Management System for Sensitive Loads by Integration of Online UPS and Grid-Tie PV Source.

Jamal Sultan[1], Sameer Khader[2], Abd Alwadood Sultan[3], Nassim Iqteit [4]

Department of Electrical Engineering
Palestine Polytechnic University (PPU)
P.O. Box 198, Hebron
PALESTINE

Abstract

This paper presents a solution to address power outages by integrating a photovoltaic (PV) solar energy source with an online uninterruptible power supply (UPS). Designed for a jewelry manufacturing factory, the system ensures uninterrupted power, preventing losses from outages, such as the solidification of molten materials. The initial hybrid setup faced issues during grid interruptions, disconnecting the solar system and relying solely on limited UPS storage.

To resolve this, a circuit was developed to redirect PV energy to recharge UPS batteries during outages, enabling the factory to operate on solar power during the day. This reduces grid dependence and electricity costs, saving 1,570 kWh and $700 monthly, or $8,400 annually which is equivalent to 35% of the original bill. The system enhances operational and economic efficiency, offering a sustainable energy solution. The proposed solution was simulated on the MATLAB/SIMULINK platform to model weather and loading behaviors, ensuring constant load voltage under varying conditions. The practical implementation was carried out, and the results were verified and measured to confirm the system's effectiveness.

Key-Words Solar energy, Hybrid system, electronic Converters, Charge controllers, UPS , & Inverters.

1. Introduction

1.1 PV system Components

Renewable energy (RE) resources are being progressively integrated into power systems to support a continuous increase in power generation due to the limitations of fossil fuel supply and to reduce negative environmental impacts [1]. Among the RE resources, the energy from the solar photovoltaic (PV) effect can be considered the most necessary and sustainable resource due to its ubiquity, large quantity, and sustainability [2]. This PV system consists of solar panels, a DC chopper, a smoothing unit, and a power management unit for operating the generator at maximum extracted power, called the Maximum Power Point Tracker (MPPT) [3], [4]. Usually, photovoltaic systems operate at a point near the point of maximum power, known as MPP, in order to obtain maximum system efficiency and extracted power.

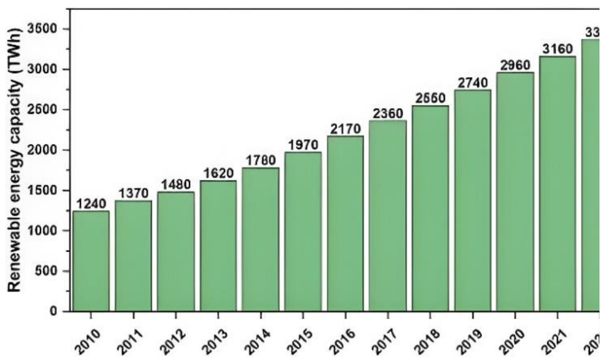


Figure 1 : Global renewable energy adaptation for the years (2010–2022) [10].

Therefore, in order to extract maximum energy with reduced chopper switching losses and minimal total system losses at high efficiency, an MPPT system is a necessary step in the energy conversion process. The proper selection of the cell's materials, a clear and stable maximum achievable solar irradiation, stable temperature within an acceptable safe limit, tilt angle, and shade can all help to maximize the PV characteristics. To determine the loss of the PV outputs, the shading impact will be modelled [5][6] Recently, there have been great investments in building PV systems in urban and residential environments. Urban environments often include obstacles that could cast shadows on a PV system, badly affecting energy production [7].

2: Corresponding author, sameer@ppu.edu,
1,3: Graduates of the Power Engineering Program,
4: Assoc. Professor at dept. of Electrical Engineering.

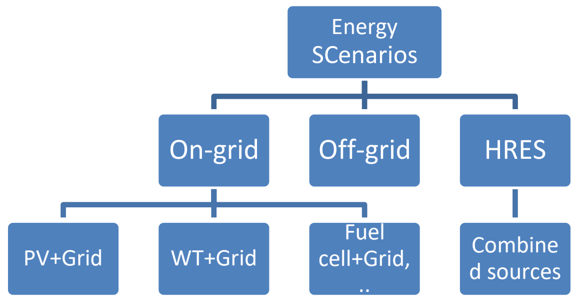


Figure 2 : Classification of energy scenarios based on their connection with the grid.

The growth in renewable energy capacity has been significant. It increased from 1,240 TWh in 2010 to 3,365 TWh in 2022. This rise highlights the global move towards cleaner energy as shown in fig.(1)[8][9]. Key drivers include technological advancements, environmental concerns, and supportive policies.

1.2: Renewable energy technologies:

The urgency of climate change demands a swift shift from fossil fuels to renewable energy sources(RES) such as Solar energy source, Wind energy source , and energy storage sources in form of Batteries but not limited to that. While solar and wind energy have advanced, their standalone systems face challenges. Solar relies on daylight and weather, while wind depends on fluctuating speeds, leading to intermittency issues, and backup sources still too much expensive to be used in addition to their short life time and cost maintenance. These challenges affect grid stability and hinder widespread adoption. Additionally, policy and economic frameworks often fall short in supporting the seamless integration of renewable resources into unified energy systems.

Figure (2) shows three scenarios for integration of the sources where the RES can be integrated with the local grid or with additional RES and with the grid leading to so called Hybrid Renewable Energy Systems (HRES). HRES, address the intermittency of individual renewable sources, improving reliability and stability [10]Solar power peaks during daylight, while wind energy is available even with reduced sunlight. Integrating these sources ensures a consistent energy supply, mitigating shortages during adverse weather and grid shutdown [11], [12] & [13] .

2. **Motivation of this study**

A Jewellery factory in Hebron faced challenges due to exceeding electrical consumption limits, frequent power outages affecting molten materials, and rising electricity costs reducing market competitiveness. To address these issues, the factory implemented a Hybrid Renewable Energy System (HRES) integrating solar and backup power sources. This solution ensured a consistent energy supply, reduced reliance on the grid, and lowered operational costs, enhancing productivity and competitiveness.

2.1 Proposed Solution

The jewelry factory in Hebron considered several solutions to address its energy challenges:

1. **Installing a PV station connected to the grid:** This option requires official approval from the electricity supplier. However, administrative hurdles prevent the construction of a system that fully covers peak-hour consumption.

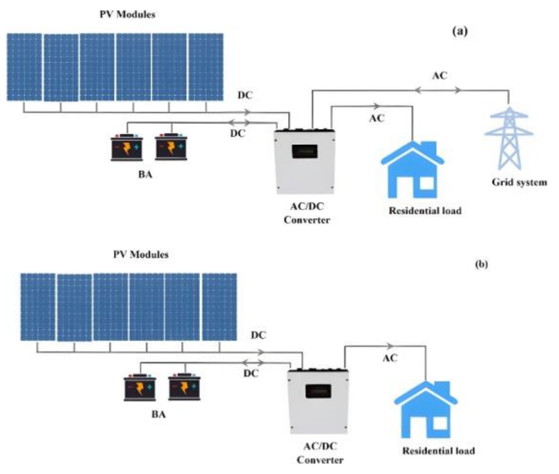


Figure 3 : HRES combining both PV source, Batteries & grid [1]-a) when grid is on, b) when grid outage.

2. **Installing a PV Station with high-capacity Battery storage:** This approach compensates for energy shortages during peak hours but is relatively expensive. While battery storage costs have been decreasing, they remain a significant investment.
3. **Implementing an integrated system combining Solar, Wind, and Grid energy:** Due to generally low wind intensity in Palestine and the factory's unsuitable location, this option was deemed unfeasible.

After evaluating these options, the factory adopted for the second solution: installing a PV station with high-capacity battery storage. Despite the higher initial costs, this choice ensures a reliable energy supply during peak hours, reduces dependence on the grid, and mitigates the impact of power outages on production as shown in fig. (3).

2.2 Advantages & limitations of using HRES

Hybrid Renewable Energy Systems (HRES) offer several advantages:

- Energy reliability: Storage units within HRES store excess energy generated, providing a buffer during periods when renewable sources are not producing power, thereby enhancing overall system reliability [14]
- Grid stability: In grid-connected configurations, energy storage aids in load leveling and peak shaving, contributing to grid stability [15]
- Optimized resource use: Advanced control systems intelligently manage energy storage to maximize the efficiency of various energy resources.

These benefits make HRES a viable alternative for supplying power to the grid, optimizing system efficiency, and ensuring a consistent energy supply.

Hybrid Renewable Energy Systems (HRES) without adequate storage face several limitations:

- Intermittency: Without storage, HRES are vulnerable to the variability of renewable resource like solar, affecting system reliability [16]. Grid Dependence: In on-grid systems lacking storage, HRES become heavily reliant on grid stability, which can be problematic during grid disturbances [17].

- Energy Wastage: Excess energy generated during periods of low demand may go to waste if it cannot be stored or fed into the grid, leading to inefficiencies.

Addressing these limitations is crucial for optimizing the performance and efficiency of HRES.

3- Modeling of HRES

This system contains PV solar generator, uninterruptable power source (UPS) and battery bank BB , where the solar irradiation varies, the load demand varies as well, therefore a combination of these sources is essential to cover the required demand.

3.1 The PV model and effect of solar irradiation variation

The photovoltaic (PV) effect enables solar cells to convert sunlight into electricity. When photons hit a semiconductor material, such as silicon, they transfer energy to electrons, freeing them from their atomic bonds. This creates electron-hole pairs. An internal electric field within the cell drives electrons toward the n-type layer and holes toward the p-type layer, generating an electric current. Connecting an external circuit allows this current to be harnessed as usable electrical power.

Variations in solar irradiance during the day significantly impact photovoltaic (PV) system performance. At a constant temperature, increased irradiance leads to a proportional rise in current output, while voltage remains relatively stable.

To assess these effects on circuit performance, it's essential to express system parameters as functions of solar irradiance (G).

This involves analyzing the current-voltage (I-V) characteristics of the PV system under varying irradiance. To analyze this model way out from the equivalent circuit of solar cell displayed on fig. (4) where the solar irradiation is converted into photo current I_{ph} **Error! Reference source not found.**. B ased on this circuit, the cell voltage at standard test conditions can be stated according eq. (1) .

$$Vpv = \frac{A.K.T_c}{q}\ln\left(\frac{I_{ph}+I_d-Ipv}{Ipv}\right) - R_s.Ipv. \tag{1}$$

Where, A is diode idealistic factor, Gr is the reference solar irradiation; I_d is the diode saturation current; I_{ph} is the cell photo current, I_{PV} is the Photovoltaic current, I_{SC} is the short circuit current, K is Boltzmann constant, q is the electric charge, and Rs is the PV intersinc series resistance. The photo current in terms of irradiation and temperature is:

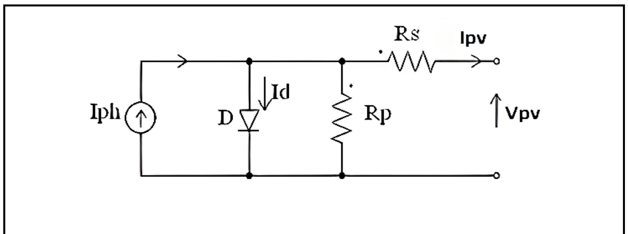


Figure 4: Equivalent circuit of PV cell.

$$I_{ph} = N_p.\left[I_{sc}.{}^{G}/_{Gr} + I_t(T_c - T_r)\right] \tag{2}$$

The output cell current is :

$$Ipv = N_P(I_{Ph} - I_d\left(e^{\frac{q.Vo/Ns}{A.K.Tc}} - 1\right) \qquad (3)$$

The diode current can be stated as:

$$I_d = I_{or}\left(\frac{Tc}{Tr}\right)^3 . e^{\frac{q.Eg}{B.K}\left(\frac{1}{Tr}-\frac{1}{Tc}\right)} \qquad (4)$$

where, B is diode idealistic factor, Eg is the band gap energy of the semiconductor, T_C, T_r are the cell and reference temperature respectively; I_{or} , It are constants given at standard conditions. The idealistic diode factors A & B are with values vary between 1 and 2 depending on I-V performance shaping and approximations.

3.2. Simulation of PV generator.

By using MATLAB/Simulink platform [19]the PV generator is simulated for various irradiation levels taking into account the solar cell data given in table(1) and the Simulink model with PV characteristics are shown on fig.(5)

Table 1. Data specification for SPR-315E-WHT-D[20]

q	K	I_{ph}	I_d	R_S	R_P
1.602e-19 C	1.38e-23J/°K	6.14A	0.059A	0.15Ω	1090Ω
N_S	N_P	V_{cell}	V_{OC}	I_{SC}	V_{MPP}
32	3	0.6V	64.6V	6.14A	54.7V
I_{MPP}	Eg	N_{Pm}	V_{pv}	R_{load}	T_C
5.76A	1.1	1	54.7V	9.6Ω	25°C

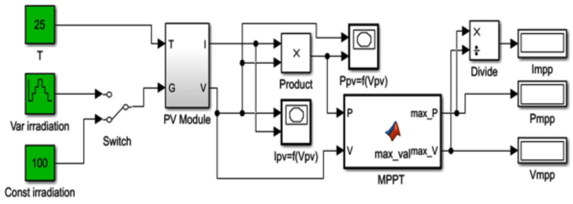
According to the equivalent circuit of solar cell displayed on fig. (4) and the displayed results in fig. (5) the variation in irradiation much affects the current rather than the voltage.

3.3. Combined HRES model.

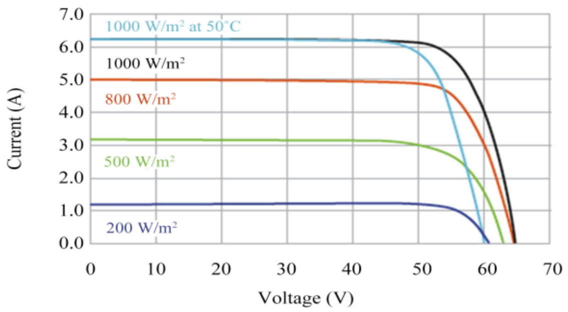
Combining a Battery (BB) and a Photovoltaic (PV) system for energy storage in both on-grid and off-grid scenarios involves modelling the energy flow, power conversions, battery state-of-charge (SOC), and interactions with the grid or load.

A) Energy Balance Equations:

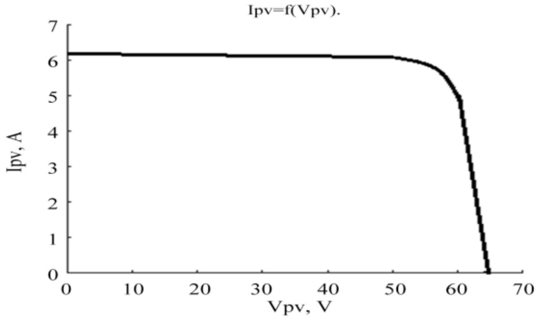
- ➢ PV Power Generation (Ppv): Depends on solar irradiance and panel efficiency.
- ➢ Load demand (P_{Load}): Power required by the connected loads.
- ➢ Battery charging/discharging Power (P_{BB}):



a) Simulink model



b) Panel I-V performances at various irradiation [20].



c) The obtained I-V simulation performance at full Sun.

Figure 5: PV Simulink model and PV performances.

- Charging: When excess PV power is available i.e $P_{pv} > P_{Load}$ & $P_{BB} < 0$
- Discharging: When PV power is insufficient to meet the load. i.e $P_{pv} < P_{Load}$ & $P_{BB} > 0$

➢ Grid power exchange (balance) **(P_{Grid}):**

- ✓ On-Grid mode $P_{Grid} \pm 0$.
  - ▪ Importing power: When both PV and battery cannot meet the load.

    $$P_{pv} + P_{BB} + P_{Grid} = P_{Load} \qquad (5)$$

  - ▪ Exporting power: When excess power is available.
- ✓ Off-Grid mode: $P_{Grid} = 0$.

  $$P_{pv} + P_{BB} = P_{Load} \qquad (6)$$

B) *Power conversion efficiency*:

- Inverter efficiency (η_{INV}): Efficiency of converting DC to AC power.
- Battery charge/discharge Efficiency (η_{BB}): Efficiency during charging and discharging cycles.

C) State-of-Charge (SOC) Dynamics:

- SOC equation**:**

$$SOC(t) = SOC(t - \Delta t) + P_{BB} * \frac{\Delta t}{E_{BB}max}. \qquad (7)$$

Where E_{BBmax} is the maximum energy storage capacity of the battery.

- ✓ Power from/to the grid for on-grid:

$$P_{Grid} = P_{Load} - (P_{PV} + P_{BB}). \qquad (8)$$

When $P_{\text{Grid}} > 0$, the system is importing power from the grid.

When $P_{\text{Grid}} < 0$, the system is exporting power to the grid.

- ✓ Energy balance for on-grid:

$$P_{BB} = \eta_{BB} * \eta_{INV} * (P_{PV} + P_{Grid} - P_{Load}). \qquad (9)$$

- ✓ Power charged/discharged by the BB for off-grid:

$$P_{BB} = Eff * (P_{PV} - P_{Load}). \qquad (10)$$

Where $E_{fconv} = \eta_{BB} * \eta_{INV}$ presents total conversion efficiency of the battery bank and the inverter; dt is the calculation step time, j, n and the iteration indexes.

Refer to the manufactory installed systems:

P_{BB}=38.4 kW for 1 hour; P_{inv}=33 kWac;

Ppv=26.5 kWp; and SOC_{max} =85%.

Figure (6) illustrates the built flowchart describing the up mentioned mathematical model [21] .

3.4. Complete simulation model.

To keep the input hybrid inverter voltage constant at various irradiation level a Matlab/SIMULINK model is performed for on-grid scenario is applied, while when the off-grid scenario is applied the battery charge controller maintains fixed input dc voltage to the inverter. Figure (7) illustrates the Simulink model and the obtained related results, where it can be shown that the output voltage remains constant irrespective of solar irradiation variation.

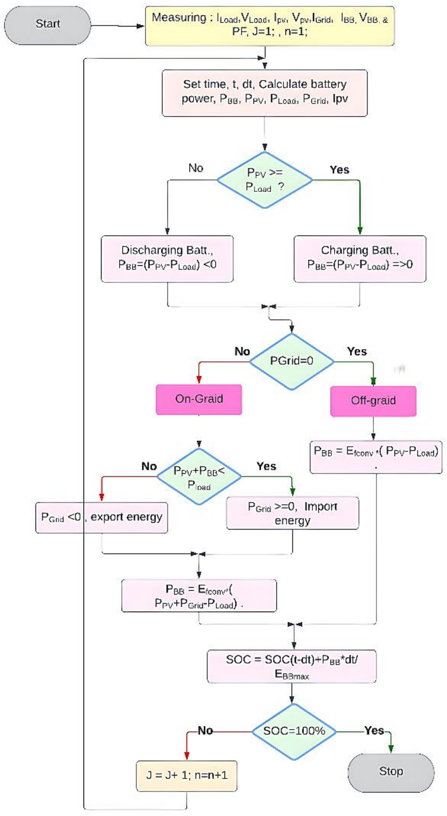


Figure 6. Energy balance flowchart [21]

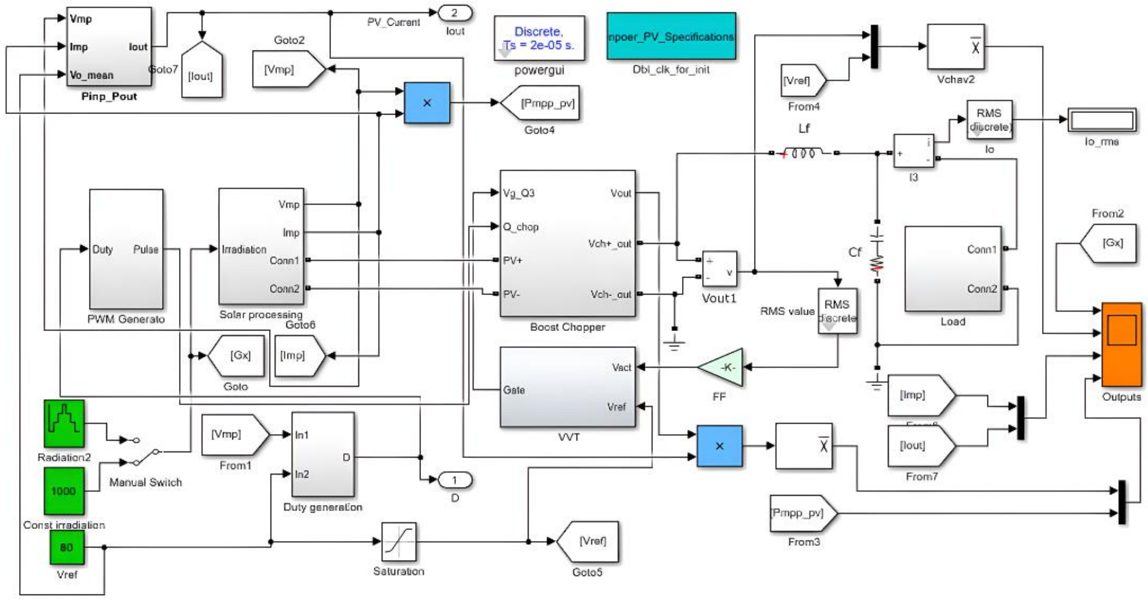
4. Practical Implementation

4.1 System components

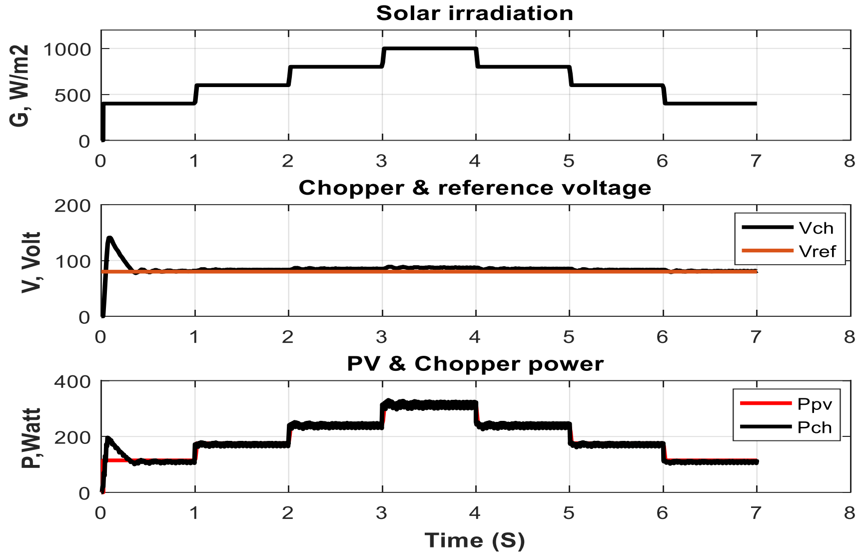
After discussing the system components and energy scenarios a real implementation case is applied with the following key elements:

The installed PV generator:

The initial design for the photovoltaic (PV) system included 61 Jinko Tiger Pro 72HC 550W panels, totaling 33.5 kWp, oriented southward [23]. However, due to significant shading from neighboring buildings, the configuration was adjusted to 48 panels facing east with a 40° tilt angle with total power of 26.4kWp. This revised setup effectively meets the factory's energy requirements.



a) Matlab / SIMULINK model.



b) Irradiation levels, voltages and powers.

Figure 7. PV-Chopper simulation & results [22]

It's important to note that the orientation and tilt angle of solar panels significantly influence their performance. South-facing panels typically receive maximum sunlight, but in certain situations, east or west orientations may be more practical. The optimal tilt angle varies based on geographic location and specific site conditions as shown on fig. (8). In this case, the 40° tilt angle was chosen to optimize energy production, considering the building's location and surrounding structures. Adjusting the number of panels and their orientation ensured that the installed system fully covers the load demand, despite the challenges posed by shading. For more detailed information on the specifications of the Jinko Tiger Pro 72HC 550W panels refer to the official datasheet [23].

- ***The installed PV Inverter:*** To accommodate the distribution of photovoltaic (PV) panels, a 33 kW AC SUNGROW inverter with three Maximum Power Point Trackers (MPPTs) was selected. This model, the SG33CX, is designed for 1000 V DC systems and offers a maximum efficiency of 98.6% [24]

The inclusion of three MPPTs allows for optimal energy harvesting from PV arrays with varying

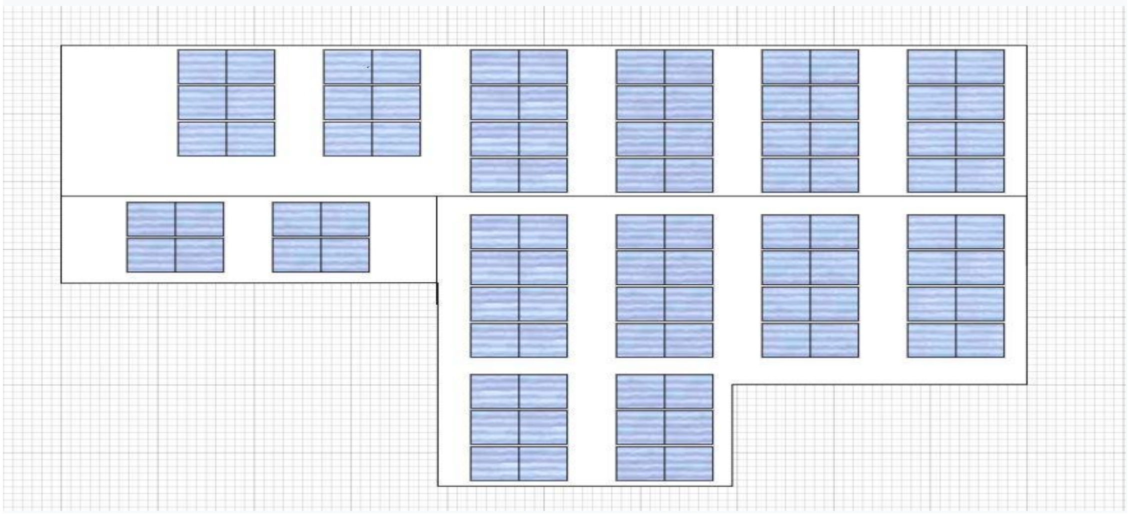


Figure 8. Solar panels installation over the building's roof top.

orientations or shading conditions, ensuring maximum power output as shown on fig. (9), Additionally, the inverter is compatible with bifacial PV modules and features a built-in Potential Induced Degradation (PID) recovery function, enhancing system reliability and longevity.

- *UPS Installation:*

Due to sensitivity of the yield products, the manufactory administration decided to install on-line UPS that should provide energy to all loads. The selected on-line UPS is the Gamatronic model with a capacity of 100 KVA, featuring a power factor Pf= 0.99 and a maximum rated current of 145 A [25],[26]. This choice is selected due to its proven reliability and the team's positive experience with its maintenance. Figure (10) shows principal circuit diagram of on-line UPS configuration. The battery bank comprises 32 batteries of 12 volts and 100 ampere-hours each, connected in series. This configuration results in a total voltage across the bank terminals of 430 volts [27]while they are considered discharged and in need of recharging when the voltage drops to 380 volts.

✓ Battery bank selection

The battery bank consists of 32 series-connected 12V, 100Ah LiFePO4 Deep Cycle batteries [28]yielding a total voltage of 384V when fully charged with total power of 38.4kWhr. The system is considered completely depleted and requires recharging when the voltage drops to 380V as shown on fig.(11)..

4.2 Control and calibration circuits

To facilitate battery charging within the UPS unit, the following electronic circuits were implemented:

➢ *Off-line Flyback Regulator*

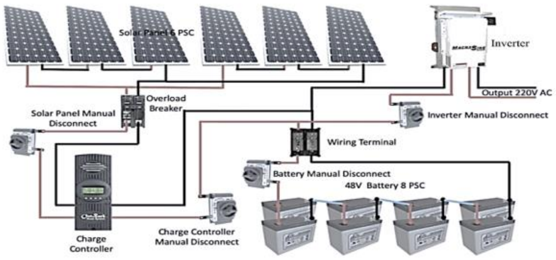


Figure 9: Solar panel wiring program with battery bank [28]

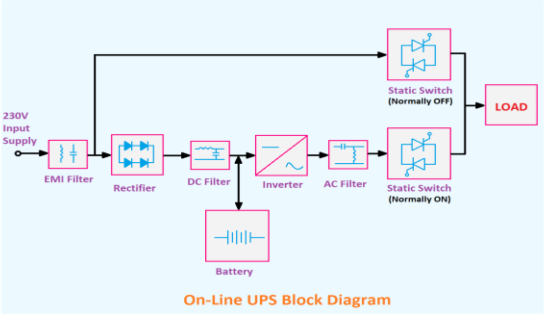


Figure 10: Circuit diagram of on-line UPS [26]

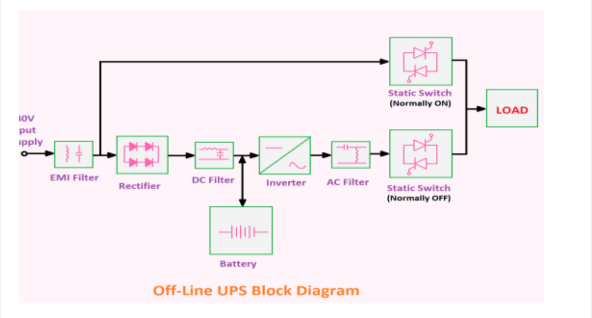


Figure 11: Circuit diagram of off-line UPS [26]

The offline fly back regulator was selected due to its compatibility with DC input voltage, considering that the batteries serve as the primary power source for this circuit. Given the battery voltage range of 380-430V

.

➢ ***- Three-phase controlled rectifier***

In the battery section, the rectifier is designed to provide a DC voltage of 430 volts for charging the battery. It operates as a full-wave controlled three-phase rectifier with an input of 380V with converter firing angle according to eq. (11) of [29]

$$V_{DC} = \frac{3\sqrt{6}}{\pi} V_{ph} * \cos\alpha$$

$$\therefore\ \alpha = \cos^{-1}\frac{\pi . V_{DC}}{3\sqrt{6} . V_{ph}} = 33°. \qquad (11)$$

Where, V_{DC}=430V presents the battery charging voltage; and V_{ph}=220V presents the input phase AC voltage.

➢ ***Charge controller***

The charge controller efficiently manages battery charging by prioritizing power sources, ensuring optimal operation. Implementing the conducted modifications on the main charging circuit permits effective charging from the PV generator and realizing effective performance.

The modified circuit is illustrated on fig. (12) where the PV generator charges the battery during light loading intervals, therefore using the surplus energy for charging the battery bank. The complete circuit diagram including all control modules is illustrated on fig. (13).

4.3 Calculations verifications

To validate the proposed design and circuit modifications, the following calculations were performed:

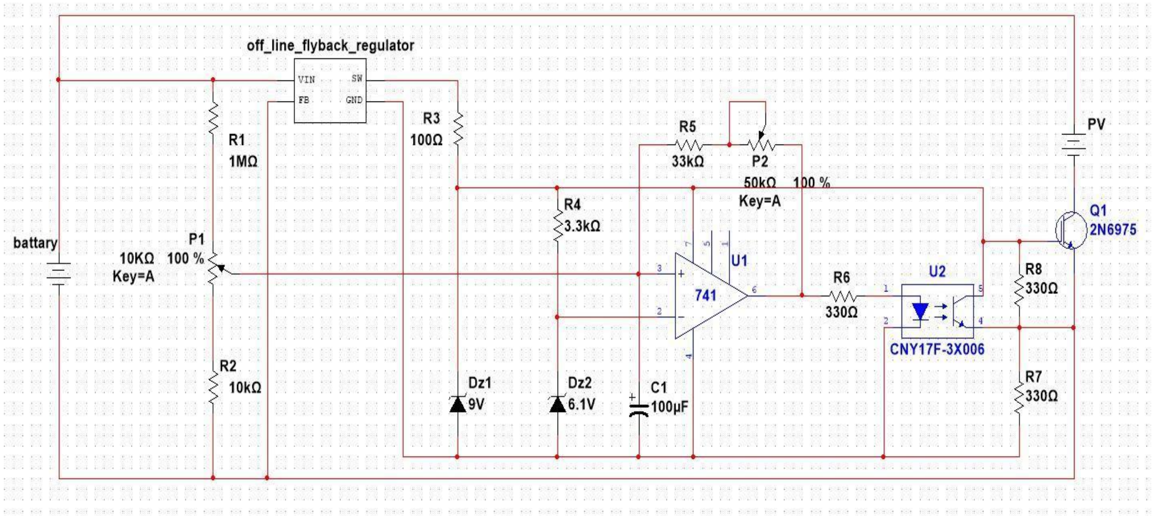


Figure 12: Modified charge controller circuit.

- *PV power provided to the Battery bank*:

$$P_{PV} = V_{BB} * I_{CH} = 22.84\ kWdc \qquad (12)$$

Where, V_{BB}= 431V is the battery voltage

I_{CH}= 53 A is the charging current.

- *The power consumed by the three-phase load is:*

$$\begin{aligned} P_{Load} &= P_{Phase1} + P_{Phase2} + P_{Phase3} \\ &= V_{ph}\left(I_{ph1} + I_{ph2} + I_{ph2}\right) * PF \\ &= 230 * (\ 24.5 + 36.3 + 20.1) * 0.95 \\ &= 18.6\ kW \qquad (13) \end{aligned}$$

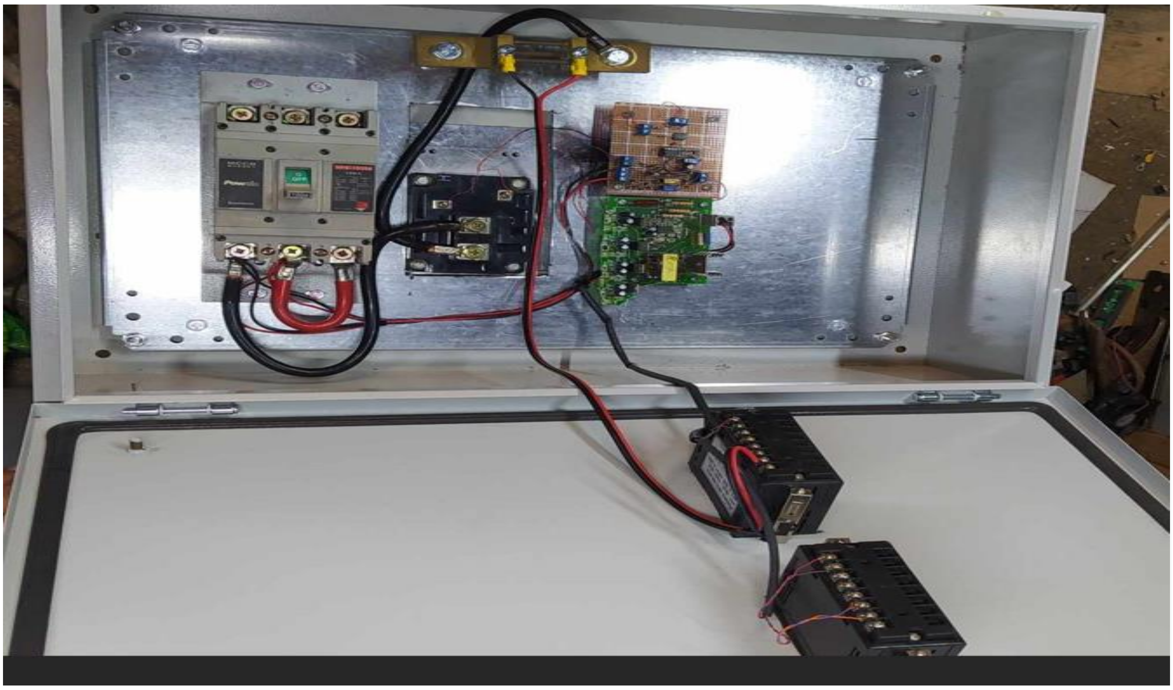


Figure13: Complete circuit assembly

Where the power per phase various due to unequal load current drawn in these phases as shown on fig. (14).

- *The power balance:*

$$P_{balance} = P_{PV} - P_{Load} = 22.84\ kW - 18.6\ kW = +\ 4.24\ kW \quad (14)$$

Therefore, the PV system directly powers the load, minimizing reliance on grid electricity. Additionally, the system is designed to accommodate future expansions, enabling it to support additional light loads seamlessly.

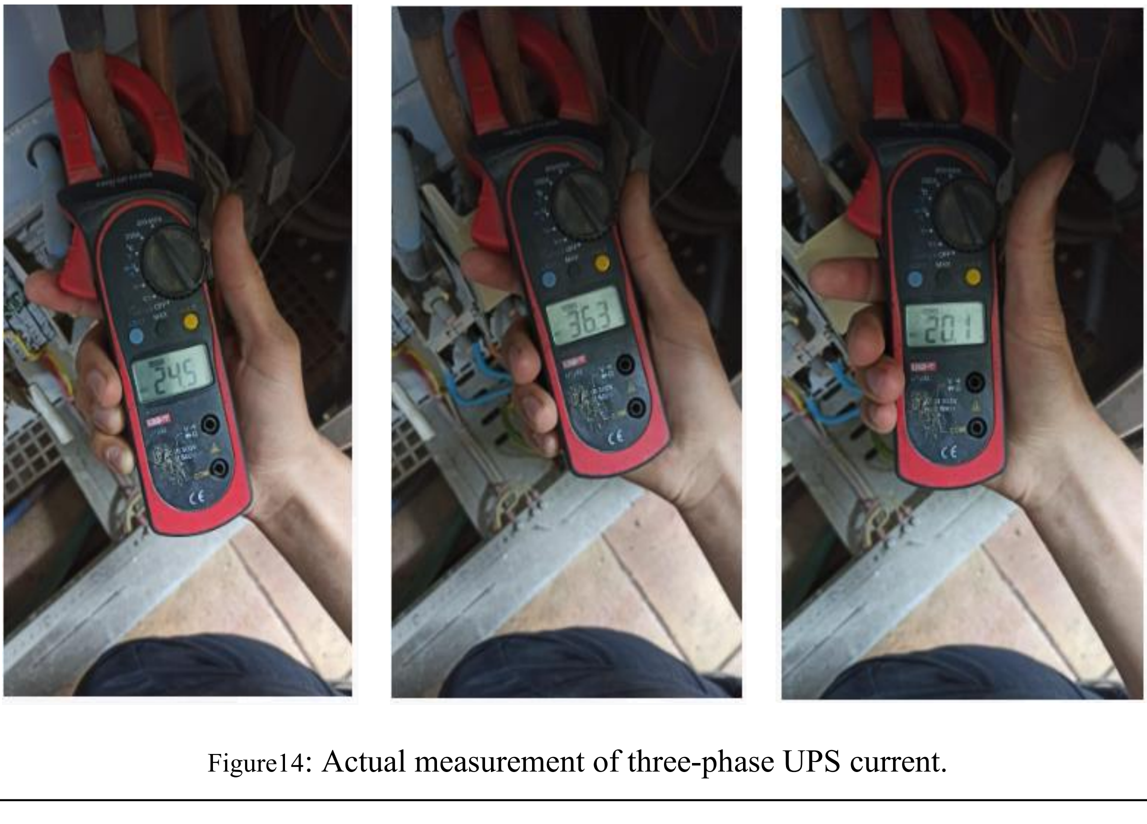


Figure14: Actual measurement of three-phase UPS current.

4.4 Annual revenue.

After constructing and operating the complete electrical circuit, monitoring the monthly energy consumption cost, and calculating the annual consumption, the results are summarized as follows based on the stated copy of the invoice shown on fig. (15):

تاريخ القراءة السابقة 08/05/2023 تاريخ القراءة الحالية 08/06/2023 عدد الايام 31

رقم العداد	قراءة سابقة	قراءة حالية	معامل ضرب	معامل قدرة	الاستهلاك	التعرفة	ثمن الاستهلاك
25700123794	81743	86114	1		4371	صناعي	2,680.55
925700123794	26033	27752	1	93%	1719	KVAR	0.00

Meter#	Previous reading	Present reading	Multiple	Power factor	Consumption	Tarif	Consumption price

a) Electricity bill for May 2023

تاريخ القراءة السابقة 04/04/2024 تاريخ القراءة الحالية 04/05/2024 عدد الأيام 30

رقم العداد	قراءة سابقة	قراءة حالية	معامل ضرب	معامل قدرة	الاستهلاك	التعرفة	ثمن الاستهلاك
25700123794	129860	132652	1		2792	صناعي	1,724.29
925700123794	39633	40108	1	99%	475	KVAR	0.00

Meter#	Previous reading	Present reading	Multiple	Power factor	Consumption	Tarif	Consumption price

معلومات عامة عن الخدمة والذمم

تفاصيل الفاتورة الحالية

b) Electricity bill for April 2024

Figure15: Monthly energy consumption and related cost in NIS.

- Energy Consumption for May,2023:
  EMay = 4371 kWhr.

- Energy Consumption for April, 2024:
  EApril = 2729 kWhr

- The realized energy saving is :

$$\Delta E = EMay - EApril = 1642 \text{ kWhar .} \qquad (15)$$

- This saving is converted to US$:
  ΔEmonth = (4371-2729)0.62/3.60=*700$,

♠ The annual saving ~ : 12*700=8400 $ ♠

4 Conclusion

The most significant achievement of this project was modifying the control circuit to ensure the UPS draws energy from the solar system instead of the grid, thereby reducing both consumption and dependency on the grid. Additionally, modifications to the UPS battery charging control circuit reduced grid energy consumption costs by 35%. This improvement positively impacts the company's profits, lowers manufacturing costs, and enhances competitiveness by enabling a reduction in product prices.

Finally, the challenge of power outages and their impact on molten precious materials was resolved, along with the limitation of energy supply from the grid. This advancement enables an increase in the factory's production capacity.

References

[1] Martin, S. S., Chebak, A., Barka, N., Development of renewable energy laboratory based on integration of wind, solar and biodiesel energies through a virtual and physical environment, 2015, *3rd International Renewable and Sustainable Energy Conference, Marrakech, 2015*, pp. 1-8. https://doi.org/10.1109/irsec.2015.7455086.

[2] Mahmoud, Y., Xiao, W., Zeineldin, H. H., A simple approach to modeling and simulation of photovoltaic modules, IEEE Trans. Sustain. Energy, vol. 3, no. 1, Jan. 2012, pp. 185–186. https://doi.org/10.1109/tste.2011.2170776.

[3] Mastromauro, R. A., Liserre, M., Dell'Aquila, A., Control issues in single-stage photovoltaic

systems: MPPT, current and voltage control, *IEEE Trans. Ind. Informat.,* vol. 8, no. 2, May. 2012, pp. 241– 254. https://doi.org/10.1109/tii.2012.2186973.

[4] Khader, S., Daud, A.K., Boost chopper behaviors in Solar photovoltaic system, *Smart Grid and Renewable Energy* , Vol.12, No.3, March 2021, https://doi.org/10.4236/sgre.2021.123003.

[5] Martín Silva, Justo Jose Roberts& Pedro Osvaldo Prado, " Calculation of the Shading Factors for Solar Modules with MATLAB", Energies 2021, 14(15), 4713; pp.1-23. https://doi.org/10.1051/matecconf/201821802004

[6] RusianaIskandar , Yuda Bakti Zainal, and Susanto Sambasr, "Study and Analysis of Shading Effects on Photovoltaic Application System", MATEC Web of Conferences 218, IVIEE,2018,https://doi.org/10.1051/matecconf/201821802004

[7] Ellabban, O.; Abu-Rub, H.; Blaabjerg, F. Renewable energy resources: Current status, future prospects and their enabling technology. Renew. Sustain. Energy Rev. 2014, 39, 748–764. https://doi.org/10.1016/j.rser.2014.07.113

[8] Qusay Hassan , Sameer Algburi, , Aws Zuhair Sameen , Hayder M. Salman, Marek Jaszczur , " A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications", Elsivier, Results in Engineering, Volume 20, December 2023,https://doi.org/10.1016/j.rineng.2023.101621

[9] A. Garratt, I. Petrella, Y. Zhang, " Asymmetry and interdependence when evaluating US energy information administration forecasts", Energy Econ., 121 (2023), Article 106620, https://doi.org/10.1016/j.eneco.2023.106620

[10] Hassan, M.K. Abbas, V.S. Tabar, S. Tohidi, M. Al-itmi, M. Jaszczur, H.M. Salman, "Collective self-consumption of solar photovoltaic and batteries for a micro-grid energy system", Results Eng., 17 (2023), Article 100925,: www.sciencedirect.com/journal/results-in-engineering

[11] N. Kannan, D. Vakeesan Solar energy for future world:-A review Renew. Sustain. Energy Rev., 62 (2016),pp. 1092-1105, https://doi.org/10.1016/j.rser.2016.05.022

[12] T. Ma, H. Yang, L. Lu, A feasibility study of a stand-alone hybrid solar–wind–battery system for a remote island, Appl. Energy 121 (2014) 149–158. https://doi.org/10.1016/j.rineng.2023.100925

[13] G. Merei, J. Mosh¨ovel, D. Magnor, D.U. Sauer, Optimization of self-consumption and techno-economic analysis of PV-battery systems in commercial applications, Appl. Energy 168 (2016) 171–178. DOI: 10.1016/j.apenergy.2016.01.083

[14] P. Palej, H. Qusay, S. Kleszcz, R. Hanus, M. Jaszczur, " Analysis and optimization of hybrid renewable energy systems" Polityka Energetyczna, Energy Policy, 22 (2) (2019), pp. 107-120, DOI: https://doi.org/10.33223/epj/109911

[15] Y. He, S. Guo, P. Dong, Y. Zhang, J. Huang, J. Zhou, "A state-of-the-art review and bibliometric analysis on the sizing optimization of off-grid hybrid renewable energy systems", Renew. Sustain. Energy Rev., 183 (2023), Article 113476, https://doi.org/10.1016/j.rser.2023.113476

[16] Q. Hassan, M. Jaszczur, A.M. Abdulateef, J. Abdulateef, A. Hasan, A. Mohamad, "An analysis of photovoltaic/supercapacitor energy system for improving self-consumption and self-sufficiency", Energy Rep., 8 (2022), pp. 680-695, https://doi.org/10.1016/j.egyr.2021.12.021.

[17] M. Jaszczur, Q. Hassan, A.M. Abdulateef, J. Abdulateef, "Assessing the temporal load resolution effect on the photovoltaic energy flows and self-consumption", Renew. Energy, 169 (2021), pp. 1077-1090, https://doi.org/10.1016/j.renene.2021.01.076

[18] Krivoshein, Y.O., Tolstykh, A.V., Tsvetkov, N.A. and Khutornoy, A.N. (2020) Mathematical Model for Calculating Solar Radiation on Horizontal and Inclined Surfaces

for the Conditions of Yakutsk. IOP Conference Series : Earth and Environmental, Science , 408, 1-8.https://doi.org/10.1088/1755-1315/408/1/012002

[19] Matlab and Simulink, The Mathworks, Inc., Version R2016b, http://www.mathworks.com

[20] SUNPOWER,.Datasheet,SPR-315E-WHT-D, http://www.solardesigntool.com/components/module-panel-solar/Sunpower/21/SPR-315E-WHT-D.

[21] Lucidchart.https://lucid.app/lucidchart/76d5afbb-1d12-4d10-96a8-fb21d13fe47b

[22] Sameer Khader, Abdel-Karim Daud, "Boost Chopper Behaviors in Solar Photovoltaic System", **Smart Grid and Renewable Energy, 2021, Vol.12, pp. 31-52**

https://doi.org/10.4236/sgre.2021.123003

[23] Solar Panels type Jinco Tiger Pro 72HC 550W, https://www.jinkosolar.com

[24] Solar inverter type SUNGROW, DS SG33CX https://en.sungrowpower.com/upload/documentFile/DS_SG33CX.

[25] GAMA System Technology, Online UPS, 100kVA, https://gamasystemtech.com/portfolio/power-fs-ups-10kva-50kva-100kva

[26] Understanding on-line and off-line UPS, https://issuu.com/smartpowerltd/docs/understanding_offline_and_online_ups_diagram

[27] BSLBAT bbattery specification, 100Ah 12V LiFePO4 Deep Cycle https://www.lithium-battery-factory.com/product/lifepo4-battery-12v-100ah/

[28] Solar panel wiring with battery bank wiring diagram , https://www.pinterest.com/pin/eee-community-solar-power-system-wiring-diagram--681380618635750645/

[29] M. H. Rashid, Power Electronics, Devices, Circuits, and Applications. 4th edition, Pearson Education Limited 2014, ch.10, pp. 525-545. ISBN97800-13-3125900.

[30] https://lucid.app/lucidchart/76d5afbb-1d12-4d10-96a8-fb21d13fe47b

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.