DENSYS

MASTER ERASMUS MUNDUS DECENTRALISED SMART ENERGY SYSTEMS

# MICROPROJECT

## [Cost Optimization of Stand-Alone System]


***Submitted To:***

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# 1. INTRODUCTION

The undeniable link between human activities, particularly fossil fuel utilization, and detrimental environmental emissions is a stark reality. These emissions pose a significant threat to the very ecosystem that sustains us, highlighting the crucial need for solutions that prioritize sustainability. Governments and policymakers, recognizing this urgency, are actively encouraging investments in renewable energy technologies like solar panels and wind turbines. However, the intermittent nature of these sources presents a formidable challenge for grid operators integrating them into the larger power network.

Microgrids emerge as a potential solution to this conundrum. These localized power systems operate independently or in conjunction with the main grid, harnessing locally available renewable resources like solar or wind to generate electricity. Additionally, they incorporate energy storage devices like batteries (for short-term needs) and electrolyzer-fuel cell systems (for long-term storage) to mitigate the intermittent nature of renewable sources.

The impact of microgrids extends far beyond addressing the challenges of renewables. They offer immense possibilities in:

**Empowering Remote Communities:** Microgrids offer a viable solution for regions far from the grid or where grid expansion is economically infeasible. These communities gain access to reliable and clean energy, fostering development and improving living standards.

**Enhancing Grid Resilience:** By acting as independent power units, microgrids provide communities with backup power during blackouts or grid instability. This ensures crucial services like hospitals and water treatment plants remain operational, safeguarding public safety and well-being.

The benefits of microgrids are multifaceted:

**Environmental Sustainability:** By leveraging renewable sources and reducing reliance on fossil fuels, microgrids contribute significantly to lowering greenhouse gas emissions and fostering a cleaner environment.

**Increased Energy Security:** The localized nature of microgrids enhances energy security, making them less vulnerable to large-scale outages or cyberattacks that can cripple centralized grids.

**Improved Efficiency:** Microgrids optimize energy management by balancing generation and consumption locally, minimizing transmission losses inherent in traditional grids and potentially lowering costs.

As technology advances and costs become more favorable, microgrids are poised to play an increasingly central role in shaping the future of energy. Their ability to deliver reliable, sustainable, and resilient power makes them a compelling solution for communities and organizations seeking to create a cleaner and more secure energy future.

# 2. METHODOLOGY

- **Mathematical Modelling:**

  In this part we are going to model our variables, objective function and constraints as follows:

**Variables**:

Following are the variables used in **CASE 1 and 2** for the optimization function:

1. Npv: Number of PV panels
2. Ncell: Number of battery cells
3. SOC_ini: Initial charging state of the battery

**Objective:**

In this project, we are working on a mono-objective function. Our objective is to optimize the cost of our stand-alone project by finding the appropriate number of PV panels & battery cells. The objective function is as follows:

Obj = @ (X) X(1)*Cinv_panel + X(2)*Cinv_cell

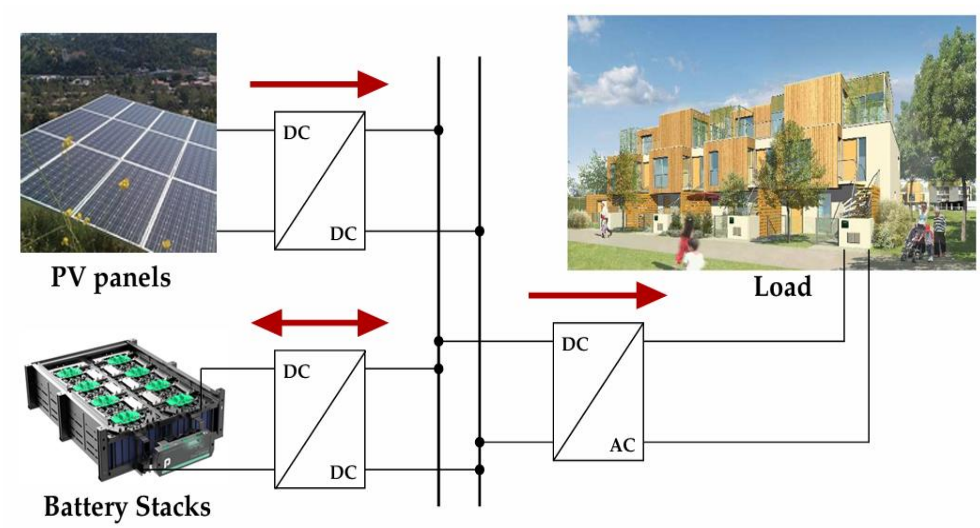
Whereas,
X (1) = The optimized number of PV panels
X (2) = The optimized number of battery cells

**Constraints:**

The following constraints are kept under consideration while optimizing the cost:

1. Final SOC > Initial SOC: Final State of charge at the end of day should be greater than the initial state of charge.
2. SOC_min < SOC < SOC_max: The state of charge at any instant should be greater than the pre-defined minimum & maximum SOC.
3. P_unsup = 0: The load should be supplied all time

- **Type of microgrid selected:** The load demand will be fulfilled using solar photovoltaic and batteries system.



### CASE 1: Optimization of ($N_{pv}, N_{cell}, SOC_{ini}$ & $Cost$) for each month separately.

- **Load profile:** In this case, the standard load profile of 114,156 Watts of belt load customers in Berlin has been chosen and is represented on the scale of one day.

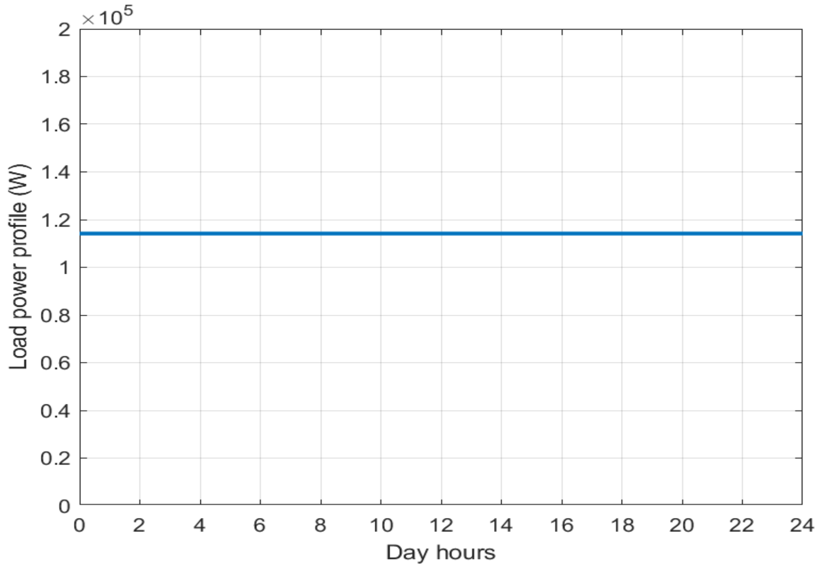
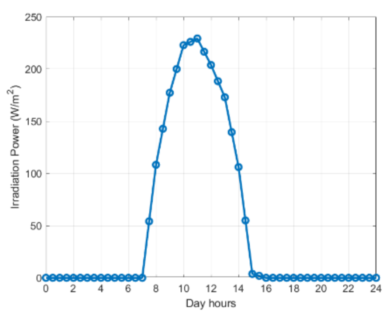
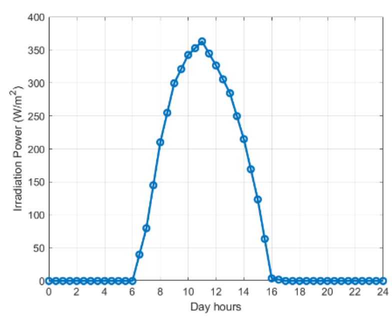



***Figure 2: Load demand presented on time scale of one day (24 hours).***

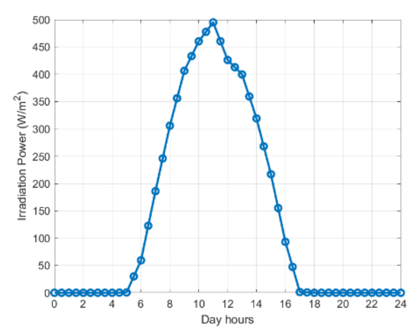
- **Solar irradiance profile:** In this case, the solar irradiance profile of each month has been considered and is represented on the scale of one day.



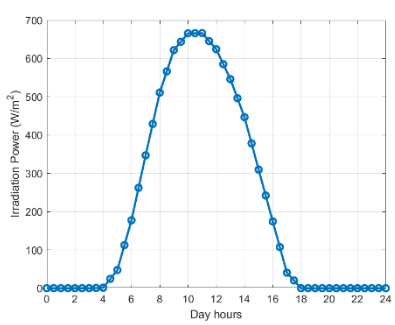

January (Peak: 200-250)



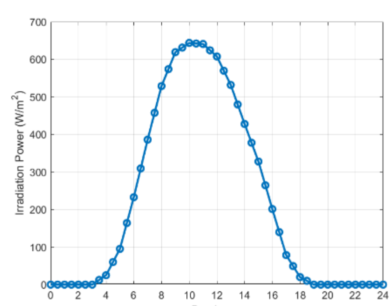

February (Peak: 350-400)



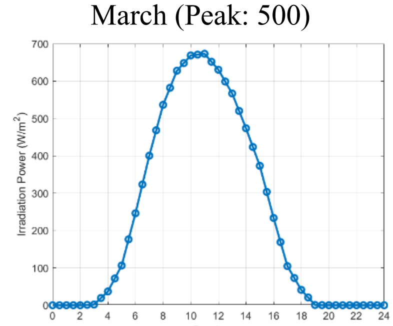

March (Peak: 500)



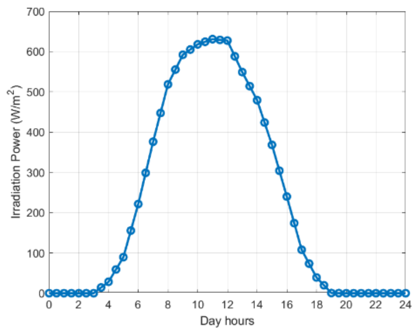

April (Peak: 650-700)



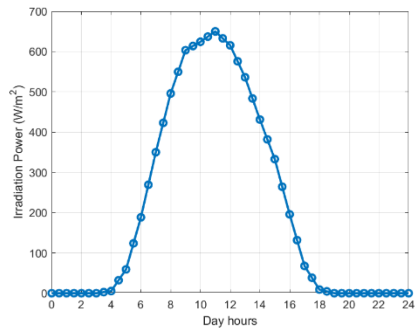

May (Peak: 650-700)



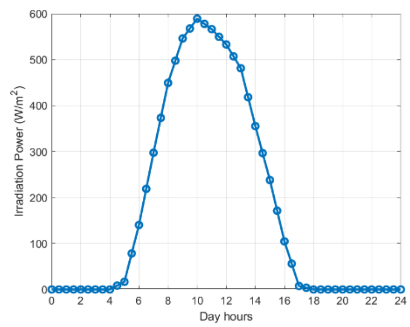

June (Peak: 650-700)



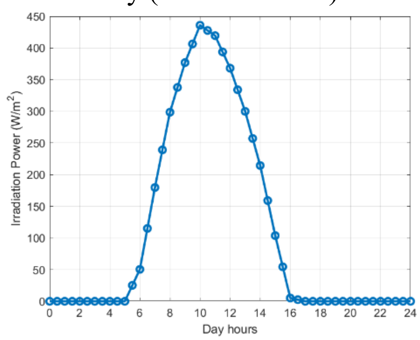
July (Peak: 600-650)



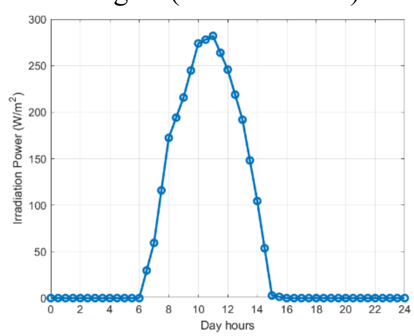
August (Peak: 600-650)



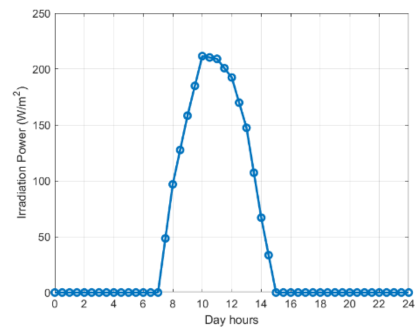
September (Peak: 600)



October (Peak: 400-450)



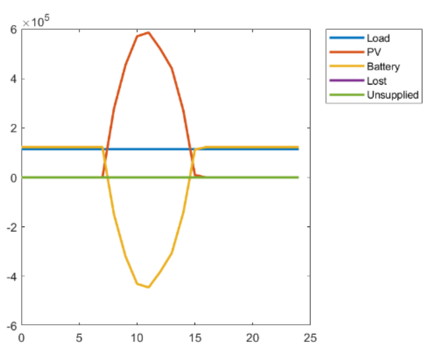
November (Peak: 250-300)



December (Peak: 200-250)

***Figure 3: Solar Irradiance profile of each month represented on time scale of one day (24 hours).***

- **Results and Discussion:**



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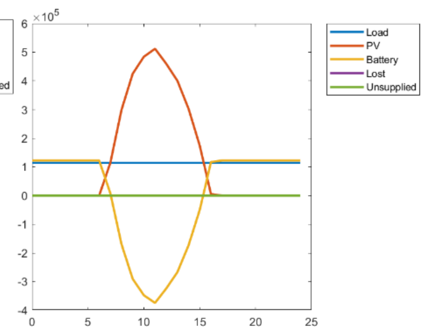
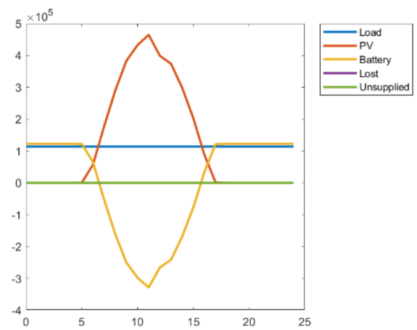
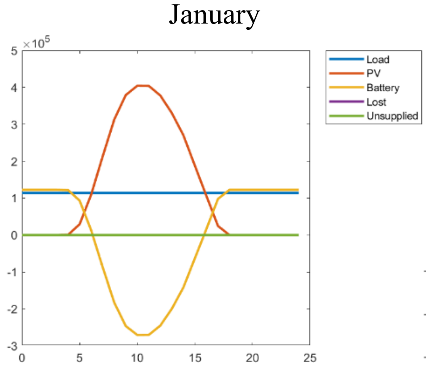


February



March



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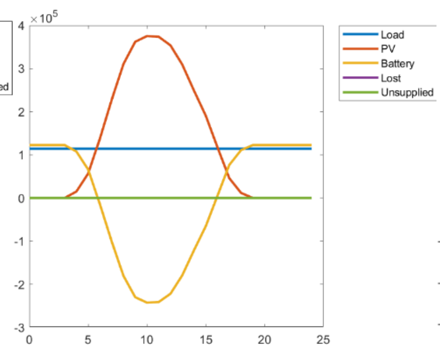
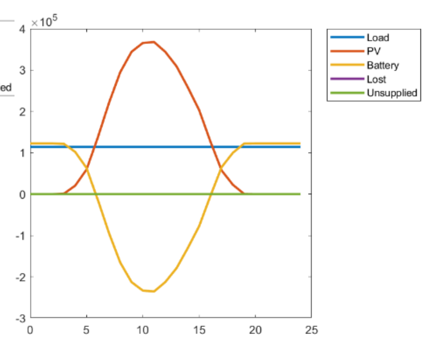


May



June

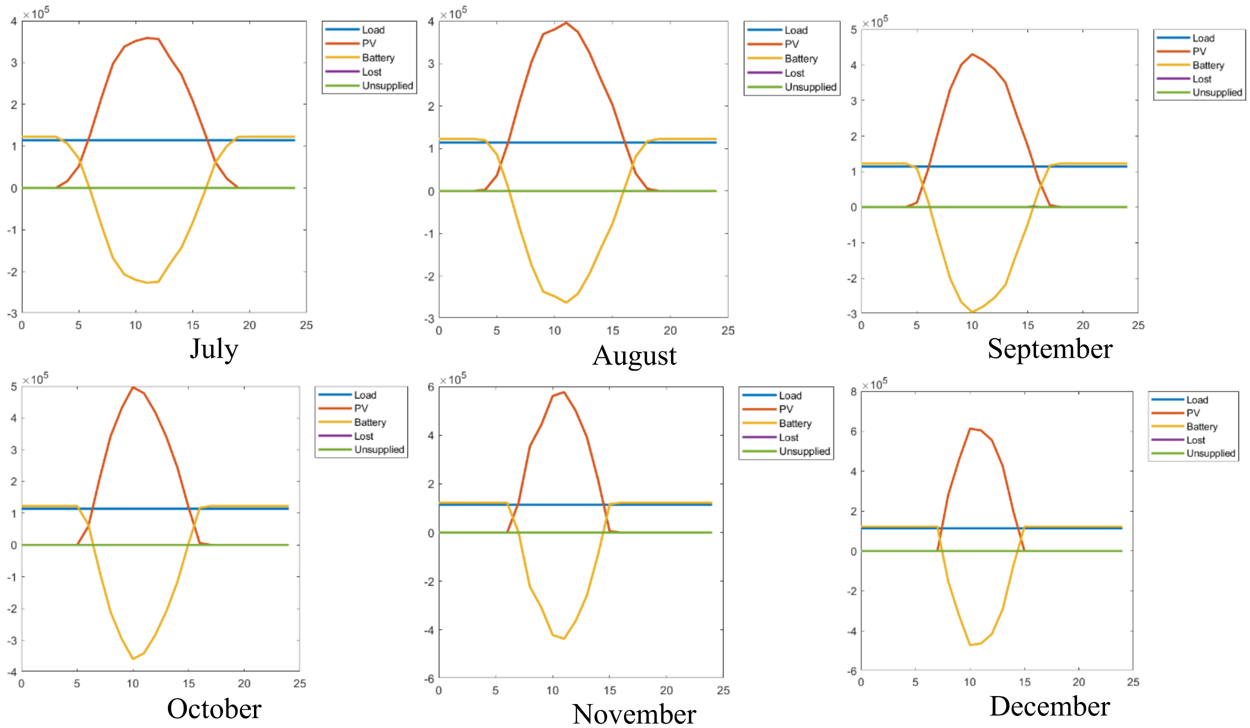



***Figure 4: Power profile of the system.***

In Fig. 4 results for each month have been shown. As seen, the load demand of each month is fulfilled using the combination of PV panels and batteries, that is, there is no unsupplied power. In addition, there is also no lost power in the system when the optimization was performed for each month separately.

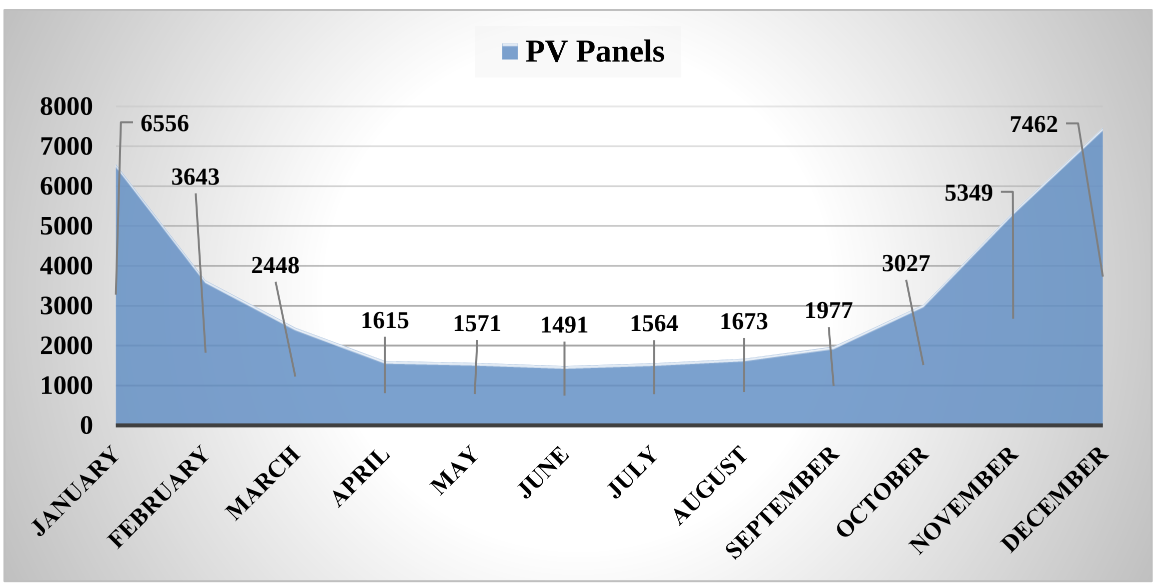



***Figure 5: Optimized value of PV panels for each month. Figure 1: Solar PV and Batteries Figure 1: PV panels and Battery based Microgrid.***

As seen in the figure, from January to December, first the required number of panels decreases, it reaches its minimum for the month of June, and then again starts increasing. The reasoning can be explained using solar irradiance profile of each month. For the same capacity panel, power generation is higher when the solar irradiance is higher. Therefore, keeping the load demand constant, the requirement of solar panel is higher for the months with low solar irradiation, and it is lower for the month with high solar irradiation. Since solar irradiation is the highest for the month of June, therefore, the number of panels required are the lowest.

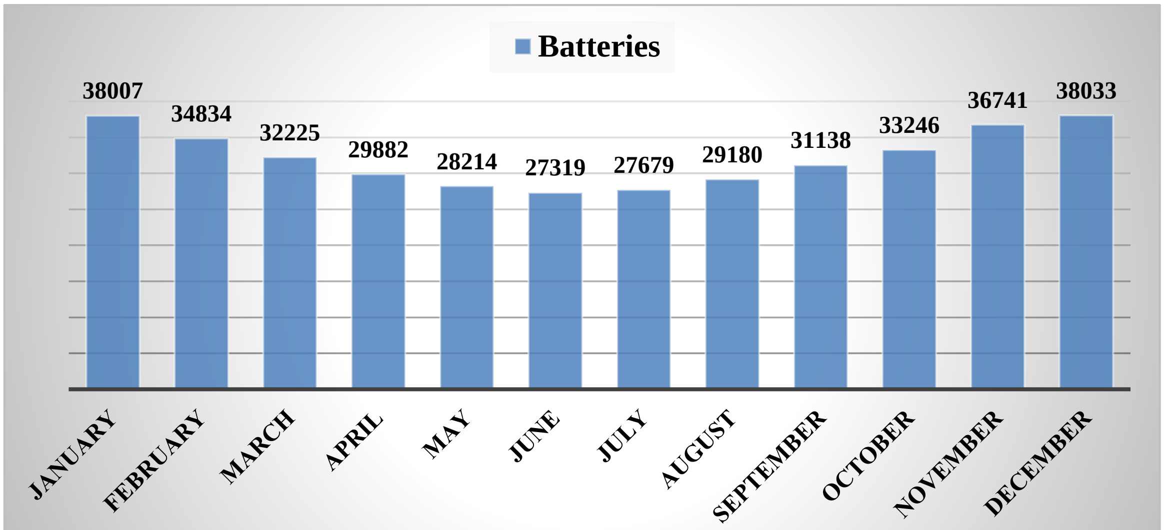



***Figure 6: Optimized value of Batteries for each month.***

As shown in Fig. 6., from January to December, the number of batteries required for backup first decreases, it reaches the minimum in June and then it starts increasing. Again, the reason can be explained using solar irradiance profile of each month. The longer the duration of sun hours, the lower the number of batteries required for backup. As seen in Fig. 3., the days are longer for the month of June, therefore, the number of batteries required for June is also the lowest.

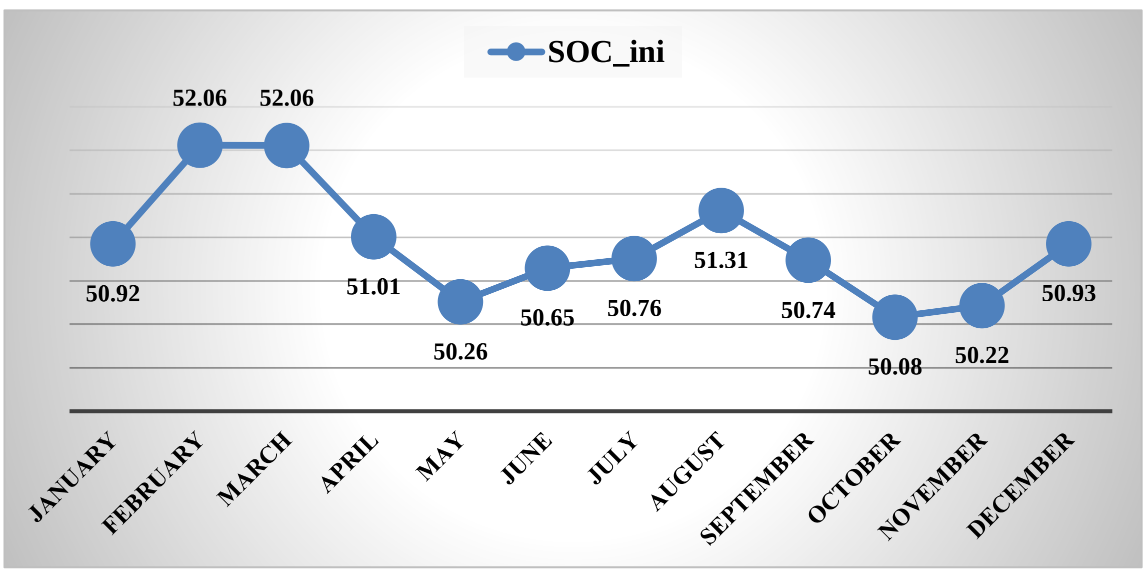



***Figure 7: Optimized value of initial SOC for each month.***

Fig. 7 shows how initial SOC value changes for each month. The value of initial SOC is nearly the same for each month, with maximum variation of only 2%.

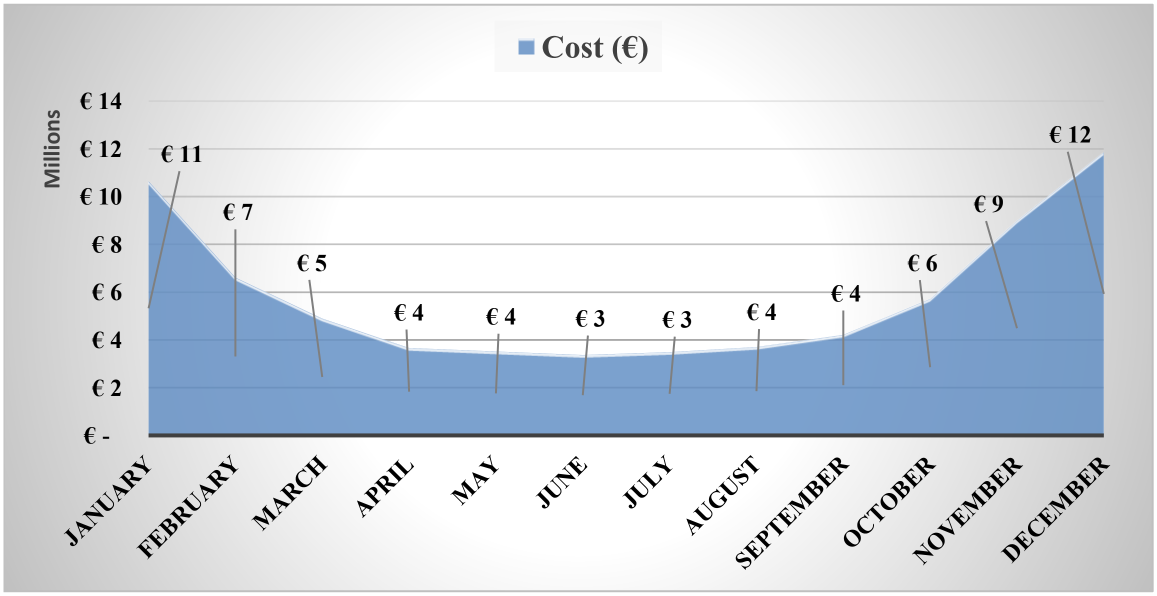



*Figure 8: Optimized value of Cost for each month.*

Since the cost of the system is directly dependent on the number of PV panels and the batteries required. Therefore, it can be seen in Fig. 8 that the cost of the system changes accordingly. It is a minimum for the month of June while it is maximum for the month of December.

### CASE 2: Optimized parameters ($N_{pv}, N_{cell}, SOC_{ini}$ & $Cost$) for whole year.

- **Load profile**: In this case, the same standard load profile has been chosen. However, here all month's load profile has been combined with each other and profile is represented on the time scale of 12 days (288 hours).

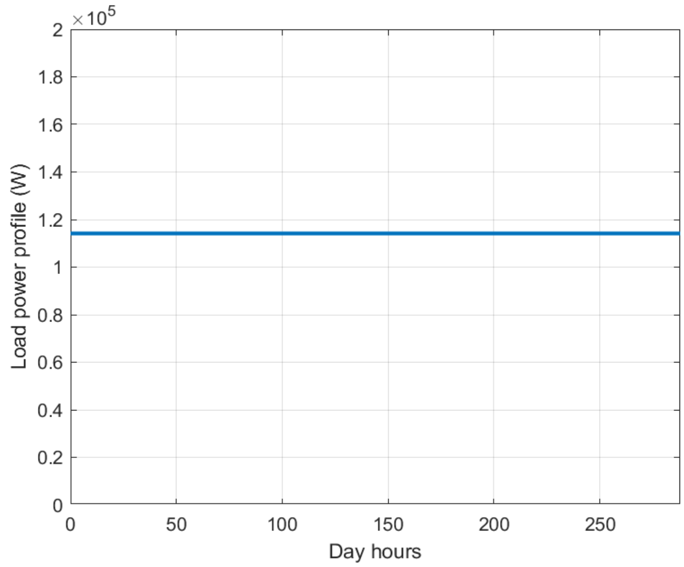



***Figure 9: Load demand of one year represented on the time scale of 12 days (288 hours).***

- **Solar irradiance profile**: Like load profile, the solar irradiance profile of all the months is merged into a single profile that is represented on the scale of 12 days (288 hours).

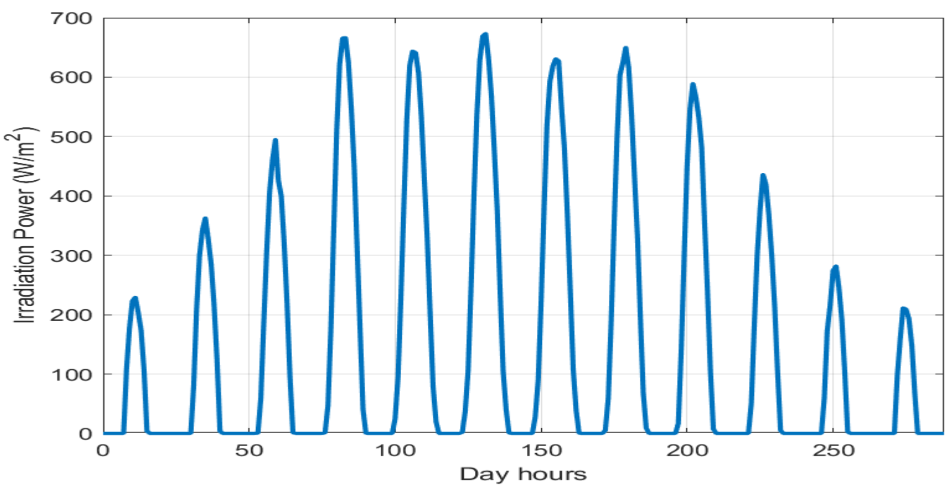



***Figure 10: Solar irradiance profile of one year represented on the time scale of 12 days (288 hours).***

- **Results & Discussion:**

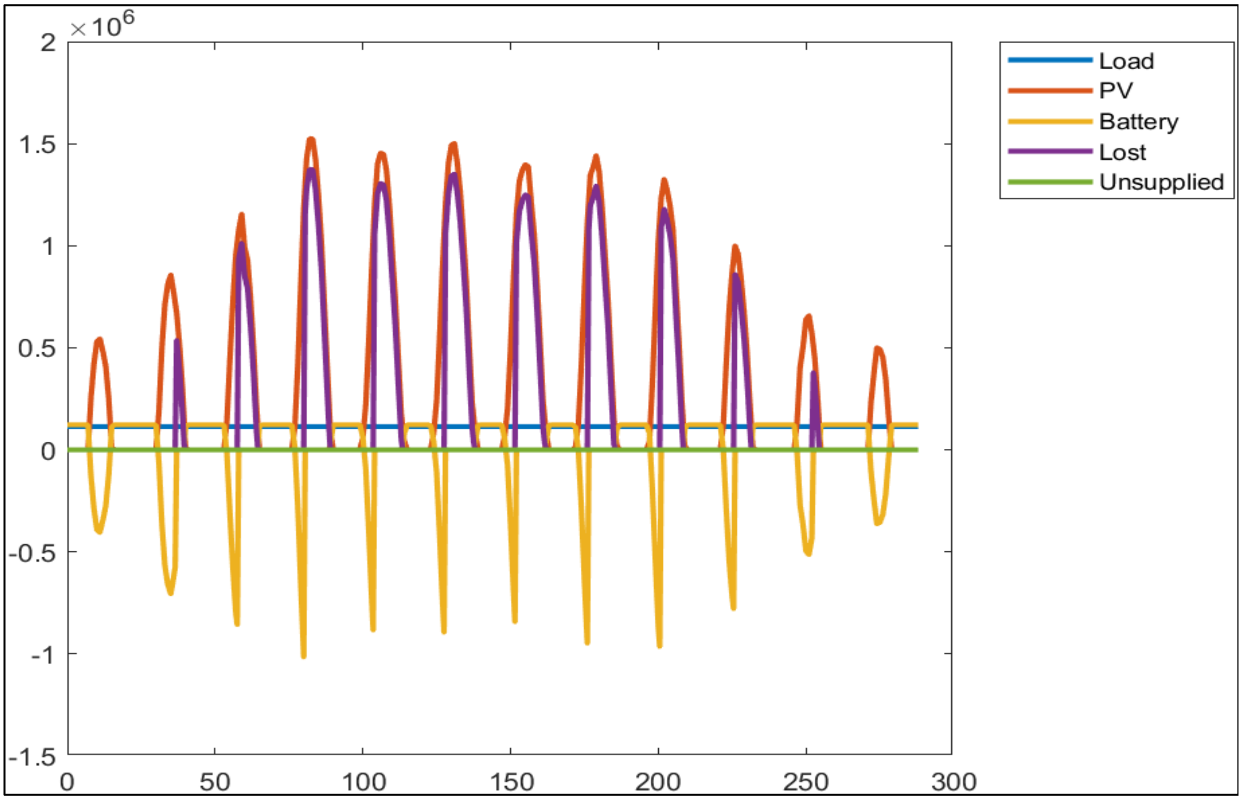



***Figure 11: Power profile of the system.***

In Fig. 11 a combined power profile of all the months has been presented. As seen, all the load power demand has been fulfilled using the PV panels and batteries system, that is, there is no unsupplied power in the system. However, there is a huge amount of lost power associated with the system because the optimization is being performed in accordance with the worst-case scenarios such as January and December. Consequently, this results in excess power production during the month with good solar conditions such as June.

| **Optimum value of parameters** | | | |
|---|---|---|---|
| $N_{pv}$ | $N_{cell}$ | $SOC_{ini}$ | $Cost$ (€) |
| **6087** | 49,852 | 48.67 | 10 million |

The value of parameters shows the optimal number of PV panels, number of batteries required, initial SOC, and the cost required to install the system. One important point can be noted, in case of overall optimization, the value optimal number of panels is less than that of January and December in case of monthly optimization; number of batteries are higher than required for monthly optimization and the cost requirement is almost less than that of January and December.

## 3.CONCLUSION of CASE 1 and 2

In this report, the standard load profile of belt load customers in Berlin was taken into consideration. To achieve the optimization, two cases were considered:

In Case 1, both the load profile and solar irradiance profile of each month were represented on the time scale of 1 day (24 hours). The optimal parameters were determined for each month separately and we saw that the month with higher solar irradiance and longer sun hours requires lesser number of panels and batteries which consequently results in lesser amount of cost needed to fulfill the load power demand. In addition, when the optimization of each month performed separately, no lost power was associated with system because the optimal parameters values were entirely based on that month.

In Case 2, the solar irradiance profile of all the month were merged to represent the one-year solar irradiance profile on the time scale of 12 days (288 hours). Similarly, load profile was also represented on the same time scale to find the overall value of optimal parameters. We saw that the optimal number of PV panels required are lower than the monthly case of January and December; number of batteries required are higher than all the monthly cases and the cost is lower than the monthly case of January and December. However, in addition, the is also lost power associated with the system in case of overall optimization because the optimal point highly depends on the worst-case scenarios of the year.

In conclusion, whether a person should opt for monthly optimal point or overall depends on the load power requirement of the person. If one wants to supply the load power with solar and battery system, he can go for overall optimal parameters. However, if one wants to supply the load power with solar and batteries system during only a specific month, he may opt for monthly optimal parameters except for January and December in which cases the overall optimal parameters are relatively better. Regarding lost power in case of overall optimization, one can sell this power to grid. One can also use this excess power to install electrolyzer-fuel cell system to store long term energy in the form of hydrogen which can reduce the number of batteries required.

## 4. SOLUTION TO LOST POWER IN CASE 2

To utilize the lost power in case 2, we have further optimized the system by integrating electrolyzer-fuel cell Power to Power (P2P) technology in our system. Following picture shows the schematic of the proposed system:

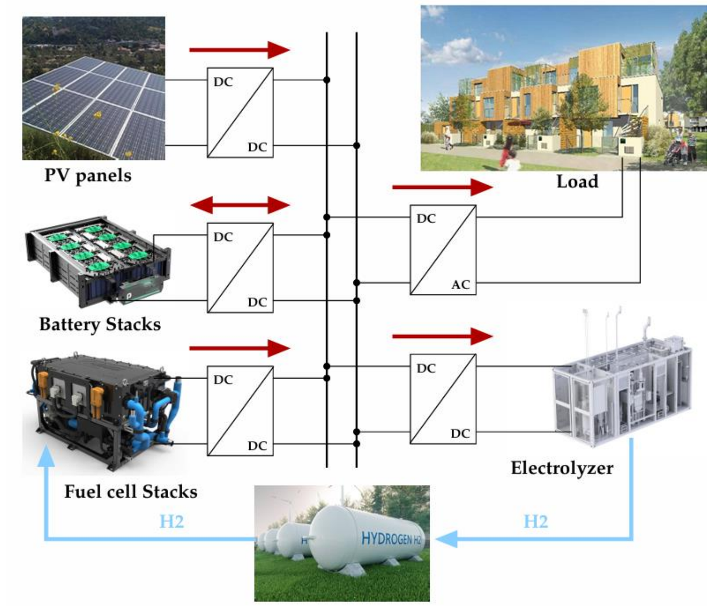



*Figure 12: PV panels, Batteries, Electrolyzer, H2 Storage and Fuel Cell based Microgrid.*

- **Mathematical Modelling:**

In this part we are going to model our variables, objective function and constraints as follows:

**Variables**:

Following are the variables used in this case for the optimization function:

1. Npv: Number of PV panels
2. Ncell : Number of battery cell
3. SOC_ini: Initial state of charge of the battery
4. Nel: Number of electrolyzers
5. Nfc: Number of fuel cells
6. SOC_H2_ini: Initial state of charge of hydrogen storage tank

**Objective:**

In this project, we are working on a mono-objective function. Our objective is to optimize the cost of our stand-alone project by finding the appropriate number of PV panels & battery cells. The objective function is as follows:

Obj = @ (X) X(1)*Cinv_panel + X(2)*Cinv_cell + X(3)*Cinv_el + X(4)*Cinv_fc

Whereas,

X (1) = The optimized number of PV panels
X (2) = The optimized number of battery cells
X (3) = The optimized number of electrolyzer
X (4) = The optimized number of fuel cells

**Constraints:**

The following constraints are kept under consideration while optimizing the cost:

1. Final SOC > Initial SOC: Final State of charge at the end of day should be greater than the initial state of charge for both battery and hydrogen storage tank.
2. SOC_min < SOC < SOC_max: For both batteries and hydrogen storage tank, the state of charge at any instant should be greater than the pre-defined minimum & maximum SOC.
3. P_unsup = 0: The load should be supplied all time

**Results & Discussions:**

| Optimum Value of parameters | | | | | | |
|---|---|---|---|---|---|---|
| $N_{PV}$ | $N_{cell}$ | SOC_ini | SOC_H2_ini | $N_{el}$ | $N_{fc}$ | $Cost$ (€) |
| **2859** | 29648 | 40 | 83.31 | 50 | 50 | 5.6 million |

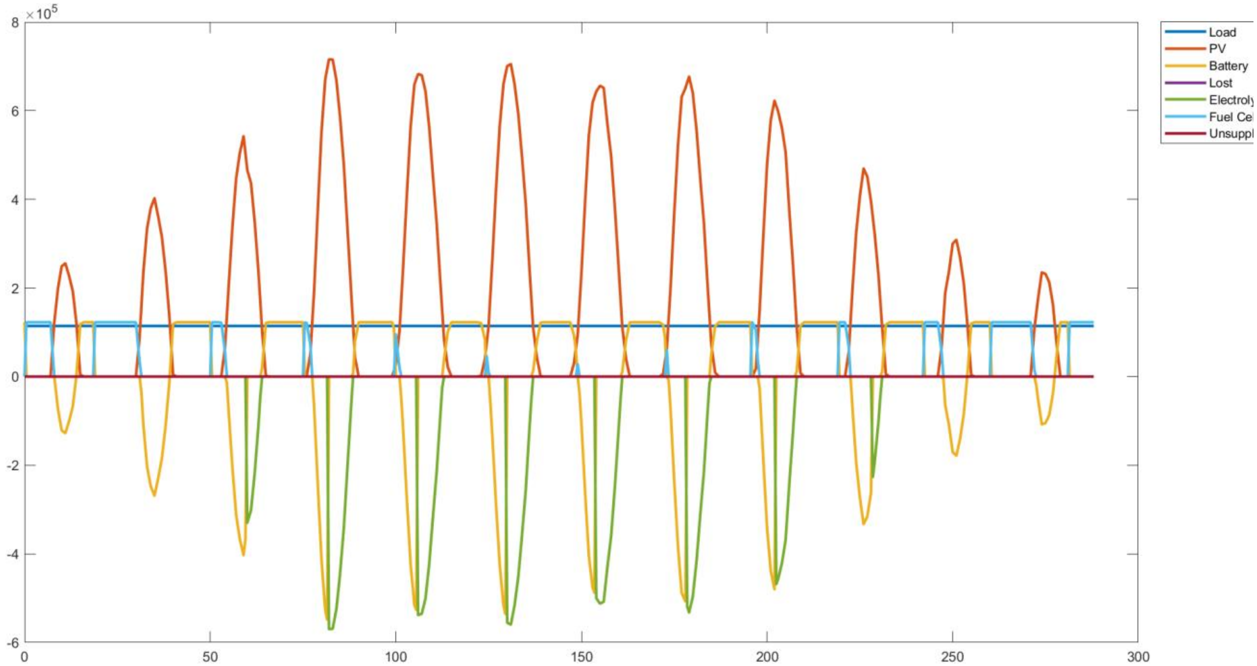



***Figure 33: Power profile of the system.***

As shown in Fig. 13, by incorporating the electrolyzer-fuel cell model, we see that there is no lost power associated with the system because it has been stored in the form of hydrogen which can be reconverted into electrical energy when needed. Besides, integrating the electrolyzer-fuel cell has also impacted the number of PV panels and batteries required by the system. Therefore, the overall cost of the system has also been reduced to 5.6 million euros.

# 5.REFRENCES

[1] H. H. M. K. S. H. P. R. K. Achim Kampker, "Fuel cell system production cost modeling and analysis," in *2022 9th International Conference on Power and Energy Systems Engineering (CPESE 2022)*, Kyoto, 2022.

[2] International Renewable Energy Agency, "Making the breakthrough: Green hydrogen policies and technology costs," International Renewable Energy Agency, Abu Dhabi, 2021.