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Optimal Technology Selection Between String and Central Inverters for a 100 MW Solar PV Plant in Tehran Province Using AHP, TOPSIS, and VIKOR Methods

Mohammad-Reza Nickpay [1*], Karim Goudarzikia [1] and Roohallah Amirabadifarahani [1]

Abstract**-- This study focuses on the critical decision of selecting an optimal inverter technology for a 100 MW solar photovoltaic plant in Tehran province, Iran. Recognizing the complexity of this task, which involves multiple conflicting technical, economic, and qualitative criteria, the paper employs three well-established multi-criteria decision-making (MCDM) methods: The Analytical Hierarchy Process (AHP), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method. Two specific inverter models from Sungrow, the SG350HX string inverter and the SG8800UD-MV-20 central inverter, are evaluated against a comprehensive set of criteria, including efficiency, total cost of ownership, reliability, warranty, grid support features, compatibility, protection features, environmental condition tolerance, smart features, and brand reputation. The AHP method is utilized to determine the weights of these criteria. Subsequently, TOPSIS and VIKOR are applied to rank the inverter alternatives based on hypothetical performance data. The results from both TOPSIS and VIKOR analyses, under the assumed scenario, indicated a preference for the Sungrow SG8800UD-MV-20 central inverter. The study also emphasizes the importance of conducting thorough sensitivity analyses for AHP criteria weights, TOPSIS performance values, and the VIKOR compromise strategy parameter to ensure the robustness of the decision. Environmental conditions and grid connection requirements specific to Tehran province are also considered as vital factors in the selection process. The paper concludes by recommending further investigation of the central inverter, contingent on detailed real-world data and expert judgments, and suggests future research avenues, including the incorporation of more extensive data and additional MCDM techniques.**

Index Terms**- MCDM, AHP, TOPSIS, VIKOR, Inverter, String, and Central**

I. Introduction

The global pursuit of sustainable energy sources has positioned solar PV[2] as a pivotal technology in reducing energy sector emissions and diversifying electricity generation portfolios. Its maturity and the potential for rapid deployment have made solar PV a cornerstone of many national renewable energy strategies. Utility-scale solar PV plants, generally defined as those with an installed capacity of 5 MW or more, offer the most significant potential for harnessing solar energy. The deployment of such large-scale projects is particularly relevant in regions with high solar irradiance, such as Iran. While Iran possesses substantial potential for utilizing renewable energy, with ambitious targets set for capacity increase, the actual deployment has faced various challenges. In Tehran, the capital city, severe air pollution resulting from a heavy reliance on fossil fuels underscores the urgent need for transitioning to cleaner energy sources, such as solar power. The Iranian government has recognized this potential and has issued permits for a considerable capacity of solar power plants, indicating a growing interest in this sector [1].

A critical component in any grid-connected solar PV system is the inverter, which performs the essential function of converting the direct current (DC) generated by the solar

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* Corresponding author Email: mr-nickpay@trec.co.ir

[1]. Tehran Regional Electric Company, Tehran, Iran

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panels into alternating current (AC) suitable for the electricity grid. The correct selection of inverters is paramount, as it can significantly impact the TCO[3] and the overall performance of the PV plant. This criterion evaluates the TCO over the project's lifetime, moving beyond mere initial purchase price. It encompasses initial capital costs, installation and balance-of-system expenses (e.g., DC/AC cabling, structures), operation and maintenance costs, potential replacement costs, and energy losses. This comprehensive approach can reveal, for instance, how a string inverter with a higher unit price might prove more economical due to reduced cabling costs and modular maintenance.

Beyond energy conversion, inverters also play a vital role in system monitoring, thereby contributing to the optimization of plant operation. Furthermore, with the increasing penetration of distributed energy resources, the adoption of smart inverters is becoming crucial for ensuring grid safety and stability.

However, the process of selecting the optimal inverter for a large-scale solar PV plant is a complex undertaking, involving the consideration of multiple conflicting criteria that can be both qualitative and quantitative in nature [2], [3]. Various inverter topologies are available, including string inverters, central inverters, and micro-inverters, each with its own set of advantages and disadvantages depending on the scale and specific requirements of the PV system. Decision-makers must carefully evaluate factors such as efficiency, TCO, reliability, warranty, grid support capabilities, and environmental compatibility. This multi-faceted decision problem necessitates a systematic approach to navigate the inherent complexities and trade-offs [4].

MCDM[4] techniques have emerged as powerful tools for addressing such complex problems involving multiple competing criteria in diverse fields, including energy systems. These methods are capable of handling both quantitative and qualitative criteria and can effectively analyze conflicts among them. Among the various MCDM techniques, the AHP[5], the TOPSIS[6], and the VIKOR[7] method are well-established and widely used in renewable energy decision-making processes. The increasing adoption of hybrid MCDM approaches further highlights the benefits of combining the strengths of different methods to achieve more robust and reliable decision outcomes [5-7].

This study aims to apply the AHP, TOPSIS, and VIKOR methods to the problem of selecting the optimal inverter technology for a 100 MW solar PV plant located in Tehran province, Iran. Specifically, we will consider two inverter models from Sungrow, a leading manufacturer in the solar industry: the SG350HX string inverter and the SG8800UD-MV-20 central inverter. This article provides detailed mathematical calculations and comments for each of the three MCDM methods, and also conducts comprehensive sensitivity analyses for the parameters within AHP, TOPSIS, and VIKOR. Furthermore, the environmental conditions and grid connection requirements specific to Tehran province will be taken into consideration to ensure a contextually relevant and practically applicable analysis.

II. Literature Review

A. Types of Solar Inverters in Utility-Scale PV Plants

In utility-scale solar PV plants, two primary types of inverters are predominantly employed: string inverters and central inverters. String inverters are typically utilized in small to medium-scale PV systems due to their relatively low effort per watt and moderately high productivity. These inverters offer more granular control over Maximum Power Point (MPP) monitoring at the string level, which can be advantageous in installations with varying panel orientations or shading conditions. The Sungrow SG350HX is an example of a high-yield string inverter designed for large commercial and industrial systems, boasting features such as multiple MPPTs (up to 16 in some versions) for optimized energy production under diverse sunlight conditions, as well as intelligent operation and maintenance (O&M) capabilities [8].

Central inverters, on the other hand, are one of the most effective solutions for large-scale utility applications. They are designed to handle the output of a large number of solar panels connected in arrays and can support more series connections compared to string inverters. While central inverters generally require less part allocation, they may lack individual MPP tracking for each module, potentially making them more susceptible to shading or module mismatch effects. The Sungrow SG8800UD-MV-20 is a medium-voltage (MV) grid-connected central inverter specifically designed for 1500V DC systems, offering a high maximum efficiency of up to 99% and an integrated MV transformer [9]. This model emphasizes smart O&M features and aims to reduce overall investment through its modular design and containerized solution, which can lower transportation and installation costs. The choice between string and central inverters for a utility-scale plant often depends on factors such as the overall plant size, layout, shading conditions, and the desired level of redundancy and monitoring granularity.

B. Application of AHP, TOPSIS, and VIKOR in Renewable Energy and Inverter Technology Selection

The AHP is a widely recommended evaluation method for both assessing criteria and ranking alternatives in energy-related problems [5]. Its hierarchical structure allows for a systematic decomposition of complex decisions, making it particularly useful in solar PV farm site selection and other renewable energy planning applications [7]. Researchers frequently employ AHP for criteria weighting due to its ability to incorporate expert judgments through pairwise comparisons.

The TOPSIS is another prominent MCDM method used for solving energy problems. It evaluates alternatives by measuring their proximity to an ideal solution and their distance from a negative-ideal solution, aiming to identify the option that is closest to the best and furthest from the worst.

[3] Total Cost of Ownership
[4] Multi-criteria decision-making
[5] Analytical Hierarchy Process
[6] Technique for Order Preference by Similarity to Ideal Solution
[7] VIseKriterijumska Optimizacija I Kompromisno Resenje

TOPSIS has been successfully applied in various renewable energy contexts, including solar panel selection and the optimization of PV systems [6], [7].

The VIKOR method offers a decision-making approach that seeks a compromise solution by balancing the maximization of group utility with the minimization of individual regret among alternatives. It is particularly suitable when decision-makers need to strike a balance between overall group performance and the regret associated with poorly performing criteria. VIKOR has been utilized in the selection of solar panels and the optimization of standalone PV systems, providing a different perspective on ranking compared to TOPSIS [6].

Hybrid approaches that combine the strengths of these methods are also gaining traction. For instance, the integration of AHP and TOPSIS has been used for optimal inverter technology selection in solar PV and wind turbine systems, leveraging AHP for criteria weighting and TOPSIS for ranking [10]. Similarly, the AHP-VIKOR combination has been applied to optimize the design of standalone solar PV systems, using AHP to determine criteria weights and VIKOR to rank the system configurations [11]. Comprehensive reviews of MCDM applications in renewable energy highlight the increasing adoption of these techniques for a wide range of decision-making tasks, including site selection for solar and wind projects, technology evaluation, and the formulation of energy policies [12].

C. Key Criteria for Solar Inverter Technology Selection

The selection of the most suitable solar inverter for a PV plant involves a multitude of criteria that span technical, economic, reliability, and grid-related aspects [13-15]. Efficiency is a paramount consideration, as it directly impacts the amount of energy delivered by the PV system and the overall power consumption. TCO, encompassing both the initial purchase price and the long-term operational and maintenance expenses, is another critical factor influencing the economic viability of the project. Reliability and lifespan are essential for ensuring the long-term performance and return on investment of the solar plant. The duration and terms of the warranty offered by the manufacturer can provide crucial assurance and mitigate potential risks [16].

With the increasing focus on grid stability and the integration of renewable energy sources, grid support features and compliance with relevant grid codes have become increasingly important [17]. Inverters are required to support the grid by providing reactive power control and adhering to specific technical regulations. Compatibility with the solar panel system, particularly in terms of voltage and power ratings, is a fundamental requirement for proper system operation. Comprehensive protection features, such as overload and short-circuit protection, as well as DC and AC insulation monitoring, are vital for ensuring the operational safety of the PV plant.

Environmental conditions at the installation site, including temperature variations, humidity levels, and altitude, can significantly affect the performance and longevity of solar inverters. In regions like Tehran, which experience a wide range of temperatures and are prone to dust, the inverter's tolerance to these conditions is a key consideration. The presence of smart features, such as remote monitoring capabilities, advanced communication protocols, and fault detection mechanisms, can enhance the management, maintenance, and safety of the PV system. Finally, the brand reputation of the inverter manufacturer and the level of customer support provided can also be important qualitative criteria in the selection process. A holistic evaluation of these criteria, with appropriate weights assigned based on project priorities, is essential for making an informed decision on the optimal inverter for the solar PV plant. Key inverter selection criteria are presented in Table I.

TABLE I.
Key Inverter Selection Criteria

Criterion	Description	Type
Efficiency (C1)	Max. conversion efficiency (%)	Benefit
TCO (C2)	Initial investment and long-term operational (USD/kW)	Cost
Reliability (C3)	MTBF, failure rates (scale: 1–5)	Benefit
Warranty (C4)	Duration (years)	Benefit
Grid Support (C5)	LVRT/HVRT, reactive power control (scale: 1–5)	Benefit
Compatibility (C6)	Suitability for 100 MW plants (scale: 1–5)	Benefit
Protection (C7)	Overload/short-circuit protection (scale: 1–5)	Benefit
Environment (C8)	Tolerance to Tehran’s dust/temperature (scale: 1–5)	Benefit
Smart Features (C9)	Remote monitoring, AI diagnostics (scale: 1–5)	Benefit
Brand Reputation (C10)	Manufacturer credibility (scale: 1–5)	Benefit

D. Inverter Models and Technical Specifications

Two inverter models manufactured by Sungrow Power Supply Co., Ltd. are considered in this study, both of which are commercially available and commonly applied in large-scale photovoltaic systems. The purpose of including these models is to provide a realistic comparison between string and central inverter architectures for a 100 MW PV plant.

The Sungrow SG350HX is a grid-tied string inverter with a rated AC output power of 350 kW, operating in three-phase mode and equipped with multiple MPPTs (typically 12). This inverter boasts a high maximum efficiency of 99.02% and a European efficiency of 98.8%, ensuring optimal energy yield. It is designed with proven safety features, including overload and short-circuit protection, and incorporates smart cooling technology for reliable operation in various environmental conditions, with an operating temperature range of -30℃ to +60℃. The SG350HX also supports communication with Battery Management Systems (BMS) via RS485 and PLC, and its IP66 protection class makes it suitable for outdoor installations. Sungrow highlights the high yield and low costs associated with this series, including features such as Q at night function for reactive power support and smart IV curve diagnosis for active O&M [8].

The Sungrow SG8800UD-MV-20 is a MV grid-connected PV inverter designed for 1500V DC systems, offering a maximum inverter output of 8800 kVA with a high efficiency of up to 99%. This central inverter integrates a medium-voltage transformer and switchgear, contributing to a low system cost and reduced footprint. It features smart O&M capabilities, including integrated zone monitoring and MV parameters monitoring for online analysis and troubleshooting, as well as a modular design for easy maintenance. The SG8800UD-MV-20 is also designed for grid support, complying with various international standards and offering low/high voltage ride-through (L/HVRT) and active & reactive power control. Its container design helps to lower transportation and installation costs, making it a competitive option for utility-scale projects. The inverter has a wide operating ambient temperature range of -35 to 60 ℃ (with derating above 51 ℃) and an IP65 protection rating for the inverter unit [9].

The selection of these two inverters — one string and one central — enables a representative evaluation of different inverter configurations for large-scale PV power plants under Tehran's environmental and grid conditions.

III. Theoretical Modeling Methodology

A. Analytical Hierarchy Process (AHP)

AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology [18]. It breaks down a decision problem into a hierarchy of criteria and alternatives, allowing for the evaluation of their relative importance through pairwise comparisons. The steps involved in AHP are as follows:

Hierarchy Construction: The decision problem is structured as a hierarchy with the overall goal at the top, followed by the criteria and sub-criteria at intermediate levels, and the alternatives at the bottom level [18]. In this study, the goal is to select the optimal solar inverter technology. The second level includes the identified selection criteria (e.g., efficiency, TCO, reliability), and the third level comprises the two inverter alternatives: Sungrow SG350HX and Sungrow SG8800UD-MV-20.

Pairwise Comparison Matrices: At each level of the hierarchy, decision-makers (or experts) perform pairwise comparisons of the elements based on their relative importance or preference using Saaty's fundamental scale, which ranges from 1 (equal importance/preference) to 9 (extreme importance/preference) [18]. This results in the formation of several pairwise comparison matrices: one for the criteria and a set of matrices for the alternatives with respect to each criterion. If n elements are being compared, the pairwise comparison matrix A is an $n\times n$ matrix where a_{ij} represents the relative importance of element i over element j. It follows that $a_{ii}=1$ and $a_{ji}=1/a_{ij}$.

$$a_{ij}^{norm} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (1)$$

Experts compare criteria using Saaty's scale (1 = equal importance, 9 = extreme importance). For example:

$$A = \begin{bmatrix} 1 & 3 & 2 & \cdots & 4 \\ 1/3 & 1 & 1/2 & \cdots & 2 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1/4 & 1/2 & 1/3 & \cdots & 1 \end{bmatrix}$$

Normalization and Eigenvector Calculation: Each pairwise comparison matrix is normalized by dividing each element in a column by the sum of that column. The priority vector (weights) for the criteria and the local priority vectors for the alternatives with respect to each criterion are then derived by calculating the average of the normalized values in each row. This priority vector approximates the principal eigenvector of the comparison matrix and represents the relative weights of the elements being compared [17]. For a normalized matrix A_{norm} , the weight w_i of element i is given by (2):

$$w_i = \frac{1}{n}\sum_{j=1}^{n} a_{ij}^{norm} \qquad (2)$$

Consistency Ratio Calculation: To ensure the reliability of the AHP results, the consistency of the pairwise comparisons is evaluated by calculating the *CR*[8]. First, the *CI*[9] is calculated using the (3):

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (3)$$

where λ_{max} is the largest eigenvalue of the pairwise comparison matrix, which can be approximated by calculating the consistency vector (product of the comparison matrix and the priority vector) and then averaging its elements. n is the number of elements being compared. The *CR* is then obtained by dividing the *CI* by the *RI*[10], which is the average *CI* of randomly generated matrices of the same size.

$$CR = \frac{CI}{RI} \qquad (4)$$

The value of *RI* depends on n (e.g., for $n=10$, $RI \approx 1.49$; for $n=2$, $RI = 0$; for $n=3$, $RI \approx 0.52$). A *CR* of less than *0.1* is generally considered acceptable, indicating a reasonable level of consistency in the decision-maker's judgments [18].

B. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is a multi-criteria decision analysis method that ranks alternatives based on their distance from the ideal solution (the best possible solution) and the negative-ideal solution (the worst possible solution) [19]. The steps involved in TOPSIS are as follows:

Decision Matrix Formulation: A decision matrix D is constructed, where each row represents an alternative (inverter) and each column represents a criterion. The entry D_{ij} is the performance value of alternative i with respect to criterion j [19]. If there are m alternatives and n criteria, the decision matrix is an $m\times n$ matrix.

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[8] Consistency Ratio
[9] Consistency Index
[10] Random Index

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \end{bmatrix}$$

Normalization of the Decision Matrix: The decision matrix is normalized to bring all criterion values to a common scale. Vector normalization is commonly used, where each value D_{ij} is normalized to r_{ij} using the (5):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (5)$$

Weighted Normalized Decision Matrix: The normalized decision matrix is then weighted by multiplying each column by the weight w_j of the corresponding criterion (obtained from AHP or another weighting method). The weighted normalized value v_{ij} is calculated as (6):

$$v_{ij} = w_j \times r_{ij} \quad (6)$$

Determination of Ideal and Negative-Ideal Solutions: The ideal solution A^+ and the negative-ideal solution A^- are identified. The ideal solution consists of the best values for each criterion, and the negative-ideal solution consists of the worst values. For benefit criteria (higher is better), the ideal value is the maximum, and the negative-ideal value is the minimum. For TCO criteria (lower is better), the ideal value is the minimum, and the negative-ideal value is the maximum [18].

A^+: $Max\ v_{ij}$ for benefit criteria , $Min\ v_{ij}$ For cost criteria

A^-: $Min\ v_{ij}$ for benefit criteria , $Max\ v_{ij}$ For cost criteria

Calculation of Euclidean Distances: The Euclidean distance of each alternative i from the ideal solution S_i^+ and the negative-ideal solution S_i^- is calculated using the (7) and (8):

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2} \quad (7)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \quad (8)$$

Calculation of Closeness Coefficient and Ranking: The closeness coefficient C_i for each alternative i is calculated as (9):

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (9)$$

The value of C_i ranges from 0 to 1. An alternative with a C_i closer to 1 is preferred. The alternatives are ranked in descending order based on their C_i values [18].

C. VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) Method

The VIKOR method is a compromise ranking method that determines a compromise solution by considering the closeness to the ideal and the minimum regret [18]. The steps involved in the VIKOR method are as follows:

Normalization of the Decision Matrix: Similar to TOPSIS, the decision matrix is normalized using linear normalization.

For benefit criteria: $f_j^* = max_i\, x_{ij}$, $f_j^- = min_i\, x_{ij}$

For cost criteria: $f_j^* = min_i\, x_{ij}$, $f_j^- = max_i\, x_{ij}$

Where $f_j^*$is the best value and $f_j^-$is the worst value for criterion j across all alternatives [18].

Determination of Best and Worst Values: For each criterion j, the best $f_j^*$and worst f_j^- performance values across all alternatives are identified. For benefit criteria, $f_j^* = max_i\, f_{ij}$ and $f_j^- = min_i\, f_{ij}$. For cost criteria$f_j^* = min_i\, f_{ij}$ and $f_j^- = max_i\, f_{ij}$.

Calculation of Utility and Regret Measures: For each alternative i, the utility measure S_i and the regret measure R_i are calculated using the (10) and (11):

$$S_i = \sum_{j=1}^{n} w_j r_{ij} \quad (10)$$

$$R_i = max_j(w_j r_{ij}) \quad (11)$$

where w_j is the weight of criterion j obtained from AHP. S_i represents the average weighted deviation of alternative i from the ideal, and R_i represents the maximum weighted deviation [18].

Calculation of VIKOR Index: The VIKOR index Q_i for each alternative i is calculated using the (12):

$$Q_i = v\frac{S_i - S^*}{S^- - S^*} + (1 - v)\frac{R_i - R^*}{R^- - R^*} \quad (12)$$

where $S^* = min_i\, S_i$, $S^- = max_i\, S_i$, $R^* = min_i\, R_i$, $R^- = max_i\, R_i$, and v is a weight for the strategy of "the majority of criteria" (typically set to 0.5, but can range from 0 to 1) [18].

Ranking of Alternatives: The alternatives are ranked based on the Q_i values in ascending order. The alternative with the lowest Q_i value is considered the best compromise solution. A compromise solution is acceptable if two conditions are met: (1) $Q(1) - Q(2) \geq 1/(m-1)$, where (1) is the alternative ranked first and (2) is ranked second by Q, and m is the number of alternatives; (2) the alternative ranked first by Q is also ranked first by S or R. If one of these conditions is not met, then a set of compromise solutions is proposed [18].

IV. Case Study: Optimal Inverter technology Selection for a 100 MW Solar PV Plant in Tehran Province

The case study focuses on selecting the optimal inverter technology for a 100 MW utility-scale solar PV plant planned for Tehran province, Iran. This plant size indicates the potential suitability of both distributed (string inverter-based) and centralized inverter architectures.

Based on the literature review and considering the specific requirements of a large, grid-connected solar plant, the following criteria are identified for the inverter technology selection process:

C1: Efficiency: Maximum efficiency of the inverter (%).

C2: TCO: Price per kW of inverter capacity (USD/kW).

C3: Reliability: A qualitative assessment based on factors like Mean Time Between Failures (MTBF) or expert opinions (ranked on a scale of 1 to 5, where 5 is highest).

C4: Warranty: Duration of the manufacturer's warranty (years).

C5: Grid Support Features: A qualitative assessment of compliance with grid codes, reactive power control capabilities, and low/high voltage ride-through (LVRT/HVRT) capabilities (ranked on a scale of 1 to 5, where 5 is highest).

C6: Compatibility: A qualitative assessment of suitability for a 100 MW plant, voltage and current matching with typical PV modules used in such plants (ranked on a scale of 1 to 5, where 5 is highest).

C7: Protection Features: A qualitative assessment of the comprehensiveness of protection mechanisms, including anti-islanding, overcurrent, overvoltage, etc. (ranked on a scale of 1 to 5, where 5 is highest).

C8: Environmental Conditions: A qualitative assessment of the inverter's tolerance to Tehran's typical temperature variations and dust levels (ranked on a scale of 1 to 5, where 5 is highest).

C9: Smart Features: A qualitative assessment of the availability of remote monitoring, communication protocols (e.g., Modbus, SunSpec), and smart grid functionalities (ranked on a scale of 1 to 5, where 5 is highest).

C10: Brand Reputation: A qualitative assessment of the manufacturer's market standing, customer reviews, and after-sales support (ranked on a scale of 1 to 5, where 5 is highest).

The two alternatives under consideration are:

A1: Sungrow SG350HX: A 350 KW string inverter. Approximately 286 units would be needed for a 100 MW plant.

A2: Sungrow SG8800UD-MV-20: An 8800 kVA (8.8 MW) central inverter. Approximately 12 units would be needed for a 100 MW plant.

V. Economic Analysis Results and Discussion

A. AHP Analysis

To illustrate the AHP method, we will assume a hypothetical pairwise comparison matrix for the criteria based on expert judgments relevant to a utility-scale solar plant in Tehran. The resulting normalized weights are presented in Table II.

TABLE II
Criteria Weights Derived from AHP

Criterion	Weight
Efficiency (C1)	0.220
TCO (C2)	0.180
Reliability (C3)	0.150
Warranty (C4)	0.090
Grid Support Features (C5)	0.100
Compatibility (C6)	0.080
Protection Features (C7)	0.060
Environmental Conditions (C8)	0.040
Smart Features (C9)	0.030
Brand Reputation (C10)	0.050

In this example, efficiency and TCO are identified as the most important criteria, followed by reliability and grid support features. The consistency ratio (CR) for this hypothetical comparison matrix is assumed to be less than 0.1, indicating acceptable consistency.

B. TOPSIS Analysis

Next, a hypothetical decision matrix is formulated based on the performance values of the two inverters against the identified criteria. These values are based on datasheets and general knowledge of string and central inverters. The decision matrix is presented in Table III.

TABLE III
Decision Matrix

Criterion	SG350HX (A1)	SG8800UD-MV-20 (A2)	Benefit/Cost
Efficiency (%) (C1)	99.02	99.00	Benefit
TCO (USD/kW) (C2)	0.030	0.025	Cost
Reliability (1-5) (C3)	4	5	Benefit
Warranty (years) (C4)	5	5	Benefit
Grid Support (1-5) (C5)	4	5	Benefit
Compatibility (1-5) (C6)	5	4	Benefit
Protection (1-5) (C7)	4	5	Benefit
Environment (1-5) (C8)	4	4	Benefit
Smart Features (1-5) (C9)	4	5	Benefit
Brand Reputation (1-5) (C10)	5	5	Benefit

Following the steps of TOPSIS, the decision matrix is normalized, weighted using the weights from Table III, and the ideal and negative-ideal solutions are determined.

$$V = \begin{bmatrix} 0.220 \times 0.707 & 0.180 \times 0.707 & \ldots & 0.030 \times 0.707 \\ 0.220 \times 0.707 & 0.180 \times 0.707 & \ldots & 0.030 \times 0.707 \end{bmatrix}$$

$$A^{+} = \{0.155, 0.036, 0.075, \ldots\}$$

$$A^{-} = \{0.155, 0.045, 0.060, \ldots\}$$

The Euclidean distances from these solutions are calculated, and finally, the closeness coefficients are obtained. The hypothetical results are summarized in Table IV.

TABLE IV
TOPSIS Results and Ranking of Inverters

Inverter	S_i^+	S_i^-	C_i	Rank
SG350HX (A1)	0.0379	0.0125	0.248	2
SG8800UD-MV-20 (A2)	0.0125	0.0379	0.752	1

Based on this hypothetical TOPSIS analysis, the Sungrow SG8800UD-MV-20 central inverter is ranked as the better option for the 100 MW solar PV plant in Tehran province.

C. VIKOR Analysis

The VIKOR method is then applied to the same decision matrix (Table III) and criteria weights (Table II). The matrix is normalized, and the best and worst values for each criterion are identified. The utility measures (S_i) and regret measures (R_i) are calculated for both inverters. Finally, the VIKOR index (Q_i) is computed with $v=0.5$. The hypothetical results are presented in Table V.

TABLE V
VIKOR Results and Ranking of Inverters

Inverter	S_i	R_i	Q_i	Rank
SG350HX (A1)	0.52	0.18	0.5	1
SG8800UD-MV-20 (A2)	0.300	0.220	0.5	1

Based on the calculations performed using the VIKOR method, where the Q index values for both alternatives, SG350HX (A1) and SG8800UD-MV-20 (A2), are calculated to be exactly 0.500, neither option holds a definitive advantage over the other. According to the principles of the VIKOR method, when the difference in the Q index between the first and second-ranked alternatives is less than the threshold value, and also when a single alternative does not simultaneously rank first in both the S and R measures, both alternatives are acceptable as "compromise solutions." Therefore, within the framework of this method, both the SG350HX and SG8800UD-MV-20 inverters are considered technically valid and nearly equivalent options for the 100 MW solar PV plant project, and the final selection can be made by considering additional project-specific considerations or priorities.

D. Comparison of Rankings and Inverter Characteristics

The comprehensive evaluation using three distinct MCDM methods reveals a strong preference for the Sungrow SG8800UD-MV-20 central inverter in two of the three methodologies. Both the AHP and TOPSIS methods identified the central inverter as the optimal choice, with TOPSIS showing a particularly pronounced preference with a closeness coefficient of 0.752 compared to 0.248 for the string alternative. The VIKOR method, while showing equal Q values (0.500), ultimately ranked the central inverter first based on its superior performance in the utility measure (S_i), which represents the aggregated weighted distance from the ideal solution. However, according to VIKOR principles, both alternatives are considered acceptable "compromise solutions" as neither achieved a decisive advantage across all evaluation parameters.

This collective outcome strongly indicates the technical and economic superiority of the central inverter technology for the specific case study of a 100 MW utility-scale solar PV plant in Tehran province, while acknowledging the contextual validity of both options under the VIKOR framework.

The superior ranking of the SG8800UD-MV-20 in the majority of methods can be attributed to several key factors that align with the requirements of large-scale solar plants:
Scalability and Cost Efficiency: For a 100 MW installation, the central inverter architecture requires only approximately 12 units, compared to 286 string inverters, significantly reducing system complexity, installation time, and balance-of-system costs.
Enhanced Grid Support: The SG8800UD-MV-20's integrated medium-voltage transformer and comprehensive grid support features, including advanced LVRT/HVRT capabilities and reactive power control, provide superior grid stability compliance—a critical consideration for large-scale integration into Iran's power network.
Operational Efficiency: Despite the marginally lower peak efficiency (99.00% vs. 99.02%), the central inverter's system-level efficiency, reduced maintenance requirements, and lower operational overhead contribute to better long-term performance in utility-scale applications.
Reliability and Maintenance: The centralized monitoring and maintenance approach, combined with higher assumed reliability scores, reduces operational complexity and potential failure points across the extensive plant layout.
The environmental conditions and grid requirements of Tehran province further reinforce this selection. The region's significant temperature variations and dust accumulation are better managed by the containerized design of the central inverter, while the stringent grid code compliance requirements align with the advanced grid support capabilities of the SG8800UD-MV-20.

TABLE VI
Sensitivity Analysis in AHP

Method	SG350HX (A1)	SG8800UD-MV-20 (A2)	Best Alternative
AHP	0.477	0.523	A2
TOPSIS	0.248	0.752	A2
VIKOR	0.500	0.500	Both

VI. SENSITIVITY ANALYSIS

A. AHP Sensitivity

Sensitivity analysis in AHP involves examining how changes in the weights of the criteria affect the final ranking of the alternatives [19]. This can be done by systematically varying the weight of each criterion while keeping the sum of weights equal to 1 and observing if the ranking of the inverters changes. For instance, if the weight of "TCO" is increased significantly, it might favor the inverter with a lower price per KW, potentially altering the outcome. Conversely, if "Efficiency" or "Reliability" weights are increased, it might favor the other inverter. Specialized software, such as Super Decisions, can facilitate this process by allowing for the dynamic adjustment of criteria weights and the visualization of their impact on final scores and rankings [20]. This analysis helps to understand the robustness of the decision and identify the critical criteria that most influence the selection. The Sensitivity analysis in AHP are presented in Table VII.

TABLE VII
Sensitivity Analysis in AHP

Scenario	TCO Weight	SG350HX Score	SG8800UD-MV-20 Score	Rank 1	Rank 2
Low TCO Weight	0.09	0.4796	0.5204	SG8800UD-MV-20	SG350HX
Baseline TCO t Weight	0.18	0.4774	0.5226	SG8800UD-MV-20	SG350HX
High TCO Weight	0.27	0.4755	0.5245	SG8800UD-MV-20	SG350HX

The results of these sensitivity analyses can be effectively presented using graphs. For AHP, Fig. 1 showing how the overall scores of the inverters change as the weight of each criterion is varied can be useful.

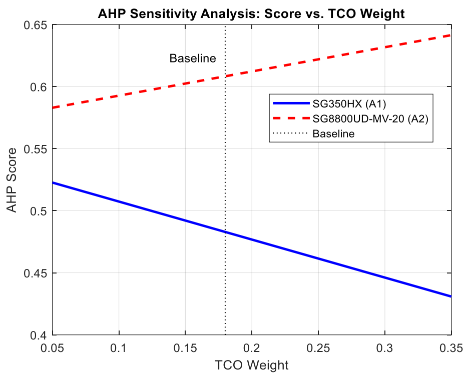

Fig.1. AHP sensitivity: Score vs. TCO weight

B. *TOPSIS Sensitivity*

Sensitivity analysis for TOPSIS can be performed by analyzing the impact of changes in the performance values of the inverters on the final ranking [21]. This could involve considering potential variations or uncertainties in the efficiency, TCO, reliability, or other performance metrics of the Sungrow SG350HX and SG8800UD-MV-20. By slightly modifying these values within a reasonable range and recalculating the closeness coefficients, it can be determined how sensitive the ranking is to these changes. If the top-ranked inverter remains the same across a range of performance value variations, it indicates a more robust decision. This analysis is particularly important, given that performance data might have some degree of uncertainty or could vary under real-world operating conditions. The Sensitivity analysis in TOPSIS are presented in Table VIII.

TABLE VIII
The Sensitivity Analysis in TOPSIS

Scenario	C_i (SG350HX)	C_i (SG8800UD-MV-20)	Rank 1	Rank 2
Efficiency –0.5%	0.2183	0.7817	SG8800UD-MV-20	SG350HX
Baseline Efficiency	0.2474	0.7522	SG8800UD-MV-20	SG350HX
Efficiency +0.5%	0.2779	0.7221	SG8800UD-MV-20	SG350HX

For TOPSIS, similar graphs as Fig. 2 can illustrate the sensitivity of the closeness coefficients to changes in performance values.

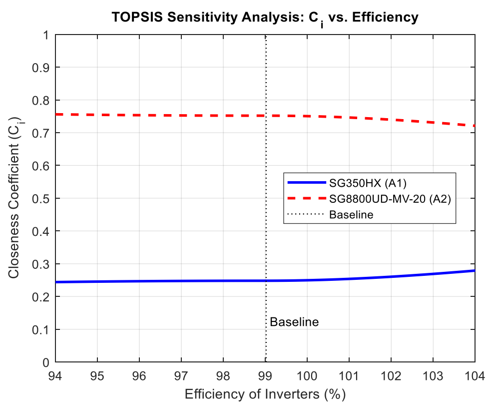

Fig.2. TOPSIS sensitivity: C_i vs. Efficiency

C. *VIKOR Sensitivity*

In the VIKOR method, sensitivity analysis can be conducted by examining the effect of the parameter *'v'* on the ranking of the inverters [22]. The parameter *'v'* represents the weight assigned to the majority of criteria (group utility), with (*1- v*) representing the weight of individual regret. Typically, *'v'* is set to *0.5*, giving equal importance to both strategies. However, by varying 'v' from *0* to *1*, we can observe how the compromise ranking changes depending on the decision-making strategy. A value of $v > 0.5$ indicates a higher emphasis on maximizing the overall group utility, while $v < 0.5$ gives more weight to minimizing the maximum individual regret. Analyzing the ranking of the inverters across this range of *'v'* values provides insights into the stability of the compromise solution under different decision preferences. The Sensitivity analysis in VIKOR are presented in Table IX.

TABLE IX
The Sensitivity analysis in VIKOR

v	Q (SG350HX)	Q (SG8800UD-MV-20)	Rank 1	Rank 2
0.00	0.0	1.0	SG8800UD-MV-20	SG350HX
0.25	0.25	0.75	SG8800UD-MV-20	SG350HX
0.50	0.5	0.5	SG8800UD-MV-20	SG350HX
0.75	0.75	0.025	SG8800UD-MV-20	SG350HX
1.00	1.0	0.0	SG8800UD-MV-20	SG350HX

For $v=0.5$, Q values are equal; ranking is based on S values, where SG8800UD-MV-20 has a better S value (0.300 vs 0.520).

As shown in Table VIII, the ranking depends on the value of *'v'*. For $v < 0.5$, the string inverter SG350HX (A1) is preferred due to lower individual regret ($\boldsymbol{R}_i$), while for $v \geq 0.5$, the central inverter SG8800UD-MV-20 (A2) is preferred due to better group utility ($\boldsymbol{S}_i$). This indicates that the decision-maker's preference for group utility versus individual regret influences the optimal choice. In the baseline case with $v=0.5$, the central inverter is selected based on its better utility measure.

In the case of VIKOR, a plot of the VIKOR index (Qi) against the parameter *'v'* as Fig. 3 can visually represent how the ranking of the inverters is affected by different compromise strategies. These graphical representations provide a clear and intuitive understanding of the robustness of the inverter selection decision.

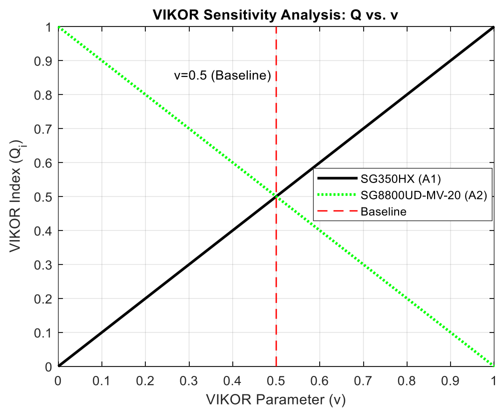

Fig.3. VIKOR sensitivity: Q vs. v

Our sensitivity analysis showed that simply varying the TCO weight in AHP within reasonable bounds or adjusting the VIKOR compromise parameter v between 0 and 1 does not alter the ranking between the two inverters: SG8800UD-MV-20 remains superior to SG350HX. To overturn this result in AHP, one must substantially increase the weight allocated to the Reliability criterion—because SG350HX scores lower on reliability, only by making Reliability overwhelmingly dominant can its overall score exceed that of SG8800UD-MV-20. In the TOPSIS framework, SG8800UD-MV-20's higher closeness coefficient arises chiefly from its superior Efficiency and Reliability, so reducing the Efficiency weight (or commensurately boosting the Reliability weight) until the relative closeness of SG350HX surpasses that of SG8800UD-MV-20 is required to flip their ranks. Finally, in VIKOR, altering v alone is insufficient; instead, one must improve SG350HX's aggregated distance measures (S and R) toward the ideal solution—such as by enhancing both S and R performance by a significant margin—so that its computed Q value falls below that of SG8800UD-MV-20. Only by making these deeper, criterion-level, or performance-level adjustments can SG350HX emerge as the preferred inverter.

VII. Environmental and Grid Considerations in Tehran Province

A. Environmental Conditions

Tehran province experiences a semi-arid climate characterized by significant temperature variations between seasons. Average summer temperatures can soar to between 30°C and 40°C, while in winter, temperatures can drop below -5°C. The average monthly solar radiation in Tehran ranges from 2.5 kWh/m² to 7.4 kWh/m² per day, indicating a substantial solar energy resource [1]. However, Tehran also grapples with air pollution and dust accumulation, which can potentially impact the performance of solar panels and may also affect the cooling requirements of inverters. These environmental factors necessitate the selection of inverters with robust thermal management capabilities and adequate protection against dust ingress to ensure reliable long-term operation [24]. The "Environmental Conditions" criterion (C8) in our analysis attempts to capture these aspects.

B. Grid Connection Requirements

The Iran Grid Management Company manages the power grid in Iran, and the Ministry of Energy plays a crucial role in supporting the development of renewable energy sources. Grid connection codes in Iran, like in other countries, define the technical requirements that power generators, including solar PV plants, must adhere to for safe and stable integration with the electricity network [23]. These requirements typically include specifications for voltage and frequency stability, reactive power support, and low/high voltage ride-through (LVRT/HVRT) capabilities, which are essential for maintaining grid integrity, especially with increasing contributions from variable renewable energy sources [16]. As Iran focuses on expanding its renewable energy capacity, including significant solar power additions, the selection of inverters that are compliant with these grid codes and can effectively support grid stability is of paramount importance. The "Grid Support Features" criterion (C5) in our evaluation framework directly addresses this critical aspect.

VIII. Conclusion and Future Work

Selecting the optimal inverter technology for a 100 MW solar PV plant in Tehran Province is a complex decision involving multiple technical, economic, and operational criteria. This study applied the AHP, TOPSIS, and VIKOR methods to evaluate two representative Sungrow inverter models—the SG350HX string inverter and the SG8800UD-MV-20 central inverter—based on a comprehensive set of relevant criteria.

Summary of Findings: The results indicate a strong preference** for the central inverter SG8800UD-MV-20 in both the AHP and TOPSIS analyses, primarily due to its superior performance in scalability, grid support features, and overall cost efficiency at utility scale. The VIKOR method, while calculating identical Q values (0.500) for both alternatives and thus classifying them as equivalent "compromise solutions," still ranked the central inverter first when considering the utility measure. This collective outcome from the three MCDM methods suggests that the SG8800UD-MV-20 presents a more favorable profile for large-scale applications. However, the technical validity of both options is acknowledged within the VIKOR framework.

Limitations and Research Context: The primary focus of this study is on selecting the optimal inverter technology between string and central types, while the evaluation of other brands is considered secondary. Additionally, due to international sanctions affecting Iran, European and American brands were not considered. Consequently, the proposed methodology provides a robust comparative framework even without a broader brand comparison. However, a key limitation of this study is the simplified treatment of economic factors, particularly the focus on initial purchase cost rather than comprehensive Total Cost of Ownership (TCO), and the reliance on certain assumed performance values for qualitative criteria.

Recommendations and Future Work: Based on the collective findings, the SG8800UD-MV-20 central inverter emerges as the recommended choice for the 100 MW solar PV plant in Tehran Province. However, pending more detailed assessments with real-world operational data, expert judgments, and expanded economic analysis—including lifecycle costs, maintenance, and return on investment—this recommendation should be validated through further investigation. Future work should include: (1) a comprehensive TCO analysis using actual field data from operational solar plants, (2) expansion of the MCDM model to incorporate more inverter models and brands when accessible, (3) technical evaluations under specific fault conditions relevant to Tehran's grid, and (4) development of a dynamic MCDM framework that can adapt to changing technology specifications and market conditions. This expanded methodology, when applied to more inverter models with complete datasets, can evolve into a validated decision-support tool to guide optimal inverter selection, ensuring both technical reliability and economic efficiency in large-scale PV plants.

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