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# Comparative Study of Inverter Types Used in the Iraqi Local Market: Performance and Technical Characteristics Analysis

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**Abstract:** Inverter sets commonly used in the Iraqi market were used to install solar power systems for residential, commercial, and industrial loads. The experiment took place in Kirkuk Governorate, specifically in one of the workshops that maintain inverters used in the local solar power system market. The size and specifications of the inverters were measured, the output waveform was measured, the inverter performance was studied, and its quality was compared with its estimated costs and total waveform (THD).The rapid expansion of solar photovoltaic (PV) systems worldwide has increased the importance of power electronic converters, particularly solar inverters, which convert direct current (DC) generated by photovoltaic panels into alternating current (AC) suitable for electrical loads and grid integration. In countries experiencing unstable electricity supply, such as Iraq, solar PV systems have become an attractive solution for residential and commercial applications.

This paper offers a comparative assessment to types of commonly used inverter technologies in the Iraqi local market, off-grid, grid-tied and hybrid inverter are examined. The efficiency, total harmonic distortion (THD), voltage stability, reliability and operational flexibility are the aspects under primary consideration in performance analysis. We experimentally analyze and evaluate the technical specifications of some of the most commonly used inverter brands.

The results show that basis on stable grid, greatest energy conversion efficiency can be achieved through grid-tied inverters, while hybrid inverter enjoy the highest operational flexibility and reliability under weak/unstable grid. The results presented would give some practical suggestions to choose appropriate inverter technologies for solar PV applications in Iraq.

**Keywords:** Solar inverter, Photovoltaic systems, Hybrid inverter, signals, Power electronics, Renewable energy.

## Introduction

Since the global demand for renewable energy technologies has received a tremendous increase with emergence of environmental problems and depletion of fossil fuel. Solar photovoltaic (PV) systems are referred to as one of the most reliable renewable sources for the production of electricity. Photovoltaic (PV) technology has rapidly developed over the last two decades and this advancement can be attributed to both declining installation costs and improved effectiveness [1].

For photovoltaic systems, the inverter converts direct current from solar panels into alternating current, making it usable for electrical loads and integrating with the grid. The performance and efficiency of solar inverters significantly affect PV systems' overall performance [2].

Solar energy system applications for both residential and commercial uses have gained much momentum in countries with unsteady electrical networks like Iraq because of recurrent electricity blackouts [3]. Choosing suitable inverter technology is thus all the more important for system efficiency and reliability.

Currently, there are multiple inverters categories that exist in the local Iraqi market: String Inverter Central inverter Microinverters Hybrid inverter. Additionally, each type has its own technical specifications with respect to efficiency, and cost but also for reliability and power quality. Inverter type: generic type can be found at residential applications (low CAPEX and low design complexity - string inverters) and mess conditions (higher efficiency possibly for central big solar power plants)[22]. However, Microinverters are optimized from module-level and ultimately enhance its performance in partial shading conditions on the other hand Hybrid inverters are a combination of energy storage systems and hence, would suit perfectly to countries with unstable grid condition such as Iraq.

This highlights the importance of applying common metrics from an inverter performance viewpoint (conversion efficiency and total harmonic distortion [THD]). Moreover, efficiency presides over the inverter function to prevent energy loss in DC-AC conversion where THD quantifies output waveform quality with a large impact on electrical devices and grid stability. The THD of the waveform [23] is represented as follows, a lower THD value indicates that its power quality has been improved and harmonic interference reduced.

This study also predicts the lead via a comparison for types of inverter used in Iraq market with respect to their essential technical performance and operational characteristics requirements for different applications. This helps to establish the right inverter technology kind, both for enhancement of photovoltaic systems performances & reliability against regional environmental and electrical working scenarios, 24.

## 2. Literature Review

Solar inverters have been experimentally studied through many researches about photovoltaic system design and performance.

1. Fig: Topologies of General PV SystemsCentral, string, multi-string inverter and micro-inverter topologies (11)Architecture, cost, and performance also vary between topologies. With new semiconductor devices like insulated gate bipolar transistor (IGBT) and metal–oxide–semiconductor field-effect transistors (MOSFETs), it is possible to enhance the switching performance, resulting in less energy losses from photovoltaic (PV) systems [ 26 ].
2. Efficienciy and Performance Assess PV inverter efficiency from 94% to 99% typically topology — operate conditions (refer recent studies) On the other hand, Central inverters are used in large scale applications [27] whereas string inverters provide much higher benefit because of high cost factor associated with efficiency which proves favourable for residential systems.
3. Total Harmonic Distortion (THD) and Power Quality — Inverters – Total harmonic distortion (THD) is one of the most important parameters to assess inverter output quality. KG, including that PWM and multilevel inverter structures, representing two essential advanced control methods for the use of renewable energy resources (RESs), results in a broad decrease of overall harmonics distortion (THD) grades through improved grid stability and power quality [28].
4. Hybrid inverter and the Energy Storage System In a recent study, it has been found that hybrid inverters including battery storage with PV systems are one of the key components of AEPS. Such systems are very effective in regions with weak or unstable grids such as Iraq where continuous power supply is still a challenge29.

5. Typical inverters types found in literature reviewCentral Invertero Ripe: Offer efficiency across wide variety of utility scale pv plantsString invertero Most common inverter ( practitioners approach Microinverter30o The best performing technology under partially shaded conditionsHybrid inverterso the 'weakest' grid and back-up applicationsgeneral page0 20Structural nodalong19More general content31
6. According to IEEE Transactions on Power Electronics, inverter topology and control strategy plays a significant role in determining influential of system efficiency and power quality [3].
7. Another paper published in Energy Conversion and Management verified that core reliability difficulties for photovoltaic inverters have specified to the switching gadgets operation, thermal management, or perhaps control strategies [4].
8. Also, there have been plenty of research over transformer less inverter topologies as they reach high efficiency at relatively low price in contrast to conventional transformer based inverters [5].

## 3. Types of Solar Inverters

In general, solar inverters are classified into three main types: off-grid inverters, grid-tied inverters and hybrid inverters [10]

Off-Grid Inverters

Off-grid inverters work independently of the electrical grid and use battery storage systems to provide power when there is no solar generation. Such systems are often used in rural areas where electric grid power is not available [3].

Advantages

- Independent operation
- Suitable for remote locations
- Reliable backup power

Disadvantages

- Higher installation cost
- Reduced efficiency due to battery charging and discharging losses

Grid-Tied Inverters

Grid-tied inverters are synchronized to the AC mains, and they inject solar electricity directly into the utility grid. These inverters are very efficient and have a relatively low cost that has been implemented into many residential and commercial photovoltaics (PV) systems [2]. Grid Connected Inverters interact with the grid, such that they feed solar energy directly into utility systems.[11]

Advantages

- High efficiency
- Lower installation cost
- Simple system configuration
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Disadvantages

- System shutdown during grid outages due to anti-islanding protection.

Hybrid Inverters

Hybrid inverters, which have the functions of grid-connected and off-grid systems so that energy from solar panels can flow both to batteries as well as to appliances (if any) & power grids. In addition, this configuration also grants more flexibility to energy management functions[6].

Hybrid inverters are a kind of inverter that combines grid-connected and off-grid features all under one machine, which allows them to connect with solar panels, batteries and the electrical grid at the same time. [17].

Advantages

- Energy storage capability
- Flexible energy management
- Suitable for unstable grid environments

Disadvantages

- Higher system cost
- More complex control architecture

## 4. Performance Evaluation Parameters

The performance of solar inverters is typically evaluated using several technical indicators including efficiency, total harmonic distortion (THD), and voltage stability [9] [15].

Inverter Efficiency

Inverter efficiency is defined as the ratio between AC output power and DC input power

High efficiency is essential to maximize the energy production of photovoltaic systems [5].

Total Harmonic Distortion

Total harmonic distortion represents the level of harmonic distortion present in the inverter output waveform. High THD values can negatively affect power quality and electrical equipment performance [6].

## 5. Mathematical Modeling

### 5.1 Inverter Efficiency

The efficiency of a solar inverter can be defined as:[15] ,[20]

$$\eta=\frac{P_{AC}}{P_{DC}} X100$$

Where:

- $P_{AC}$ = AC output power
- $P_{DC}$ = DC input power
- $\eta$ = inverter efficiency

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### 5.2 Total Harmonic Distortion

Total harmonic distortion is calculated as:[14]

indicators: efficiency and total harmonic distortion (THD). The inverter efficiency is defined as the ratio between the AC output power and the DC input power supplied by the photovoltaic array. It can be expressed as $\eta$ = PAC / PDC. Another important parameter is the total harmonic distortion (THD), which measures the deviation of the inverter output waveform from a pure sinusoidal signal. Lower THD values indicate better power quality and improved system performance[21]

$$THD(\%)=\frac{\sqrt{V_2^2+V_3^2+V_4^2+\cdots+V_n^2}}{V_1} X\ 100$$

Lower THD values indicate better power quality and improved inverter performance.

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## 6. Experimental Methodology

The experimental evaluation consists of the following steps:[12]

1. Choice of most prominent inverter models within Iraqi market
2. Load test of inverter measurement
3. Tracking output voltage frequency and harmonic distortion
4. Comparison of Efficiency and Operational Characteristics.

The experiments can be conducted using:

- Power analyzer
- Oscilloscope
- DC power supply
- PV simulator

## 7. Comparative Analysis of Inverter Brands

The study evaluates several inverter manufacturers widely available in the Iraqi market[8]:

- **NM-ECO**
- MPS PLUS 5KVA-80
- VMII TWIN 6 K
- **TECO**(TTN)

| **Parameter** | **Off-Grid** | **Grid-Tied** | **Hybrid** |
|---|---|---|---|
| **Efficiency** | 88–92% | 95–98% | 94–97% |
| **Battery Support** | Yes | No | Yes |
| **THD** | Moderate | Low | Low |
| **Cost** | Medium | Low | High |
| **Flexibility** | Medium | Low | High |

**Table (1) comparison between types of inverters**

## 8.Results and Discussion

The output voltage waveform and operational data outcome from several inverter models (vm) have been consulted experimental measurements for some most commonly types of traditional inverter in the Iraqi local market (i.e. : NM-ECO, MPS PLUS & VMIII TWIN and TECO inverters). Analysis using an oscilloscope confirmed that all inverters tested generated a sinusoidal AC output waveform as required to power residential electrical loads.

However, some noted discrepancies regarding waveform quality, voltage stability and distortion factor [12]. Some of these models showed lower distortion value which indicates good power quality, smoother sinusoidal waveform and high operational stability under loaded conditions [16].

Comparing metering results also shows converted efficiencies through different inverter types. Conversion losses energy is transform servos — cause your battery charging units does not occurs grid-connected linked inverters and the efficiency was by far high. On the contrary, even though in-system hybrid efficiency was lower, these systems provide greater operation flexibility with installation of PV panels and battery storage as well fully connected to grid based systems all together.[17]

More experimental results are presented to confirm about inverter topology and control strategy being greatly influencing the output signal quality and performance of system. The circuit equivalents reaction have significantly improved Total Harmonic distortion (THD) and output voltage stability characteristics18 when advanced control circuits, and more appropriate switching schemes were implemented [2].

As a result the comparative analysis indicates that in general on grid connected inverters have low efficiency because they are directly connected to electrical grid. On the other hand, hybrid inverters are much better at providing operational flexibility and reliability if grid power is unstable. Hybrid systems which combine photovoltaic panels, battery storage and grid connection [ 7 ] have also been quarter from previous literature to improve both energy management and performance reliability of the system.


Fig (2) output signal and data of NM-ECO 6.2kw  PLUS inverter

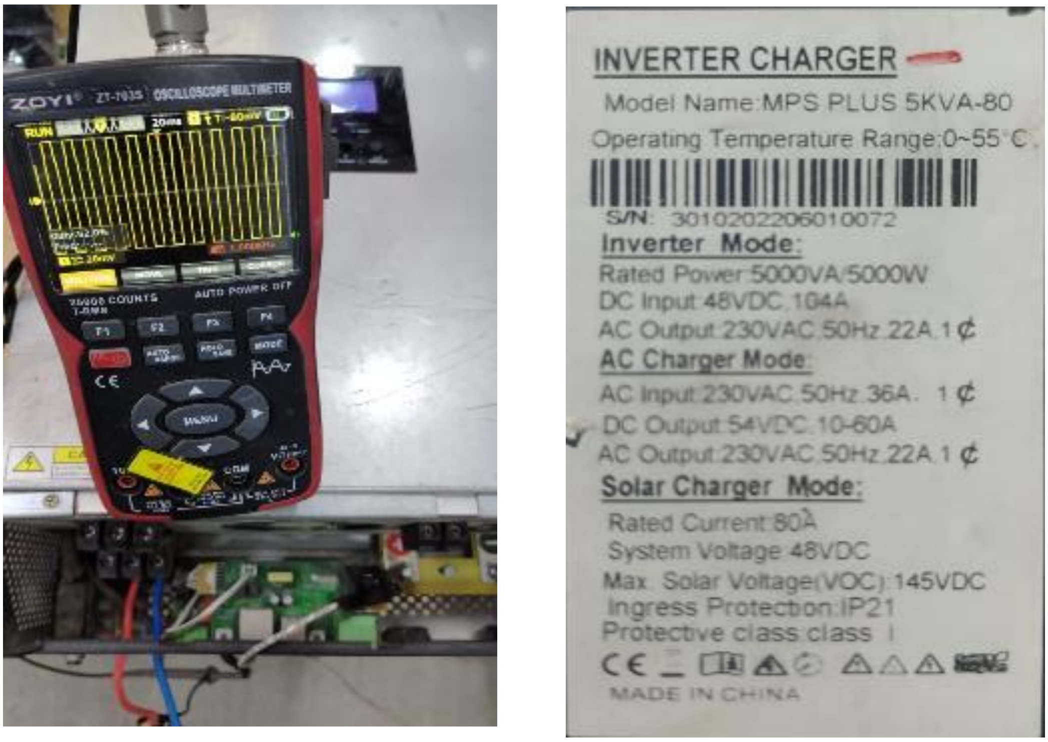


Fig (2) output signal and data of MPS PLUS 5KVA-80 inverter


Fig (3) output signal and data VMIII TWIN 6kw inverter


Fig (4) output signal and data of TECO(TTN) 6.2kw inverter

**9. Conclusion**

Provided comparative analysis of inverter technology This study provided

technologies The solar energy market in Iraq The performance results indicate that between stable ramped grids, the grid connected inverter was a superior pick; and hybrid inverters offered improved operational flexibility at unstable power provision regions.

Further researches need to focus on the performance and reliability enhancement of inverter by implementing intelligent control methods including ANN networks.

1. These finding indicate that more study in the hybrid inverter Type of Inverters used was having a minimal commonness in the Iraqi nearby market due to their prospects of operative with photovoltaic panels, battery storage systems and utility grid simultaneously. This feature is useful especially in places where power outage happens often.
2. Based on the analysis performed by the study, it has been shown that transformerless inverter topologies have relatively better efficiency and less power losses than traditional transformers based inverters.
3. All in all, the THD analysis for a true sine wave output from the inverter would be more subtle even below 3% so to compute it, vulnerable auto loads like computers may run with no risk.
4. That is also have been promoted known to find in modern in no of electives but as new status have upgrade that there are various technical supervisions can be came from Iraq like:

- Maximum Power Point Tracking (MPPT) technology
    - Over-voltage and over-current protection
    - Intelligent monitoring and communication systems.
5. The study confirms that selecting an appropriate inverter depends on several important factors, including:
    - Photovoltaic system capacity
    - Battery type and storage capacity
    - Nature of electrical loads
    - Stability of the local electrical grid.
6. Great, efficient inverters at interleaving are able to extremely reduce WHD (overall harmonic distortion) which can increase the performance of photovoltaic systems and improve energy loss and system reliability.
7. As a conclusion, and in view of the above argument it recommend (1) to use an establish framework for adoption of technical standards and evaluation criteria in Iraqi market so as to deliver quality inverter selection, but also leading to require efficiency, reliability and prolonged performance.
8. The inverter model can provide stable characteristics of an AC output signal (grid quality) in the local Iraqi market for PV systems, and domestic energy systems.
9. Grid-tied inverters showed the best efficiency regarding conversion, as it was being connected directly with electric grid-work and avoided the need of battery store.
10. On the other hand, regarding this, hybrid inverters on high operational flexibilities and highly reliable choice according to the Iraqi power environment when compared with a large part of Iraq that still using an unreliable grid energy.
11. By oscilloscope, accurate of the waveform measured. Output signals are characters of sinusoidal with little harmonic distortion.
12. We use this systematic study to characterize how the inverter topology and control strategies affect conversion performance in the case of photovoltaic power systems.
13. Lower THD improves power quality and minimizes voltage spikes which could damage sensitive electrical equipment.
14. The choice of inverter will depend on a number of factors such as system size, battery specifications (such as voltage), load characteristics and conditions under which grid is stable.

The outcomes recommend that high-proficient inverters with an accomplished control framework need to be had to be carried out for solar photovoltaic structures in iraq (particularly within the house or pool) fittings, since devoid of those tools, sun photovoltaic installation has not often been installed as correct structure.

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