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Technical article

Introducing PV Grid-Parity to Yemen Power System Experimental, Feasibility, and Environmental Studies

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ABSTRACT

In 2015, the United Nations imposed an embargo on the de facto governing authority in Yemen, coinciding with the escalation of the civil war. This development had a profound adverse impact on the national power sector. Prior to the conflict, the city of Sana'a was predominantly supplied by the National Grid. Following the imposition of the embargo, however, electricity provision effectively ceased as a consequence of acute fuel shortages and the physical destruction of key components of the transmission and distribution infrastructure. In response, residential consumers and other electricity users increasingly turned to alternative power supply options. Among these, photovoltaic (PV) systems emerged as the most economically competitive, commercially accessible, and environmentally sustainable solution. This shift led to a rapid expansion of the market for PV Solar Home Systems (SHS). In the medium to long term, Yemen's power system is expected not only to be restored to its pre-conflict configuration but also to expand its capacity to accommodate rising electricity demand from households and other consumer categories. Under such a scenario, the aggregate installed PV capacity from SHS—potentially reaching several hundred megawatts (MW)—could be incorporated into the power demand-side trading market. Within this context, the adoption of Grid-Parity practices would likely be both economically viable and environmentally advantageous. This study presents experimental, techno-economic, and environmental analyses related to the deployment of PV-based Grid-Parity in Sana'a, Yemen. The economic feasibility was evaluated using the widely recognized Levelized Cost of Energy (LCOE) methodology. The LCOE outcomes, derived from a combination of experimental data and analytical calculations, indicate a high degree of viability for the implementation of Grid-Parity in the case study area. Furthermore, the paper assesses the environmental implications of achieving Grid-Parity, demonstrating a substantial potential reduction in CO_2 emissions, and advocates for the use of Carbon Pricing Instruments as a policy mechanism to accelerate the large-scale deployment of Grid-Parity solutions.

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1. INTRODUCTION

The normal operation of the Yemeni National Grid (NG) was discontinued in mid-2015 following the

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outbreak of the civil war. Prior to this disruption, the NG's capacity was already constrained, meeting only approximately 70% of the total electrical load demand. A general technical overview of the NG is presented in Table 1. As indicated in the table, the generation capacity exhibited a deficit exceeding 50% relative to peak demand, not accounting for spinning, contingency, or other reserve margins. Additional quantitative details on NG demand and supply are provided in Appendix 1. Collectively, these data underscore the urgent requirement for new power generation capacity within the NG.

Table 1. Basic overview of the Yemeni National Grid (NG).

Peak Load	PEC Total Generation	Purchased Power	Load Shedding	Maximum Demand
1458 MW	960 MW	498 MW	758 MW	2216 MW

As previously noted, NG operations were fully suspended in the second half of 2015. Concurrently, an acute shortage of conventional fuels resulted in a complete blackout in the capital city, Sana'a. Under these conditions, photovoltaic (PV) systems emerged as the most economically feasible, commercially available, and environmentally sustainable alternative. This led to a rapid and widespread deployment of PV Solar Home Systems (SHS), which in turn drove a substantial expansion of the SHS market. A broad range of vendors—including non-specialized retail outlets—entered the market and began supplying SHS, fostering a vibrant commercial ecosystem during the blockade period. According to Al-Ashwal (2022), the cumulative installed SHS peak capacity in Yemen may have reached approximately 335 MWp. This corresponds to a significant increase in decentralized generation capacity achieved at or near grid-parity, thereby effectively promoting demand-side participation and informal electricity trading.

This paper examines the application of PV technology as an energy source under the Grid-Parity model. Grid-Parity has gained significant attention in recent decades. Breyer (2013) identifies it as a tipping point for solar energy dominance, particularly in developing countries where household energy demand exceeds industrial consumption. The paper presents experimental and feasibility studies, along with an environmental impact assessment of Grid-Parity in Sana'a, Yemen. Initially, the experimental setup is described, including objectives, components used, site conditions, and measurement of various parameters. This is followed by daily records of experimental results. System performance is illustrated through graphs, and relevant calculations are conducted. Finally, a feasibility evaluation and an environmental impact assessment based on local conditions are provided, culminating in key conclusions.

2. EXPERIMENT

The objectives of this work are to characterize all relevant parameters associated with the electrical energy generated by the photovoltaic (PV) system and its subsequent conversion from direct current (DC) to alternating current (AC), as well as its injection into the utility grid. Measurements are conducted during daytime operation, specifically from 09:05 to 16:30. The monitored parameters include solar irradiance; PV array voltage and current at the inverter input; inverter output voltage and current; inverter output frequency; total electrical energy generated; and the harmonic components injected into the grid.

2.1. EXPERIMENTAL SETUP

As shown in Figure 1, the components include:

1. 12 PV panels of 12 V and 260 Wp (yields 3.12 kWp.)
2. On-grid Maximum Power Point Tracking (MPPT) interactive Inverter and Controller; (for more information about MPPT see Appendix 2)
3. Power Quality Analyser SA2100 (6000 sample/second)
4. Solar Radiation Meter
5. Energy meter
6. Clamp Ammeters and Voltmeters.

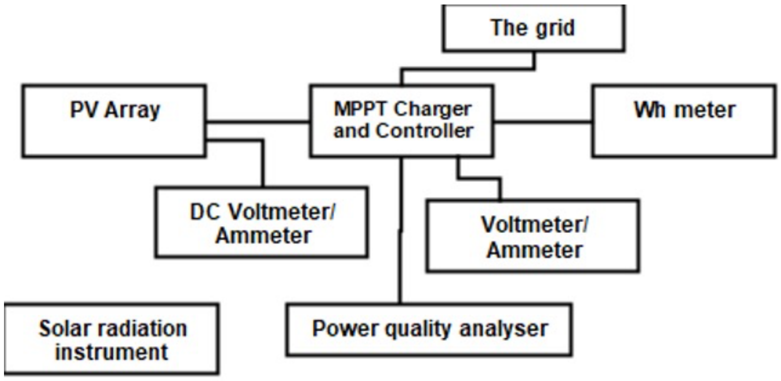

Figure 1. Experiment set-up block diagram.

2.2. SITE CONDITIONS

In this study, the location is on the roof of the Educational Building of LIU, Sana'a Campus. The output of the PV System is connected to the Power System of LIU representing the Grid. The Campus has two sources of supply, namely the National Grid and LIU local diesel generation. Site Conditions are: Solar declination angle (α) = -21.3°, latitude angle(ϕ) = 15.3694° North, Tilted angle (β) = 15°, Solar azimuth(ɣ) = 15°, longitude = 44.19, Altitude = 2200 m. Minimum ambient temperature could reach -3 °C. Maximum ambient temperature could reach +35 °C.

2.3. MEASUREMENTS

In this study, the measurements were recorded at 5-minute intervals, encompassing the following parameters: irradiance; inverter input and output voltage, current, and power; energy delivered to the grid; output frequency; and third- and fifth-order harmonic components of inverter voltage and current. The monitoring extended over a period of seven months, from which two representative days were selected to illustrate system performance. Example waveforms of key parameters are presented in Figures 2 through 9.

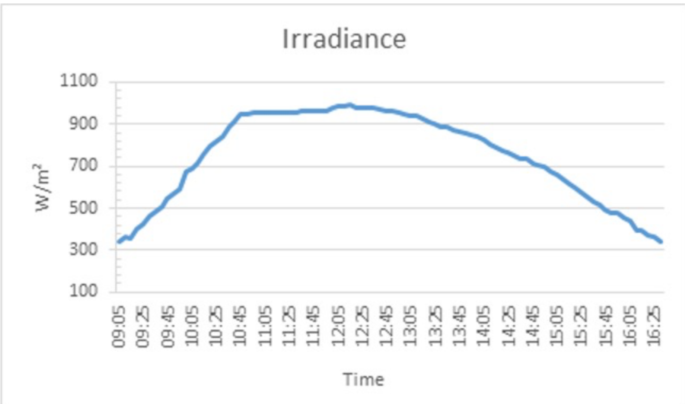

Figure 2. Irradiance measurement on 14th July.

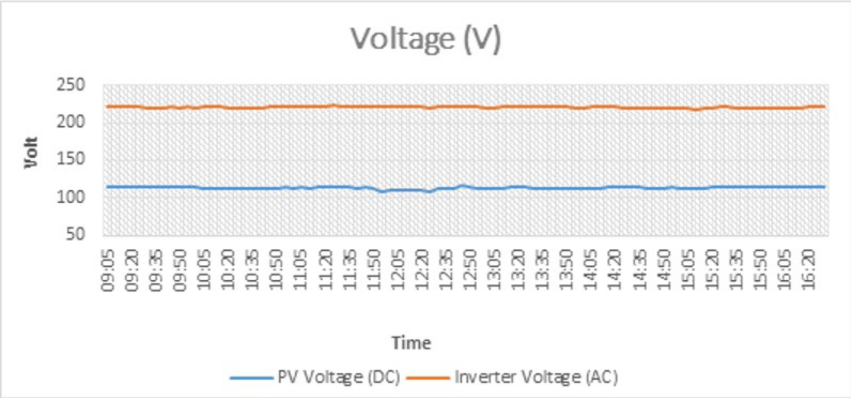

Figure 3. Voltage measurement on 14th July.

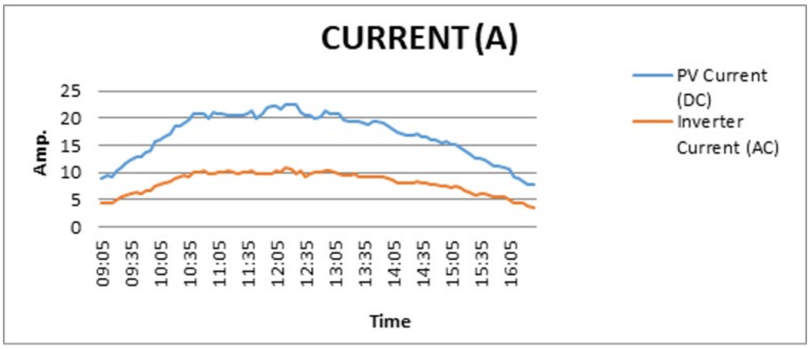

Figure 4. Current measurement on 14th July.

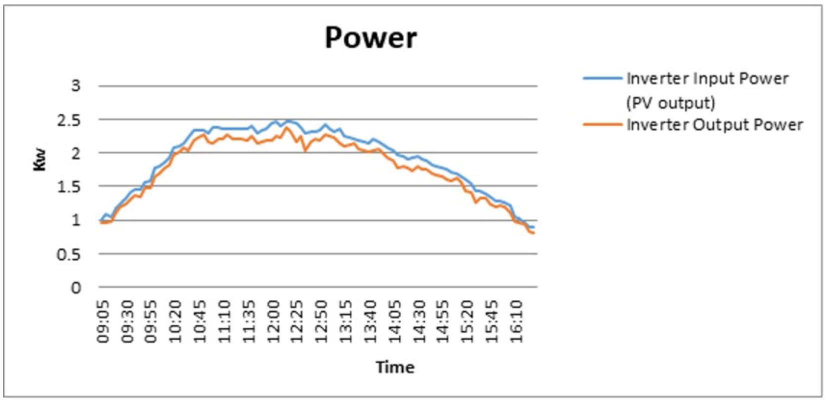

Figure 5. Power measurement on 14th July.

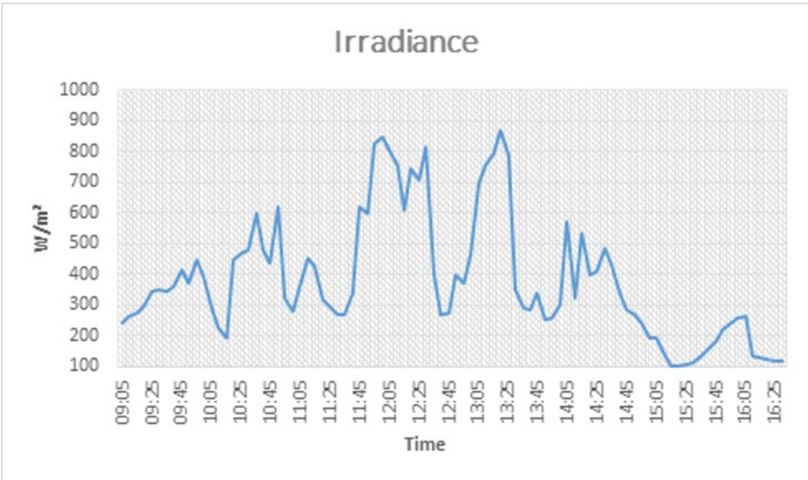

Figure 6. Irradiance measurement on 4th August.

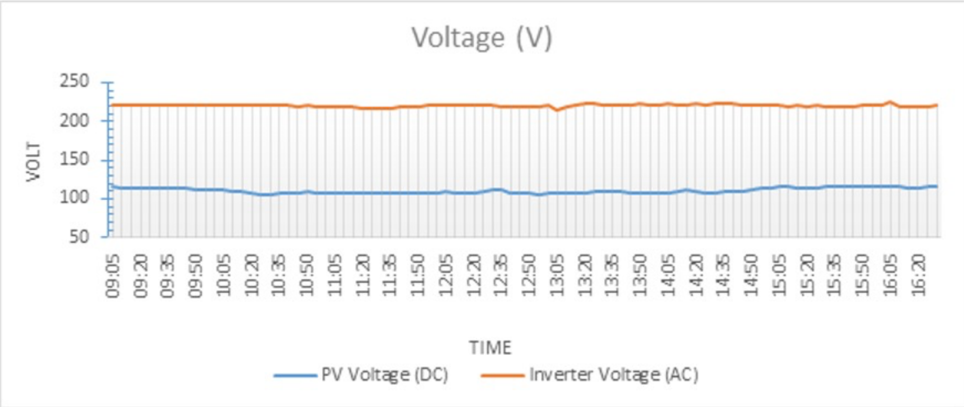

Figure 7. Voltage measurement on 4th August.

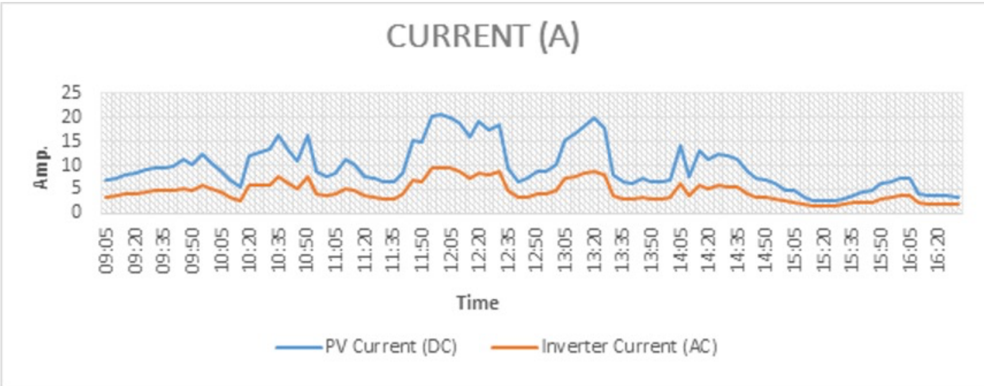

Figure 8. Current measurement on 4th August.

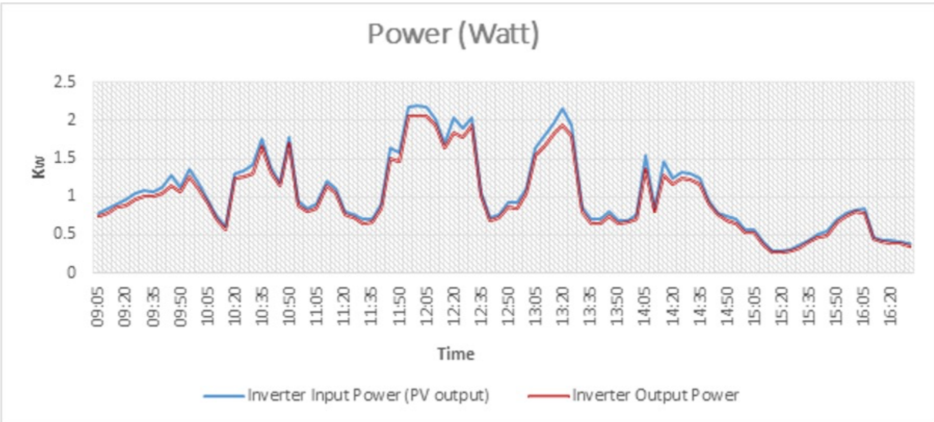

Figure 9. Power measurement on 4th August.

Meanwhile, the subsequent analyses and calculations comprised the following:

- Determination of daily mean values of inverter input and output voltage, current, and power
- Evaluation of photovoltaic (PV) module conversion efficiency and overall system efficiency
- Assessment of daily energy yield, including both PV array output and energy injected into the electrical grid
- Computation of the daily average generated power
- Quantitative analysis of the harmonic content of the inverter voltage and current

2.4. PRELIMINARY ANALYSIS OF THE PV SYSTEM PERFORMANCE

The primary energy input to the system is the solar radiation incident on the surface of the photovoltaic (PV) modules. As illustrated in Figure 1, an irradiance sensor (W/m²) is integrated into the experimental setup, given that solar irradiance constitutes the fundamental parameter governing photovoltaic energy conversion. Following the methodology detailed in the preceding section, the daily mean values reported below were computed.

1. Irradiance intensity (I_{ri}) [W/m²]
2. PV array output parameters: power (Par), current (I_{ar}), and voltage (V_{ar})
3. Inverter output parameters: current (I_{inv}), voltage (V_{inv}), power (P_{inv}), and frequency (f)

Additional calculated parameters include:

1. Total harmonic distortion (THD) for current and voltage
2. Array efficiency (η_{ar})
3. Inverter efficiency (η_{inv})
4. Daily solar radiation (Srd) [kWh]
5. Energy generated by the PV array (E_{PV}) [kWh]
6. Energy transmitted to the grid (E_{trans}) [kWh]

Calculations were then performed for two representative days—July 14 and August 4 and the results are presented in Table 2.

Table 2. Calculation Results.

No	Parameter	July 14		Aug. 4	
1	Iri [W/m^2]	752		383	
2	Par [kW]	1.908		1.06	
3	I_{ar} [A]	16.842		9.68	
4	V_{ar} [V]	113.4		110.3	
5	I_{inv} [A]	8.102		4.576	
6	V_{inv} [V]	221		220.3	
7	P_{inv} [kW]	1.781		0.991	
8	f [Hz]	50.19		50.68	
9	THD [%][1]	**THDi**	**THDv**	**THDi**	**THDv**
		12.9*	4*	10.3*	4*
		27.7**	5.3**	18.7**	5.2**
10	η_{ar} [%]	13.1		14.52	
11	η_{inv}[%]	89.89		93.46	
12	E_{irr} [kWh]	9963.077		1201.431	
13	E_{PV} [kWh]	14.30693		7.949496	
14	E_{trans} [kWh]	13.3		7.4	

[1]* Minimum value; ** Maximum value

2.5. EXPERIMENTAL RESULTS AND RESULT DISCUSSION

Two representative days were selected to demonstrate the PV grid - parity performance, namely measurements acquired on 14 July and 4 August. The monitored variables comprise global irradiance, PV array voltage and inverter input/output voltage, PV array currents and inverter current, as well as PV array power and inverter power. The kWh meter incorporated into the experimental setup registered an accumulated energy yield of 3009 kWh over a monitoring period of 215 days. This observation period can be considered sufficiently long to derive a reliable estimate of the system's average daily energy production, given that the interannual deviations of the monthly mean solar irradiation for the years 2004, 2005, and 2006 are relatively small, namely −1%, 0.83%, and 1.74%, respectively (HelioClim-3 Archive Database of Solar Irradiance v5). These low deviations are primarily attributable to the climatic characteristics of the Yemeni highland region, where the rainy season occurs during the summer months, leading to comparatively stable solar resource availability over the year.

Based on the recorded cumulative yield of 3009 kWh during 215 days, the experimentally determined average daily PV energy production is 13.995 kWh. In parallel, a theoretical estimation of the average daily energy yield was carried out, resulting in a value of Esys = 14.368 kWh (Krauter 2006; Wenham 2006). Appendix 3 presents the corresponding calculation of the annual average insolation, assuming peak sun hours (PSH) of 7.44 for the site. The discrepancy between the measured and theoretically calculated average daily energy yield is less than 2.6%. This small deviation provides strong evidence for the consistency and accuracy of both the experimental measurements and the theoretical modelling approach.

2.6. PV SYSTEM PERFORMANCE

It is worth noticing that the obtained maximum output power is around 80% of array rated peak power (P_{ar}), i.e. Par = 3120 Wp, as the actual at-site measured P_{max} = 2472.8 W. The obtained result differs from the rated because the site conditions do not satisfy the standard test conditions. The ratio of P_{max} (at site) to P_{max} (rated) = 0.7926 for a clear day (July 14). However, for August 4, P_{max} = 2198.85 W. The ratio of P_{max} (at site) to Pmax (rated) = 0.705. These results indicate that, at the site in Sana'a, Yemen, the user should anticipate a reduction of approximately 20%–30% from the selected PV peak power. The conversion efficiency at higher output power levels is lower than at reduced power levels. This behaviour is attributed to the increase in cell temperature at higher power, which in turn leads to a decrease in efficiency.

The third-harmonic distortion was also evaluated for both voltage and current in the two measurement samples. The total harmonic distortion of current (THDi) reached approximately 28% in the 14 July measurement, which is considered unacceptable. However, Ahsan (2021) has shown that harmonic distortion strongly depends on the load type, with particularly high levels associated with electronic loads such as computers, mobile phone chargers, LED luminaires, and fluorescent lamps.

It should be noted that the PV system is connected to the LIU distribution network during daytime periods, when the load profile is dominated by the aforementioned electronic appliances. This load composition explains the abnormally high level of harmonic distortion observed. To mitigate elevated harmonic levels, Ahsan (2021) proposes a straightforward mitigation approach, namely a distributed filtering scheme tailored for residential distribution networks.

Charts related to the measurements of July 14 as shown in Figure 2 indicate that this day was characterized by clear-sky conditions. The corresponding global solar irradiance profile is presented in Figure 2, which is consistent with such conditions and shows a maximum irradiance on the order of 1000 W/m².

Figure 3 shows the array voltage (DC) and output voltage of the Inverter (AC). As the array voltage has slight calibration the inverter voltage is practically constant, which reflects the high quality of the used MPPT interactive inverter. Figure 4 shows the waveform of the array current (DC) and output current of the Inverter, due to variation of irradiance the current varies. Due to the inherent existence of the energy storage elements in the PMMT controller, the inverter current goes smoother than the array current.

Figure 5 is related to the powers generated by the PV array and sent to the Grid. The sent power is less than the generated power due to losses associated with the inversion process and produced heat. The losses are bigger with higher power generation.

On the 4th of August, the weather was mostly cloudy. Therefore, the irradiance is significantly variable and its average value has less magnitude than July 14 records as shown in Figure 6. In addition, there is a big difference between the peak and trough values. However, the waveform of the array voltage (DC) and output voltage of the Inverter (AC) is very similar to July 14 records, which satisfies IV characteristic of PV cell. The array voltage has slight calibration as the inverter voltage (AC) is practically constant (see Figure 7). Figure 8 shows the waveform of the array current (DC) and output current of the Inverter, due to variation of irradiance the array current sharply varies. However, the inverter current goes much smoother than the array current, due to the inherent existence of energy storage elements in the PMMT controller. It can also be seen that the array current is lagging the irradiance in 5 minutes. Figure 9 is related to the power generated by the PV array and the power sent to the Grid of August 4th records. The sent power is close to the generated power due to lower losses associated with this case, which was cloudy, hence the generated heat is less and the losses are small with lower power generation.

3. GRID-PARITY FEASIBILITY

The concept of Grid-Parity is influenced by several factors (Kamran M. et al. 2019). In the case of Sana'a, Yemen, a significant factor promoting the feasibility is the high penetration of Solar Home Systems (SHS), having a penetration rate of 87.37% among households (Al-Ashwal 2022). This high diffusion rate enhances the country's feasibility of implementing Grid-Parity solutions because the low diffusion rate is considered a challenging factor for the Grid-Parity project implementation. Furthermore, the environmental impact promotes also the feasibility due to revenue resulted from Carbon Pricing Instruments as will be shown later.

Grid-Parity is generally deemed achievable when the cost of electricity from a Photovoltaic (PV) system equals or is less than that from the other conventional sources. The Levelized Cost of Energy (LCOE) serves as a crucial tool for quantitatively assessing Grid-Parity (Adeyemi-Kayode et al. 2023) (Kamran M. et al. 2019). The LCOE represents the lifetime cost of electricity generated by a PV system, compared against current retail electricity prices from other sources. This comparison is vital because while grid electricity prices are subject to change, the LCOE for PV remains fixed once the system is purchased, installed and commissioned.

When evaluating PV Grid-Parity viability LCOE should ideally be compared against current electricity prices and adjusted for estimated future increases in these prices.

Calculating LCOE involves two key variables:

1. All-in cost for the system (capital costs): This includes initial investment, financing costs, and subtracting any incentives received (e.g., tax credits).
2. Lifetime energy production of the solar array, which determines how much energy the system will produce over its operational lifespan.

Equation 1 is the interpretation of these points

$$LCOE = \frac{Life\ cycle\ \cos t}{Lifetime\ energy\ production} \quad (1)$$

The mathematical expression of LCOE is Equation 2

$$\sum_{t=1}^{T}\left(\frac{LCOE_t}{(1+R)^t} \times E_t\right) = I + \sum_{t=1}^{T}\frac{C_t}{(1+R)^t} \quad (2)$$

Assuming a constant value per year, LCOE can be derived by rearranging Equation 2, as follows:

$$LCOE = \frac{I+\sum_{t=1}^{T}\frac{C_t}{(1+R)^t}}{\sum_{t=1}^{T}\frac{E_t}{(1+R)^t}} \quad (3)$$

Where:
T = the average PV system lifespan
I = the initial investment
C_t = the Operation and Maintenance (Running) costs
E_t = the PV-generated electricity over the system's lifespan
r = the discount rate

To apply Equation 3 to the case using measured data the following assumptions and data are introduced:

1. The average PV system lifespan is 25 Years reduced to 22 years when taking into account the discount rate of efficiency.
2. Initial investment is US$3200.
3. Operation and Maintenance costs are assumed 1% of the investment cost per year.
4. Average produced energy per day is taken from the actual reading of the kWh meter installed within the experimental setup for 215 days where the meter showed 3009 kWh. Thus, the daily average generated energy is 13.995 kWh. Then PV-generated electricity per year will be 5,108.3 kWh, and over the system's lifespan shall be 5108.3×22 = 112.379 MWh.
5. Thus, the PV system shall produce 5.108 MWh per year.
6. Discount rate is assumed 2%.

Substituting these values in Equation 3 gives LCOE = 0.047 $/kWh

Current average electricity prices can be found on the website of the Ministry of Electricity operating in Sana'a.

a) Average private sector electricity price = US$0.486/kWh
b) Average government electricity price = US$0.428/kWh

Both prices are much higher than LCOE, confirming the feasibility of the PV system and its higher economy.

4. ENVIRONMENTAL IMPACT ASSESSMENT

The annual electrical energy generated by the photovoltaic (PV) system is 5,108 kWh. For diesel-based electricity generation, a specific fuel consumption of 3.9 kWh per liter (3.9 kWh·L^{-1}) is adopted (Al-Ashwal 2006). On this basis, the corresponding annual diesel savings are approximately 1,310 L. Meanwhile, the diesel emission factor is 2.68 kg CO_2 per liter of diesel combusted, as reported by the Intergovernmental Panel on Climate Change (IPCC, 2006). Consequently, the associated reduction in CO_2 emissions is estimated at 3,510 kg·year^{-1}. This value represents the environmental benefit attributable to the installed peak power of the experimental PV system. Expressed per unit capacity, 1 kWp of installed PV power yields a CO_2 emission reduction of approximately 1.125 t·year^{-1}. This ratio can be defined as the "CO_2 Emission Factor of Grid-Parity System Installation in Sana'a, Yemen."

By assuming that the implementation of a pilot program in Sana'a targeting coverage of 20–25% of households through Solar Home Systems (SHS). Based on the estimated installed PV peak power for Sana'a (Al-Ashwal 2022), this program could encompass more than 100,000 SHS units, with an aggregate peak capacity of up to 25 MWp. Applying the derived CO_2 Emission Factor of Grid-Parity Installation, this capacity would yield an annual CO_2 emission reduction on the order of 28,125 t·year^{-1}. This magnitude of avoided emissions indicates substantial potential for scaling Grid-Parity PV deployment via carbon finance mechanisms (Easwaran Narassimhan 2018). A recent World Bank report, "State and Trends of Carbon Pricing" (World Bank 2024), documents a marked increase in global carbon pricing, surpassing US$100 billion in 2023. This value corresponds to coverage of approximately 13 Gt CO_2-equivalent, implying an average valuation of about US$7.69 per ton of CO_2-equivalent reduced per year.

Consequently, the proposed pilot project has the potential to generate approximately USD 216,296 per annum in revenue from carbon pricing mechanisms. In addition, the World Bank report presents several examples of support provided to low-income countries to facilitate the use of internationally tradable carbon credits in the energy sector. It highlights initiatives such as the Energy Transition Accelerator and the Innovative Carbon Resource Application for Energy Transition Projects, which form part of broader strategies aimed at mobilizing large-scale climate finance and integrating carbon credit markets into sectoral transition pathways. These strategies are designed to assist developing countries in financing their low-carbon transitions.

Within this framework, the rationale for implementing a Grid-Parity pilot project in Yemen, supported by carbon pricing instruments and international assistance, is substantially reinforced. Specifically, the feasibility of achieving Grid-Parity in Yemen is underpinned by several favourable factors:

1. a high diffusion rate of solar home systems (SHS), with more than 80% already deployed in the relevant context;
2. a levelized cost of electricity generated from these systems that is significantly lower than that of conventional fossil-fuel-based generation; and
3. a high potential for additional revenue generation via carbon pricing instruments, complemented by financial and technical support from the international community.

5. CONCLUSIONS

Upon completion of this study, the following main conclusions can be drawn:

1. This paper can be regarded as a foundational contribution to the application of grid parity in Yemen, as it represents the first known study to address this subject in the country. The work confirms several well-established grid-parity phenomena, including the high total harmonic distortion (THD) of current injected into the grid by residential loads and the reduction in system efficiency at higher power transfer levels.
2. The analysis demonstrates a high technical and economic feasibility for the implementation of grid-parity photovoltaic (PV) systems in Sana'a, Yemen, with several key advantages. The levelized cost of electricity (LCOE) from the proposed PV system is significantly lower than the current retail electricity tariffs charged by both private-sector suppliers and the public utility. From an environmental perspective, the system offers substantial benefits, with potential CO_2 emission reductions exceeding 28 tons per year for an installed PV capacity of 25 MWp.
3. The study further shows that the achievable on-site PV peak power in Sana'a is approximately 70%–80% of the rated PV peak power. In addition, the research validates both experimental and theoretical

methods for estimating energy yield: the discrepancy between the two approaches is 2.6%, with the theoretical estimate being higher, which is within an acceptable range for engineering applications.
4. Moreover, this work establishes the CO_2 emission factor associated with grid-parity system installations in Sana'a, Yemen, thereby providing a reference parameter for future environmental and economic assessments. The findings also identify several promising directions for further research, including: detailed investigation of the harmonic impact of grid-parity systems, development of harmonic mitigation strategies, analysis of privately owned diesel generators operating in parallel with PV arrays, and assessment of the temperature dependence of PV efficiency under Yemeni climatic conditions.
5. Overall, this study may serve as an initial step toward the design and implementation of a grid-parity pilot project in Yemen.

APPENDIX 1

Generation System on pre-civil war (2014).

Generation [MW]	Before the Conflict [2014]		During the Conflict [2017]	
	Installed Capacity	Max. Available Capacity	Installed Capacity	Max. Available Capacity
MGPS	339	404	339	00.0
Ras. Kat. (Steam)	150	105	150	16
Mokha (Steam)	160	102.5	160	6.3
Hoswa (Steam)	185	70	185	56
Total of Steam Gen.	495	277.5	395	78.3
Total of Diesel Generation	561.7	349.2	561.7	238.9
Grand Total	1395.7	960.7	1395.7	395.5

APPENDIX 2

According to Jason Svarc (October 12, 2022) and others, the following information about the On-Grid MPPT Interactive Inverter and Controller was obtained. An on-grid MPPT (Maximum Power Point Tracking) interactive inverter and controller is a device used in solar photovoltaic (PV) systems to:

- Convert DC electricity (from solar panels) into AC electricity (for grid or household use).
- Optimize the power output from the solar panels using MPPT technology.
- Synchronize with the utility grid to export surplus power or draw power when needed.

Key Components and Functions:

1. Inverter Function - DC to AC Conversion: Converts the variable DC output from solar panels into stable AC power compatible with the utility grid. Grid Synchronization: Ensures the AC output matches grid voltage, frequency, and phase. Bidirectional Flow: Allows power to flow to and from the grid depending on load and generation.

2. MPPT Controller - Maximum Power Point Tracking: Continuously adjusts the voltage and current to ensure solar panels operate at their optimal power output. Increased Efficiency: Can improve energy harvest by 10–30% compared to traditional charge controllers.

3. Interactive Capabilities - Net Metering: Interfaces with a utility meter to track exported/imported power. Smart Grid Ready: Communicates with smart grid systems (e.g., time-of-use tariffs, demand response). Remote Monitoring: Many models offer cloud-based or app-based monitoring and analytics.

APPENDIX 3

By According to (Stefan C.W. Krauter) electrical energy generated by a PV array over an entire year is known as the system "Energy Yield"; can be calculated as follows:

$$\mathrm{Esys} = \mathrm{Parray, STC} \times \mathrm{Ftemp} \times \mathrm{Fman} \times \mathrm{Fdirt} \times \mathrm{Htilt} \times \eta\mathrm{subsystem} \times \eta\mathrm{inv}$$

Where: Esys - Energy Yields; Parray – peak power of the array; Ftemp is temperature factor; Fman is the de-rating factor for manufacturing tolerance

Htilt = daily peak Sun hours (PSH) for the selected site; ηsub-system = efficiency of sub-system (cables, connectors, etc.); ηinv = Inverter efficiency.

Esys = 14.8465 kW/m^2 when PSH is 7.44 as daily average. The yearly yield energy will be: Esys=5419 kWh per year.

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AUTHOR CONTRIBUTIONS

Ali M. Al-Ashwal: Supervised the Project, Led the analysis and writing of the paper. **Osamah Eskandar Shaalan**: Carried out literature survey, Theoretical Calculations, Taking Measurements. **Omar Omer Ahmed Obad**: studied and produced the Environmental Impact section, Taking Measurements, followed the Project progress. **Mazen Mofadl Almashwali**: performed result discussion, and finalized plotting and drawings, Taking Measurements.

COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA ACCESSIBILITY

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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