Electric vehicle and photovoltaic advanced roles in enhancing the financial performance of a manufacturing and commercial setup

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ABSTRACT

Climate change's impact on the planet forced the United Nations and governments to promote green energies and electric transportation. The deployments of photovoltaic (PV) and electric vehicle (EV) systems gained stronger momentum due to their numerous advantages over fossil fuel types. The advantages go beyond sustainability to reach financial support and stability. The work in this paper introduces the hybrid system between PV and EV to support industrial and commercial plants. This paper covers the theoretical framework of the proposed hybrid system including the required equation to complete the cost analysis when PV and EV are present. In addition, the proposed design diagram which sets the priorities and requirements of the system is presented. The proposed approach allows setup to advance their power stability, especially during power outages. The presented information supports researchers and plant owners to complete the necessary analysis while promoting the deployment of clean energy. The result of a case study that represents a dairy milk farmer supports the theoretical works and highlights its advanced benefits to existing plants. The short return on investment of the proposed approach supports the paper's novelty approach for the sustainable electrical system. In addition, the proposed system allows for an isolated power setup without the need for a transmission line which enhances the safety of the electrical network.

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1. INTRODUCTION

Transportation is a necessary activity in modern cities. Indeed, access to any services or activities, such as work, social gatherings, shopping, and education, is made possible by transportation. People's capacity to engage in social and economic activities is impacted by the caliber of the transportation options that are accessible. For manufacturers, advancing the efficiency of the plant from a transportation point of view will enhance its financial stand for manufacturing. However, the transportation sector is considered one of the main contributors to carbon dioxide emissions which has negative impacts on global warming. To overcome the environmental issue, companies and governments are shifting toward electric transportation that is supported by renewable energy resources. Recently, the industry for electric vehicles (EVs) has grown as a result of the convergence of low-cost EVs, charging infrastructure, and a desire to lessen air pollution. Numerous researches address the positive impact of deploying electric vehicles and the banned of combustion engines [1].

Governments including the United Arab Emirates (UAE) started the move toward EVs, especially in areas that contain renewable energy sources [2]. Robust charging infrastructure that not only satisfies the present demand for charging but also encourages adoption growth is necessary for sustainable growth in EV adoption. Many contend that the major obstacle to EV adoption is still the absence of widespread charging infrastructure and the potential range anxiety it may induce [3].

The deployment of electric transportation requires high electrical power and charging infrastructure. These structures required adequate management to ensure the optimum operation is maintained. The increase in electrical power system infrastructure or capacity to support the additional load for the electrical vehicle will increase the safety risks of step, touch, and transfer voltages [4], [5]. The presence of the PV system will eliminate the need for additional electrical infrastructure which reduces the risks of electrical shock or transfer. The management systems include numerous types of power distributions that include vehicle to grid, vehicle to vehicle, and vehicle to home [6]. The high energy penetration of the EV into the local grid network puts a burden on the current distribution network, especially during peak hours [7], [8]. To minimize this impact, numerous researchers use renewable energy systems to support the charging stations and reduce the stress on the grid [6]–[9]. A photovoltaic (PV) system with battery storage demonstrated excellent performance improvement for the charging stations [10], [11]. The energy storage captures the surplus energy produced from the PVs during the maximum power output and will discharge it when the PV system cannot meet the load demand. The grid connection stage will ensure a continuous supply when there is an energy shortage from the PV and the battery storage [12], [13]. For a manufacturing plant, it is recommended the deployment of renewable energy, especially PV systems. The deployment of PV systems encourages the move from fossil fuel transportation systems to electrified ones. Recently, PV and EV deployment has gained stronger momentum worldwide [14], [15]. In many countries, the cost of electrical consumption puts burdens on the commercial setup of a wide range of industries.

PV systems have a proven capability to support a larger load for a manufacturing plant [16], [17]. The PV on its own can support the plant's required load only during the day of sunny days [18], [19]. To ensure the required output power is generated during the early hours of the morning, additional numbers of PV panels will be installed [20]. The increase in the number of panels leads to surplus power that is not needed for the manufacturing plant load. Figure 1 shows the surplus power generated from the PV system. The PV output depends on the PV panels' orientation, Figure 1 represents the output of panels facing south at a nominal tilt. Figure 2 represents the output power of a PV system for different orientations, Figure 2(a) represents the shape of the output of PV panels facing east at a nominal tilt, while Figure 2(b) represents the shape of a PV panel's output facing west at a nominal tilt [21]. When combining PV panel output with a tilt orientation between east, south, and west with nominal tilts, the system will have high peak load during morning, midday and afternoon [22]. For maximum power output throughout the year, south orientation is the optimum one [22], [23].

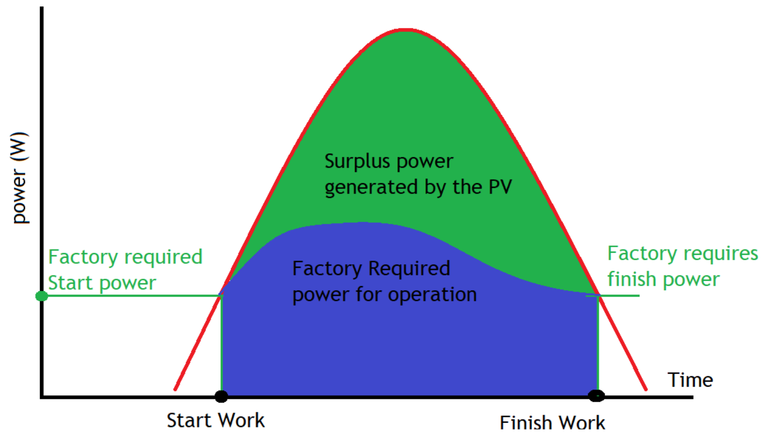

Figure 1. PV system generation versus factory-required load

In the recent years, many researchers have studied the integration of PV systems and EVs, mostly due to two factors: lower energy costs and lower emissions. Most of these studies concentrate on the unique effects of PV and EV grid integration. However, it is essential to remember that as PVs and EVs become more commonplace, the power grid will be affected by the combined effects of PV–EV integration. Tavakoli *et al.* [24] provided a detailed analysis of the effects of PV and EV grid integration on grid stability, power quality, and energy economics. Given the intermittent nature of PV energy sources and the unpredictable load characteristics of EVs, it is clear that a high penetration of PV systems and EVs individually can have a detrimental effect on grid stability and power quality. Nevertheless, coordinated or combined PV and EV operating techniques, might reduce these detrimental effects on grid stability and electricity quality. Large-scale EV load aggregators and photovoltaic systems will consider significant actors in the future energy market due to their high penetration and ability to potentially influence the pricing and outcome of the wholesale energy market in the future smart grid.

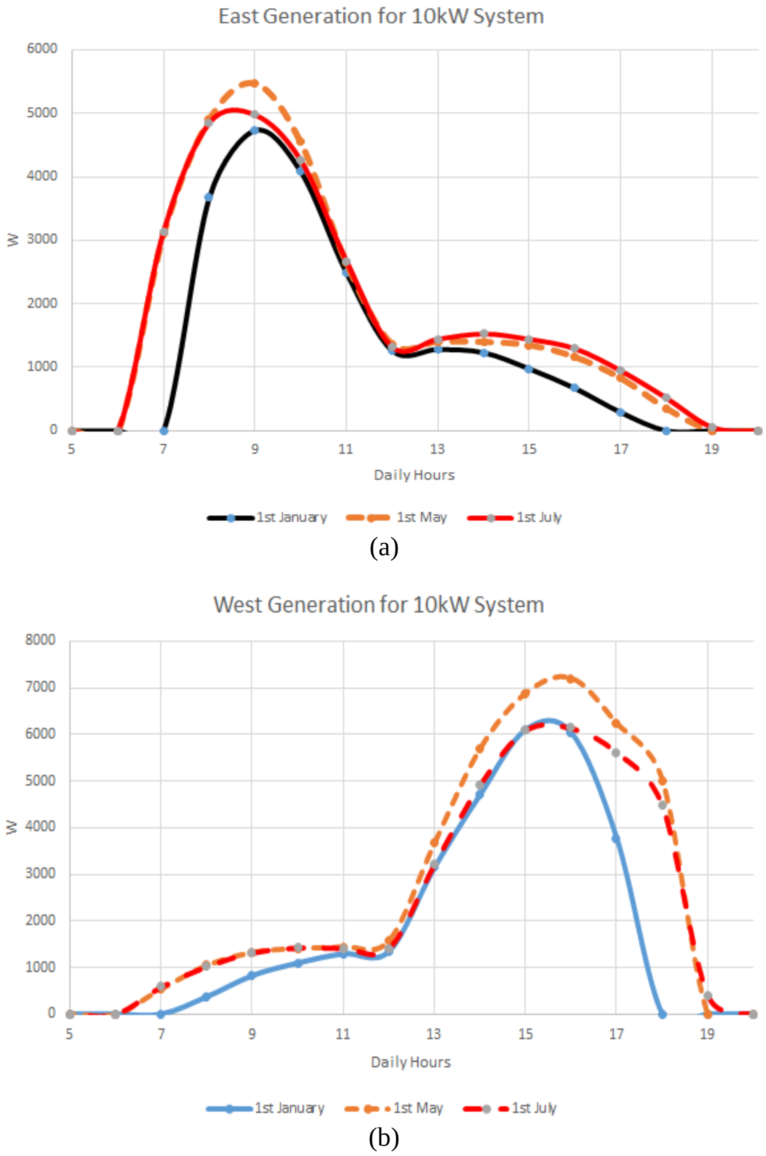

Figure 2. PV output under different orientation (a) shape of the output panels facing east, and (b) shape of the panel outputs for panels facing west

The economic feasibility of integrating renewable energy charging and electric vehicle (EV) use on a university campus was simulated in [25]. The best option for each electrical source's power loading, energy dispatch, and financial viability was found using Homer energy simulation software. Three scenarios were considered. The baseline that provided the electric parameters for a grid without the integration of renewable energy was considered in the first scenario. In the second scenario, the solar and wind systems were considered with the grid to charge the EVs. The third scenario was similar to the second but with EVs operating under the vehicle-to-grid (V2G) scheme to supply energy to the grid. The result of these scenarios showed that higher costs were required in the second scenario due to the system operation associated with extra local load to power the EVs. In addition, in the second and third scenarios, the EVs assisted the renewable energy sources' penetration into the system. Nevertheless, the operation of EVs on a V2G mechanism contributed to the highest rate of renewable energy penetration. Boström *et al.* [26] gave a conceptual analysis of a pure PV-EV-based energy system. They considered Spain as a case study. They conclude that, with EVs serving as the only energy storage resource, a whole nation like Spain can run its entire energy system entirely on photovoltaic energy.

The advancement in technologies along with PV and EV can play a critical role in reducing the burden of manufacturing financial systems especially when it comes to electrical consumption and transportation. The work in this paper highlights the novel approach of PV and EV in reducing the financial burden of a manufacturing setup. The main objectives can be summarized by: i) Highlights the financial benefits of joining forces between PV systems and electrified transportation; ii) Cover different scenarios with the presence and absence of EV, PV, and grid systems; iii) Extends to the possibility of the micro-grid system between different plants located near or within the same industrial area; and iv) Consider a dairy farmer's milk factory as a case study.

This paper is organized into five sections. First, the proposed method is described in section 2. Section 3 includes the case study scenarios. The discussion of the case study scenarios is illustrated in section 4. This paper ends with a conclusion in section 5.

2. PROPOSED METHOD

Recently, many manufacturers and companies have been shifting to renewable energy sources such as PV systems. These systems may produce power higher than the requested load. The PV surplus power as a function of time can be presented by (1).

$$P_S = P_{PV} - P_{Load} \tag{1}$$

where P_s is the surplus power in kWh, P_{PV} is the instantaneous power generated by the PV system in kWh, and P_{Load} is the factory-instantaneous power consumption in kWh. In the proposed hybrid system, an exchange of electricity power process between PV systems, grids, and EVs will be established. This process is illustrated in Figure 3. The communication line assesses the following PV-generated power (P_{PV}), the plant-required load power (P_{Load}), the available electric vehicles' on-site state of charge (SOCEV), and the grid connection voltage (VG), before it instructs the generated power distribution process. When the power provided by the PV system is higher than the required load (P_s is positive), the system allows the surplus power to be used to charge the EV batteries. In addition, when the PV system fails to provide the required load (P_s is negative), it is possible to import energy from the EVs if required by the operators. The decision-making circuit is located at the plant with the following pre-set scenarios.

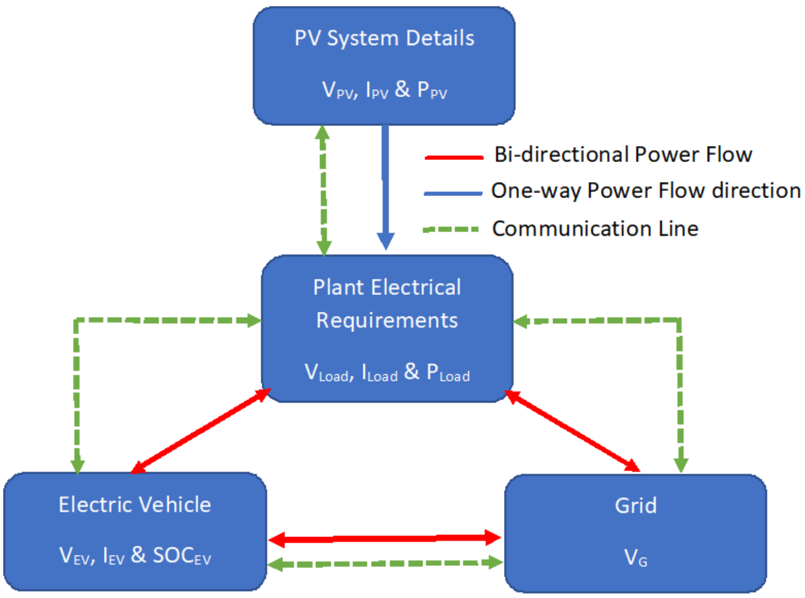

Figure 3. Design diagram of the proposed approach

- Scenario 1: The scenario covered in this part represents the case where the grid and EVs are available. Thus, the system compares the generated power to the required load of the plant. If the load is higher than the generated power, the system assesses the state of charge (SOC) of the EV and checks its deployment time. If the SOC is higher than the minimum limit (the minimum limit will be set by the operator), the system will assess if the EVs can support the load. If yes, the plant-required power will be sourced from the EV. If not, the grid will support the load. If the load is lower than the generated power, the system will check the SOC of the EVs if any EV requires charging, the control circuit allows for the surplus power to be sent to the EV batteries. If the EV SOC is at 100%, the surplus power will be injected into the grid.
- Scenario 2: This scenario covered in this part represents the case where the grid is not available but EVs are available. Thus, the system compares the generated power to the required load of the plant. If the load is higher than the generated power, the system will check the SOC of the EV. If the available power in the EVs is capable of supporting the load, the system will extract the EV's power. If the available power in the EVs is not capable of supporting the load, the system will reduce the plant load to a value that the available PV and EV's powers are sufficient to support the operation. The determination of this process is based on a critical load set by the plant operator. If the load is lower than the generated power, the system will check the SOC of the EVs, if any EV requires charging, the control circuit allows for the surplus power to be sent to the EV batteries. If the EV SOC is at 100%, the system will reduce the PV generation by communicating to the MPPT of the PV system.
- Scenario 3: This scenario represents the case where the grid and EVs are both not available. Thus, the system completes the following assessments. If the load is higher than the generated power, the system will reduce the plant power to an acceptable limit. If the load is lower than the generated power, the system will allow the plant to operate under normal conditions.

After presenting the proposed model diagram and the considered scenario, the mathematical model can be described using (2).

$$P_G = P_{PV} - P_{Load} \mp P_{EV} \quad (2)$$

where P_G is the grid's instantaneous power in kWh and P_{EV} is the EV required instantaneous power in kWh. The $\mp P_{EV}$ represents the power of the EV under both conditions, charging and discharging. When the EV is charging, the power will be considered negative and when the EV is discharging, the power will be considered positive. Equation (3) describes the cost model captures multiple scenarios that include transportation:

$$C_T = C_{Load} + C_{EV} \quad (3)$$

where C_T is the total cost saved per day, C_{Load} is the total cost saved for the load, and C_{EV} is the total cost saved on transportation of petrol. The cost-saving C_{Load} can be calculated using (4):

$$C_{Load} = (P_{Load-PV} + P_{Load-EV}) \times P_{\$} \quad (4)$$

where $P_{Load-PV}$ is the load in kWh supported by the PV-generated power, $P_{Load-EV}$ is the load in kWh supported by the EV power, and $P_{\$}$ is the cost in dollars per kWh. The cost saved on transportation is calculated using (4). The equation is generated using an average of 8 liters per petrol per 100 km fossil fuel car [24]. It is worth noting that 8 liters per 100 km are considered for an average economical car that is manufactured between 2006 and 2017 [24].

$$C_{EV} = \left(\frac{N_{km}}{100} \times 8\right) \times l_{\$} \quad (5)$$

where N_{km} is the number of km that the charged EV can travel and $l_{\$}$ is the cost per fossil fuel liter. Example: Consider a small hybrid system that contains a PV system with a maximum power of 45 kWh (P_{PV}). Figure 4 shows an illustration output of (2) for a given load and with grid power availability (P_G). It is based on a peak load of 25 kW. As shown in his figure, the PV offered 370 kWh for the day. This provided power can cover the load (220 kWh) and the EV (150 P_s). Thus, the PV-provided power is capable of powering three cars that have a total traveling distance of more than 1,000 km.

Figure 5 shows the simulated power flow without the grid presence. The simulation is based on minimizing the load consumption outside the sunlight period to the emergency components which in this case is presented by a 2 kWh load. As illustrated in Figure 5, the EV supported the factory critical load by injecting 24 kWh, and then the EV charged using 150 kWh from the PV system. Using (3), (4), and (5), the cost saving based on data in Figure 5 can be calculate. If the cost of one kWh is \$0.22, cost of one liter of car fuels is \$2.039, and the EV consume 15 kWh 100 km [27]–[31], the saving cost will be 211\$ per day.

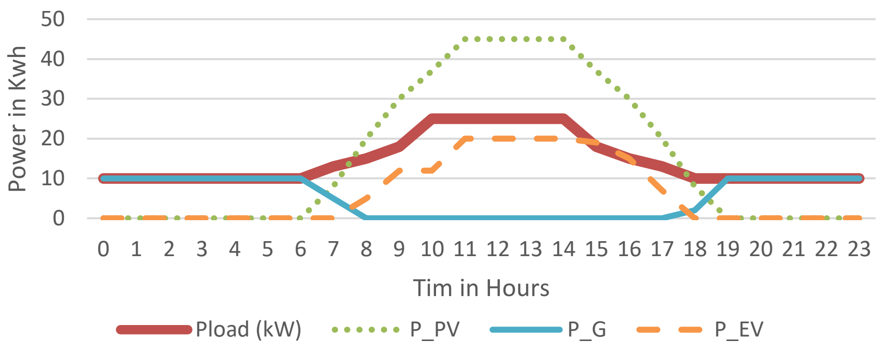

Figure 4. Power flow between the load, EV, and grid

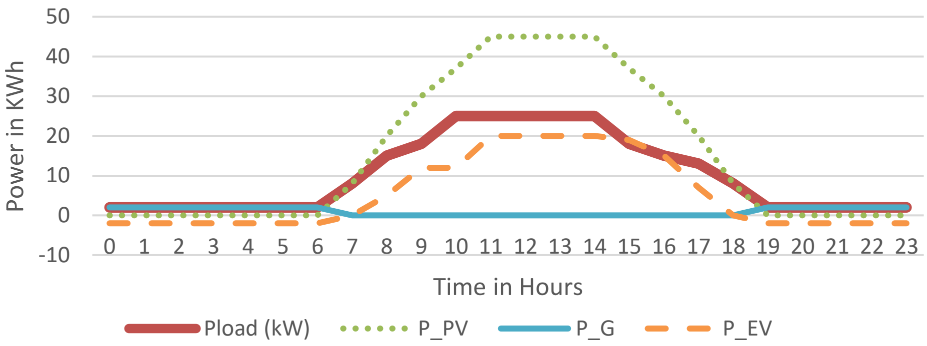

Figure 5. Power flow between the load, EV without the grid

3. RESULT AND DISCUSSION

The case study addresses the requirements of a commercial post office center and a dairy farmer milk factory. Figure 6 represents the normal daily load of each setup with the grid presence. The post office has 4 vehicles that travel every day 800 km while the dairy milk factory has 6 vehicles that travel every day 700 km. The grid electricity cost is \$0.27/kWh and the cost per car fuel is \$2.039/liter. Table 1 shows the paper's initial cost assessment of electrical consumptions and the petrol used for the car. Following the approach in this paper, both plants decided to replace their vehicles with electric ones and to install a PV system to support their electrical loading.

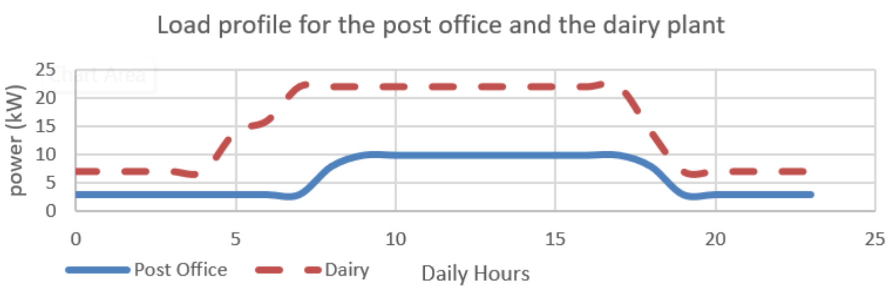

Figure 6. Load profile with the presence of the grid

Table 1. Daily and yearly petrol and electricity cost

	Daily car petrol cost	Grid electricity cost	Total daily cost	Total yearly cost
Post office	\$130.50	\$39.15	\$169.65	\$61,920.79
Dairy milk	\$114.18	\$96.12	\$210.30	\$76,760.96

The car replacement takes place at the end of the fleet life; therefore, no additional cost is considered for the vehicle replacements. Regarding the solar system cost installation, the case study uses $1.91/W as supported by the U.S. solar photovoltaic system and energy storage cost benchmark [32]. Table 2 shows the PV installation cost, the daily grid electricity cost, and the car petrol cost with the presence of PV and the absence of the EV. Table 3 reflects the analysis in this paper with the presence of PV and EV. It is clearly shown that advance in return on investment and a high reduction in operation cost especially after 3 years.

The types of plants, post offices, and dairy factories, under consideration for the case study are relevant to all countries and cities. Their adequate operation is critical for human everyday activities. The proposal under this paper highlights that converting combustion engine vehicles into electric ones saves on the operation cost, and also it allows for advanced operation with the presence of the PV solar system. The presence of the EV allows for maximum harvesting of PV energy which decreases the return-on-investment period. Also, as shown in this paper, in the presence of a power outage, the PV system along with the EV can support the operation of the plant which also advances their quality and people's trust in their services. The theoretical information presented in this paper made it easy for researchers and plant owners to assess their return on investment by simply deploying the mentioned equations. The case study supported the theoretical approach and highlighted its advantages. It is also worth noting that the kWh price that is used for the case study will increase dramatically if an electrical grid is not present and a diesel generator is required to support the load. This case exists in numerous countries within the Middle East and Africa region.

Table 2. Yearly cost for energy and return on investment

	Yearly electricity demand kWh	PV system (kW)	PV system cost	PV yearly generation (kWh)	Yearly petrol cost	Yearly electricity cost	Saving	ROI (Years)
Post Office	52,925	100	$191,000	147,094	$47,631	-$25,426	$36,495	5.23
Dairy Milk	129,940	150	$286,500	220,632	$41,677	-$24,487	$52,274	5.48

Table 3. Yearly cost in the presence of PV and EV

	Yearly electricity demand kWh	PV system (kW)	PV system Cost	PV yearly generation (kWh)	EV yearly energy (kWh)	Yearly electricity Cost	Saving	ROI (Years)
Post Office	52,925	100	$191,000	147,094	31680	-$16,872	$78,793	2.42
Dairy Milk	129,940	150	$286,500	220,632	27720	-$17,002	$93,763	3.06

4. CONCLUSION

This study highlighted the importance of PV systems when it comes to clean energy. Also, the deployments of PV and EVs are gaining stronger momentum worldwide. The presence of the PV can support the commercial plant as well as electric transportation. The proposed equations in this paper allow plant owners to understand the financial benefit of integration between PV and EV for manufacturing and commercial operation. Reducing the cost of operations leads to a healthier financial system which allows the owner to consider future growth. The theoretical study presented by the paper along with the proposed diagram shows how it is possible to achieve a higher rate of sustainability without impacting the plant operation. The presented simulation figures illustrate the electrical power flow with and without the presence of the electrical grid. This illustration shows the possibility of having a sustainable electrical system without the grid presence. The case study followed by a discussion was illustrated. The results of the case study showed that advance in return on investment and a high reduction in operation costs after less than five years. The information presented supports researchers and plant owners with all the required assessments especially when it comes to cost analyses. The case study showed the increased benefits when following the paper approach under the presence of PV and EV. With the advancements in energy management tools and PV and EV capabilities, the proposed theoretical approach can be easily implemented on sites. Finally, relying on PV and EV to support the electrical load of the commercial setup eliminates the need for electrical infrastructure uprate or upgrade which reduces the safety risks of electrical shock. This adds additional benefits of the proposed systems.

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