and 12 respectively.

3.1. Case (i)

Case (i) involves the EV user who does not have the possibility to charge his car at work. Figure 11 shows the injection time into the grid, the withdrawal time from the load, the charging time of the EV battery and the discharging time of the battery respectively.

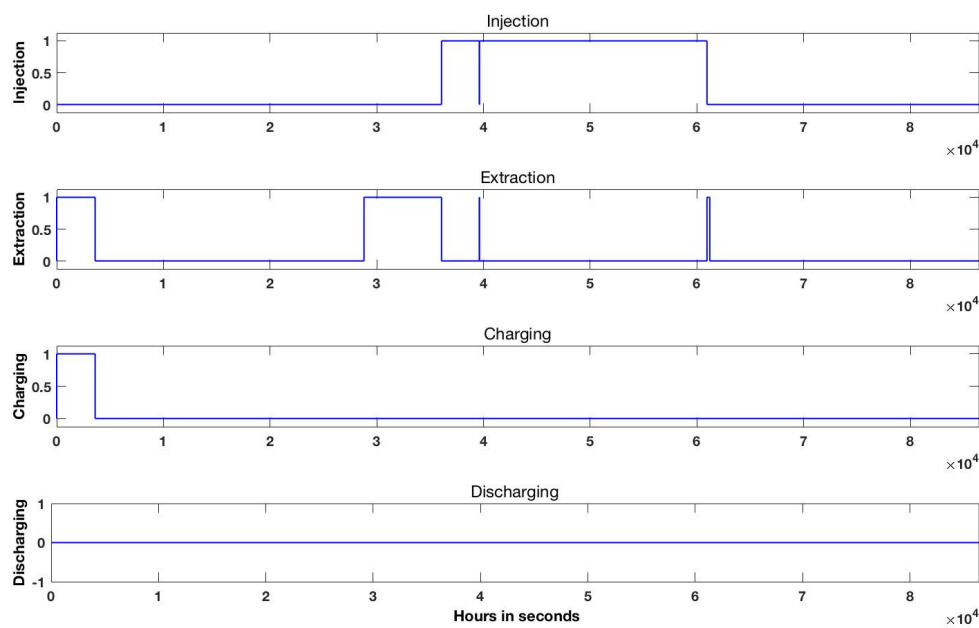


Figure 11. The behavior of the microgrid integrating an electric vehicle with the first profile.

From 8 am to 6 pm (off-peak hours), the EV is not connected to the V2G terminal. In this case, the photovoltaic production will cover the needs of the load. If there is a surplus, it will be injected into the main grid, otherwise, if there is a deficit, a withdrawal from the grid will be necessary. Table 2 represents the energy produced, on the selected day of April, by the photovoltaic generator of the <<PROPRE.MA>> project in the city of Tangier, the energy consumption of the load, and the energy injected or withdrawn each hour from 8 am to 6 pm.

Table 2. Photovoltaic, load, injection and extraction power within the microgrid integrating an electric vehicle with the first profile.

	P_v (kWh)	P_{load} (kWh)	$P_{injection}$ (kWh)	$P_{extraction}$ (kWh)
8am – 9am	12.84	24.87	0	12.03
9am – 10am	32.02	33.90	0	1.88
10am – 11am	48.99	10.92	38.07	0
11am – 12am	61.96	13.33	48.63	0
12am – 1pm	67.24	12.76	54.48	0
1pm – 2pm	59.79	8.84	50.95	0
2pm – 3pm	68.65	5.44	63.21	0
3pm – 4pm	60.43	4.90	55.53	0
4pm – 5pm	48.70	10.61	38.09	0
5pm – 6pm	33.03	20.69	12.34	0

From 6 pm, the user arrives home and plugs his car into the V2G terminal. In this case, the state of charge of the EV will be checked, if it is lower than its minimum state of charge, no action will be triggered, otherwise, if it is higher than its state of charge, the amount of energy stored in the battery of the EV will be injected into the grid during high demand.

So, in our case study we have:

At 18h the $SoC = 0.2 = 20\%$ and the $SoC_{min} = 0.2 = 20\%$ (Figure 8), so $SoC = SoC_{min}$, so there will be no discharge (Figure 11). And the EV will only be charged from midnight onwards from the public grid, the battery will store an amount of energy of 19.8 kWh because its maximum state of charge is 90%.

3.2. Case (ii)

Case (ii) implies that the EV user has the possibility to charge the car at work. Figure 12 shows the time of injection into the grid, the time of withdrawal from the load, the time of charging the EV battery and the time of discharging the battery respectively.

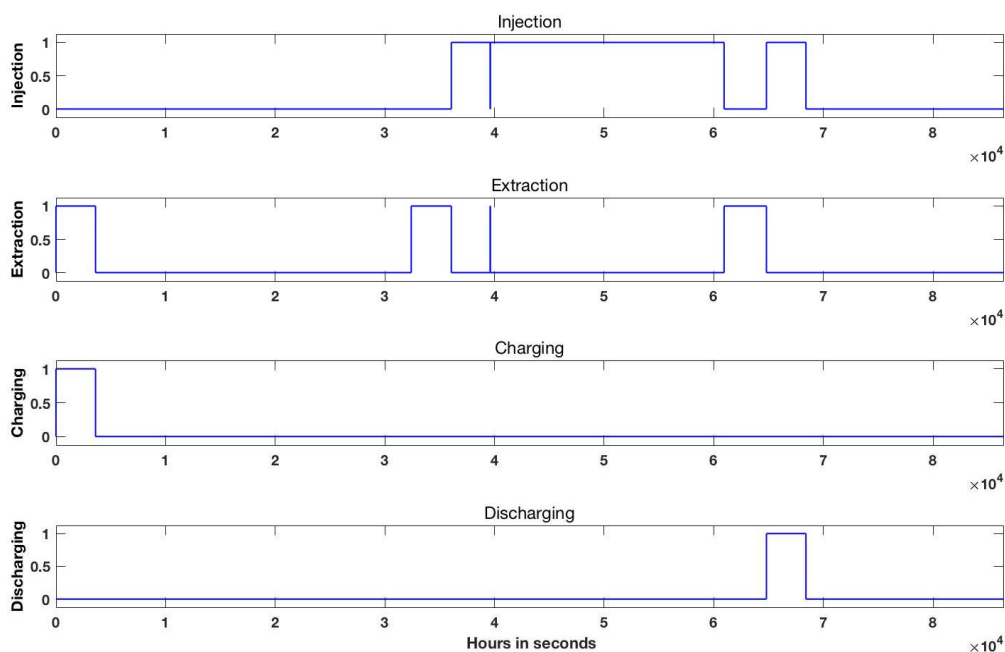


Figure 12. The behavior of the microgrid integrating an electric vehicle with the second profile.

From 10am to 7pm (10am to 6pm: off-peak and 6pm to 7pm: peak hour), the EV is not connected to the V2G terminal. In this case, the photovoltaic production will cover the charging needs. If there is a surplus, it will be injected into the main grid, otherwise, if there is a deficit, a withdrawal from the grid will be necessary. Table 3 represents the energy produced on April day by the photovoltaic array of the <<PROPRE.MA>> project in the city of Tangier, the energy consumption of the load, and the energy injected or withdrawn each hour from 10am to 7pm.

Table 3. Photovoltaic, load, injection and extraction power within the microgrid integrating an electric vehicle with the second profile.

	P_v (kWh)	P_{load} (kWh)	$P_{injection}$ (kWh)	$P_{extraction}$ (kWh)
10am – 11am	48.99	10.92	38.07	0
11am – 12am	61.96	13.33	48.63	0
12am – 1pm	67.24	12.76	54.48	0
1pm – 2pm	59.79	8.84	50.95	0
2pm – 3pm	68.65	5.44	63.21	0
3pm – 4pm	60.43	4.90	55.53	0
4pm – 5pm	48.70	10.61	38.09	0

5pm – 6pm	33.03	20.69	12.34	0
6pm – 7pm	12.92	29.50	0	16.58

From 7pm, the user arrives home and plugs his car into the V2G terminal. In this case, the EV's state of charge will be checked, if it is below its minimum state of charge, no action will be triggered, otherwise, if it is higher than its state of charge, the amount of energy stored in the EV's battery will be injected into the grid during high demand.

In our case study we find that:

At 7pm the $SoC = 0.65 = 65\%$ and the $SoC_{min} = 0.2 = 20\%$ (Figure 10), then $SoC > SoC_{min}$, and since the consumption of the EV battery is 22kWh at 100% then, the amount of energy that will be injected into the grid is 14.30 kWh during the peak hours (Figure 12). And the EV will only be charged from midnight onwards from the public grid, the battery will store an amount of energy of 19.8 kWh because its maximum state of charge is 90%.

4. Discussion of the results

The analysis of the last two graphs in Figures 11 and 12 shows that V2G technology is highly dependent on the driving profile achieved by the EV user. Because in the first case (case i) the driver does not have the possibility to charge his car at his place of work, he arrives at home with a state of charge equal to the minimum state of charge, therefore no injection into the grid, knowing that we are during high demand, so in this case the V2G technology is not beneficial. The owner will charge his car during off-peak hours, $19.80 \text{ kWh} \times 1.2467 \text{ DH/kWh} = 24.68 \text{ DH}$. And according to Table 2, we have $P_{totalinjection} = 361.30 \text{ kWh}$ so a cost of $361.30 \text{ kWh} \times 1.2467 \text{ DH/kWh} = 450.43 \text{ DH}$ and $P_{totalextraction} = 13.91 \text{ kWh}$, so a cost of $16.58 \text{ kWh} \times 1.2467 \text{ DH/kWh} = 17.34 \text{ DH}$. We conclude that the photovoltaic generator of the <<PROPRE.MA>> project contributed in this case with a percentage of 5.65% in charging the EV battery.

On the other hand, in the second case (case ii), the driver has the possibility to charge his car at his place of work, he arrives home with a state of charge higher than the minimum state of charge. In this case the amount of energy stored in the EV battery is injected into the grid, the V2G technology is beneficial. During peak hours, the owner injects an amount of energy of 14.30 kWh, so a cost of $14.30 \text{ kWh} \times 2.2441 \text{ DH/kWh} = 32.09 \text{ DH}$. And he will charge his car during off-peak hours, $19.80 \text{ kWh} \times 1.2467 \text{ DH/kWh} = 24.68 \text{ DH}$. And according to Table 3, we have $P_{totalinjection} = 116.99 \text{ kWh}$, so a cost of $116.99 \text{ kWh} \times 1.2467 \text{ DH/kWh} = 145.85 \text{ DH}$ and $P_{totalextraction} = 16.58 \text{ kWh}$, so a cost of $16.58 \text{ kWh} \times 2.2441 \text{ DH/kWh} = 37.20 \text{ DH}$. We conclude that the photovoltaic generator of the <<PROPRE.MA>> project contributed in this case with a percentage of 6.53% in charging the EV battery.

The production of the photovoltaic generator of the <<PROPRE.MA>> project in the city of Tangier, used in this study, is a production of a typical day in April. In both cases, this generator will contribute 100% to cover the other load requirements all day. In addition, we have $(P_{injection} > P_{extraction})_{case(ii)} > (P_{injection} > P_{extraction})_{case(i)}$ using V2G technology.

With, according to ONE, 1.2467 DH/ kWh the cost of electricity during off-peak hours and 2.2441 DH/kWh the cost of electricity during peak hours.

5. Conclusion

In this study, the energy stored in EV batteries is used for V2G application during high demand via the study of an energy management strategy inside a microgrid integrating photovoltaic generation of the <<PROPRE.MA>> project in Tangier city.

The results of this study show on the one hand that the V2G technology depends on the driving profile of the EV user and on the other hand the 100%, 5.65% and 6.53% contribution of the 6kW photovoltaic generator of the project <<PROPRE.MA>> in the city of Tangier. This allows to cover the needs of charging, to the charging of the battery of the electric vehicle that does not have the possibility to charge at work and to the charging of the battery of the electric vehicle that can be charged at work, and what shows the performance of the proposed strategy.

The results are obtained using Matlab/Simulink and can be applied to all microgrids integrating renewable sources.

In our future work, we propose the optimal driving profile for V2G technology to be always beneficial.

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Data Availability Statement: Restrictions apply to the availability of these data.

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Conflicts of Interest: The authors declare no conflict of interest.

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